EXPERT SYSTEM FOR DIMENSIONING REINFORCEMENT AND CONNECTIONS OF WOOD WITH STEEL

by

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Abstract

"Expert System for Dimensioning Reinforcement and Connections of Wood with Steel", degree of Master of Engineering, 2016, Janne Vosskuehler, Civil Engineering, Ryerson University

Ecological and sustainability values in the construction sector have become increasingly important, likewise the demand for timber constructions have increased. Simultaneously opportunities have developed to enhance the structural disadvantages of timber, leading to more economic and efficient structures. The engineering office Knippers Helbig does not only design timber structures frequently but is also a pioneer regarding the use of timber as a solid building material. This leads to the idea to develop a tool for a particular project and as a preparation tool for following project which enables the firm to evaluate advance calculations. Solutions were sought for strengthening in flexure and tension perpendicular to the grain of timber with steel as well as dimensioning connections with glued-in steel sections.

With the tool, quick feasibility and variant studies for reinforcement and connection types are possible. Furthermore each dimensioning method is based on standardized calculations, so detailed verification can be performed.

Da ökologische und nachhaltige Werte in den letzten Jahrzehnten auch im Bausektor von immer größerer Bedeutung werden, ist die Nachfrage nach Holzkonstruktion kontinuierlich gestiegen. Gleichzeitig oder grade deswegen entwickelten sich Möglichkeiten die strukturellen Nachteile von Holz auszubessern, was zu ökonomischeren und effizienteren Strukturen führte. Das Ingenieurbüro Knippers Helbig plant nicht nur gerne und häufig Holzkonstruktionen, sondern ist auch Vorreiter, was die Verwendung von Holz als Massivbaustoff betrifft. Daraus ergab sich die Idee, dass für ein Projekt im Speziellen und als Vorbereitung für folgende ein Tool entwickelt werden sollte, dass es ermöglicht weiterführenden Dimensionierungen zu berechnen. Dabei ging es darum Biege- und Querzugverstärkungen von Holz mit Stahl zu bemessen sowie Anschlüsse mit eingeklebten Stahlquerschnitten zu dimensionieren.

Mit dem Tool dieser Masterarbeit ist es möglich zum einen schnelle Machbarkeits-, sowie Variantenstudien von Bewehrungs- oder Anschlusstypen durchzuführen, aber zum anderen liegen jedem Nachweis genormte bzw. bauaufsichtlich zugestimmten Berechnungen zugrunde, sodass Detailnachweise geführt werden können.

Acknowledgements

I would first like to thank my thesis advisor Prof. Jan Akkermann of the University of Applied Science. Prof. Akkermann was always open for any new idea coming up in my mind. Furthermore he consistently allowed this paper to be corporative work with Knippers Helbig, but pointed out opportunities and ideas to promote me and the thesis.

I would like to thank my thesis advisor Prof. Ahmed Shaker of the Ryerson University. Since the thesis was written in Germany, I could not benefit fully of his knowledge and experience as I could hope for but I am highly grateful for his supervision while studying in Toronto.

I would also like to thank my supervisor Laurent Giampellegrini at Knippers Helbig who were involved in any crisis and always solved it with thought-provoking impulses. Without his passionate interest in fully understand new ideas and his supporting input, the thesis would not have been so successful.

I would also like to thank my colleagues at Knippers Helbig who have been very tolerant and helpful, I am gratefully indebted to their very valuable comments on this thesis.

Finally, I must express my very profound gratitude to my parents, to my brothers and to my boyfriend for providing me with unfailing support while not taking me seriously. This accomplishment would not have been possible without their soothing. Thank you.

Janne Vosskuehler

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1. Chapter - Introduction

1.1. General

This thesis is a partial fulfilment for the Double Master Degree at the Ryerson University in Toronto, Ontario, Canada and University of Applied Science of Karlsruhe, Germany and is based on the concept of a project as a cooperative thesis with Knippers Helbig GmbH.

1.2. Background

In the past few decades environmental consciousness has become a priority to the construction industry, which resulted in an increasing number of structures with the highly sustainable material timber. The demand for more efficient and economic timber constructions leads to the development of reducing the weaknesses of wood with hybrid structures. Since Knippers Helbig is a company for "Advanced Engineering" new approaches are studied about their feasibility which is the intention and purpose for why this thesis was launched.

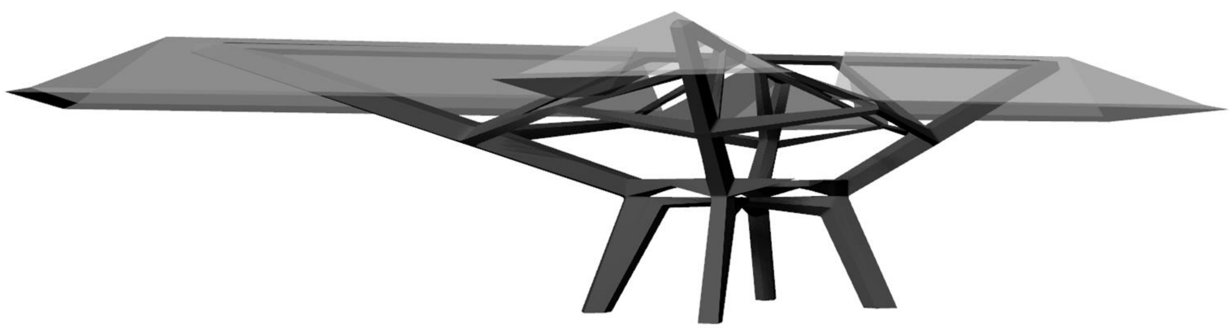

Figure 1-1 – Rendering of the timber structure

Currently a major timber structure is designed which is subjected to heavy loading out of earth quake and hurricane. Because of the open structure, shown in the rendering in Figure 1-1, the load can affect the roof from both sides. The timber structure is subject to variable stress combinations, especially the "legs", which need to carry the load to the ground.

1.3. Problem Definition and Limitations

With the intention of designing an efficient structure the feasibility to design the timber structure as hybrid cross-section need to be reviewed. The review is mainly focused on the legs of the structures since there the highest stresses are incorporated. The following problems are addressed in the thesis:

(1) Decrease of cross-section size

(2) Increase of connection efficiency

Especially the connections are an imperative consideration in terms of capability to also transfer the high loads.

Although the limitations of this thesis are a result of practical relevance as collaboration with Knippers Helbig, the advantages are obvious since the result will be applied in the company. Experimental results based on laboratory tests have not been executed but thanks to the extensive pool of research studies, this limitation does not hinder the success of the desktop study.

1.4. Scope of Research and Methodology

The scope of this thesis included the development of calculation methods for reinforcement to decrease timber cross-sections as well as efficient connections. The tensile strength of timber perpendicular to grain and in flexure are mainly the reason for failure, therefore strengthening these weaknesses are included into this thesis. Similarly the glued-in connections since not affecting the architectural attractiveness of wood structures are highly favored and very efficient due to direct load transmission.

In addition the design of these techniques was implemented into an expert system to enhance their application in future project. The system allows achieving a quick and simple overview of possibilities while designing timber construction. Since the covered techniques have been highly researched, the applied calculation methods are based on study results or standards.

1.5. Objectives

This thesis was mainly driven by the necessity for one project but also to include timber construction more extensively into the portfolio of the company Knippers Helbig GmbH. The discussed techniques allow decreasing timber quality or cross-section, leading to more sustainable and economical structures.

2. Chapter - Literature review

As research for the two main application topics this literature review summarizes the definitions and properties of materials as well as several experimental and theoretical results of these topics.

2.1. Materials

BEHAVIOR AND PROPERTIES

Functional reinforcement and connections can only be achieved with including all involved materials into consideration: timber, reinforcement/ connection material and the adhesive bond. However the functionality is not only dependent on quality but also on compatibility since incompatibilities lead to premature failure (Fiorelli & Dias, 2003).

2.1.1. Wood

The oldest and most widely used structural material is wood (Triantafillou & Deskovic, 1991) which is back in trend due to its sustainability. But wood is not only recyclable, but also a neutral resource and architecturally attractive (Raftery & Rodd, 2015). Since it is a natural material wood varies in terms of strength and stiffness due to highly unpredictable number and distribution of "natural defects and variation in growth conditions" (Glišović, Stevanović, & Petrović, 2015).

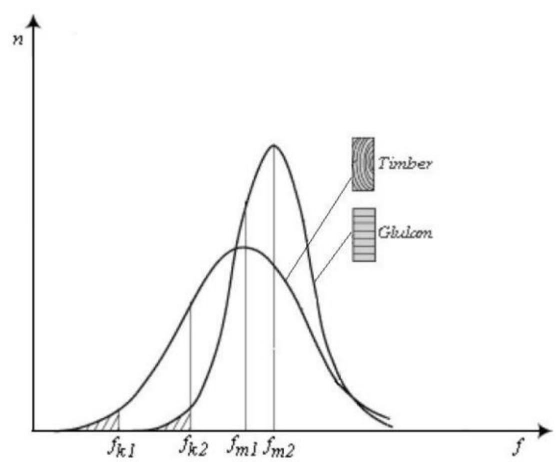

Figure 2-1 - Strength Properties of Timber and Glulam (Persson & Wogelberg, 2011)

The invention of glue laminated timber (glulam) reduced this variability since it is made of independent lamellae glued together. Occurring defects such as knots become more evenly distributed over the cross-section (Persson & Wogelberg, 2011). In Figure 2-1 the difference between natural timber and glulam in terms of strength and variability is shown effectively. Not only glulam has the higher average strength f_{m2} and characteristic strength f_{k2} but also a smaller spread of strength.

Further strength increase is possible by locating lamellae with higher quality and therefore fewer defects at the location of the cross section with the highest stress (Glišović, Stevanović, & Petrović, 2015) as done for the combined glulam Figure 2-2.

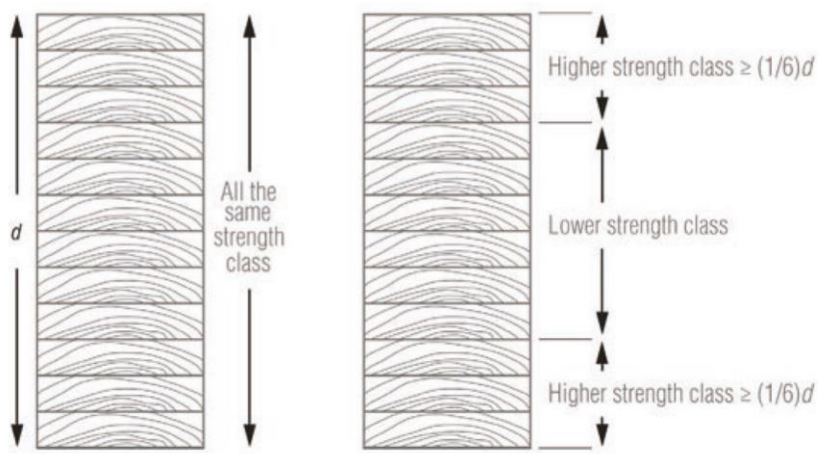

Figure 2-2 - Homogenous and combined glulam members (Structural Timber Association, 2004)

Several advantages are reasons to consider glulam to more common structural material as reinforced concrete or structural steel including the high strength to weight ratio and low costs. Furthermore timber is easy to transport and can be produced in many shapes while simple joints are able to take the full load right after completion. Durability with proper protection and reasonable fire resistance are additional benefits of timber structures while providing good building physics environment.

A disadvantage of wood is its anisotropic behavior which results in higher strength parallel as perpendicular to the grain, as shown in Figure 2-3 (b). Furthermore the stress-strain relationship of wood induces a brittle failure in the tension zone. Cracks around defects in timber are opened up while under tensile loading, which reduce the tensile strength of wood significantly.

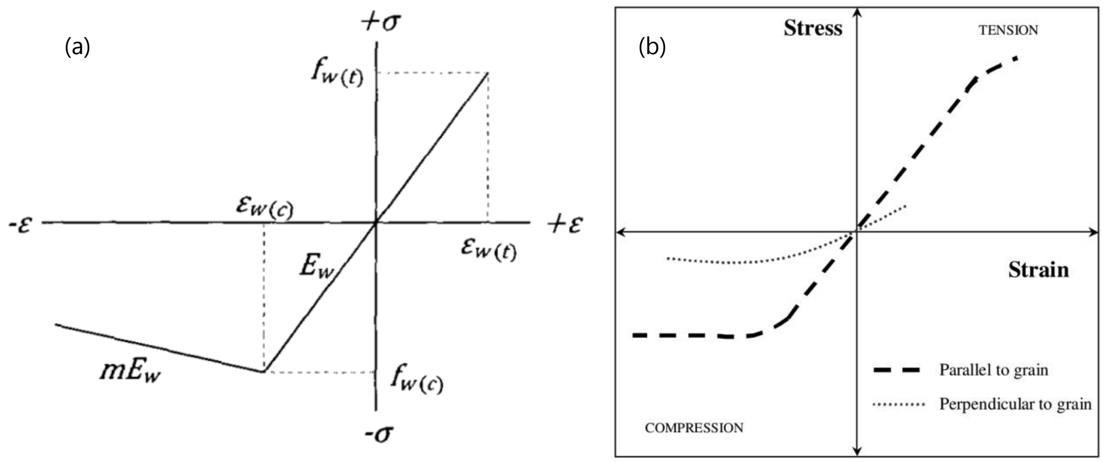

Figure 2-3 - Timber stress-strain curves (a) idealized as bilinear (Grant, 2009) and (b) with different stresses (Alam, 2004)

Since compression loading compresses the wood, it is not affected by defects. Compressive failure is assumed to be ductile (Persson & Wogelberg, 2011), because different to tension failure a wooden member, which after yielding in compression can bear a decreasing stress level while strains increase. In Figure 2-3 (a) this non-linearity of wood is shown and idealized as bilinearity.

For all states presented in the stress-strain curve stresses can be determined with Eq. 2-1.

$$\sigma_w = \begin{cases} E_w \varepsilon_{w(c)} + mE_w\left(\varepsilon - \varepsilon_{w(c)}\right) & \varepsilon < \varepsilon_{w(c)} \\ E_w \varepsilon & \varepsilon_{w(c)} < \varepsilon < \varepsilon_{w(t)} \\ 0 & \varepsilon_{w(t)} < \varepsilon \end{cases}$$

Eq. 2-1 - Stress-Strain Curve (Grant, 2009)

Because the deformation eases the prediction of collapse, compression failure is preferred to tension failure. Since wood is assumed to fail in tension, most design approaches does not consider the bilinearity of timber (Cai, 2009). And if the collapsing of timber is a result of compressive failure the tension side is over-strengthened (Persson & Wogelberg, 2011) with for example reinforcement.

Timber grading is dependent on strength properties which in turn are dependent on growth characteristics and defects (Cai, 2009). The two main types of wood are

(1) hardwood from deciduous trees (flat leaves which fall in autumn) and
(2) softwood from coniferous trees (needle shaped leaves, green the whole year).

For the production of glulam timber mainly softwood is used (Jacob & Garzon Barragán, 2007).

There are several factors affecting wood properties, (Alhayek, 2009) the dimensional stability an strength is changes with variable moisture content, furthermore loading rate and size of the wood member as well as defects are considerable factors.

Properties of timber differ strongly across the different species, Table 2-1 shows the ranges typical timber types included into EC 5.

		softwood C16 - C30	hardwood D30 - D60	glulam GL24h - GL36c
Elastic modulus [N/mm²]	min	8,000	11,000	11,600
	max	13,000	17,000	14,700
Bending strength [N/mm²]	min	26	30	24
	max	35	60	36

Table 2-1 – Ranges of elastic modulus and bending strength of softwood, hardwood and glulam (Schneider, 2012, pp. 9.8 - 9.9)

2.1.2. Reinforcement And Connection Material

Identically materials are used for either reinforcement or connections and will be discussed simultaneously. The two main materials are

(1) steel
(2) fiber reinforced polymers (FRP or composite material).

In many earlier studies composite materials was mostly in focus since it has very good strength and stiffness properties and low weight (Blaß & Romani, 2002). The application is relatively ease since it can be performed by one person and only need to be pressed to the timber by a simple roller. Unlike steel where at least two people and a presser are needed (Issa & Kmeid, 2005). Furthermore the corrosion resistance, electromagnetic neutrality and similar coefficient of thermal expansion as wood make composite material highly compatible to reinforce or strengthen timber structures (Fiorelli & Dias, 2003). The most common fibers for FRP are glass, carbon and aramid glued to a polymer net.

The results of this thesis shall be included into the design of a project immediately, in that regard, it is advisable to apply commonly used material. FRP provide great advantages but are not yet included into any standards for timber construction. Steel is a common and efficient material and is chosen as material for reinforcement and connections, since for these purposes the isotropic mechanical properties offers the required parameters. Disadvantages of steel as a strengthener or fastener are the increase of dead load, the highly corrosive property (Triantafillou & Deskovic, 1991) and the low fire resistance. These problems need to be considered although the increase of dead load can be neglected. Further protection against corrosion and fire can be applied structurally.

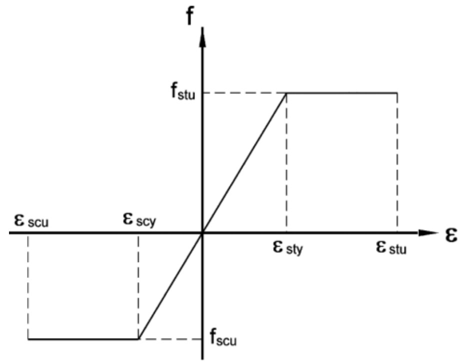

Figure 2-4 – Schematic stress–strain relationship for steel (De Luca & Marano, 2012)

The high ductility of steel is the main advantage to support the plastic deformation and helps to predict failure. Although both types of material can be customized, steel is easier to supply and less expensive compared to FRP.

2.1.3. Adhesives

In countries suffering from a scarcity of wood the research on hybrid timber construction and also epoxy resins is highly promoted, since timber and steel are essential but reinforcement or connections are not able to function without a load transmitting adhesive bond.

Sikadur 30	
Static elastic modulus	12,800 MPa
Adhesive Strength (wet)	4 MPa
Shear Strength	15 MPa
Coefficient of Expansion	$9 \cdot 10^{-5}$ per °C

Table 2-2 Properties of adhesive "Sikadur 30" (Jacob & Garzon Barragán, 2007)

For the covered applications two-component epoxy adhesive is chosen, Table 2-2 shows values of an example. Two-component epoxy resins' mechanical properties are highly developed in traction and compression and shrinkage after hardening does not occur (Borri, Corradi, & Speranzini, 2013). Another main advantages are the gap-filling characteristics as well as the low pressure which is needed while hardening to achieve the necessary full load transmission (Glišović, Stevanović, & Petrović, 2015). Furthermore the adhesive is providing a corrosion protection for the steel. In this thesis there will be no further discussion into material property differences between suppliers.

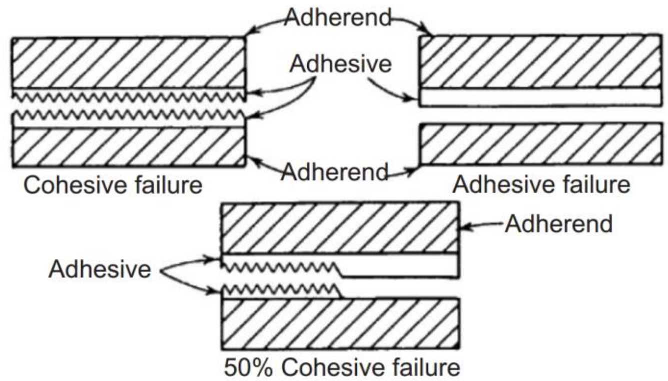

Figure 2-5 - Diagram of cohesive and adhesive failure (Hafizah, Zakiah, & Azmi, 2014)

In several studies the adhesive bond were tested in order to conclude which failure occurs (Figure 2-5):

(1) cohesive failure: in the adhesive layer itself

(2) adhesive failure: in the interface between the adhesive and another material

An general assumption is the perfectly acting adhesive bond which leads to the understanding while applied in flexure reinforced timber the adhesive is not subjected to shear stress since the strain in timber and steel are identical. And in the unlikely event of a not ideal bond the adhesive shear strength is greater than the timber shear strength (see Table 2-2), therefore timber failure would occur first. (Blaß, Krams, & Romani, 2002) investigated on this assumption in their study and concluded the capacity of the adhesive is more sufficient than of timber as long as the surface is rough enough. Though debonding of the reinforcement occurred in areas of timber failure but remained intact outside these areas. Other studies achieved the same result, (Gentile, Svecova, & Rizkalla, 2002) stated the assumption debonding is not the reason for failure of the reinforced timber cross-section which is will be also assumed in this thesis.

2.2. Methods

A GENERAL LOOK

The following chapter presents the covered techniques to achieve a general overview. Since the results shall be used immediately and be able to be implemented practically, the tool is based approved calculation models. In several studies different design methods have been developed often providing more realistic results, nevertheless these models have not been approved official as in building inspector approval or standard and are not suitable for the purpose of this thesis.

Generally can be stated that the durability and capacity of reinforcement and connection is heavily dependent on bond between timber and reinforcement as well as on sufficient protection of steel against corrosion and of high temperature during a fire (Rug & Mönck, 2008)

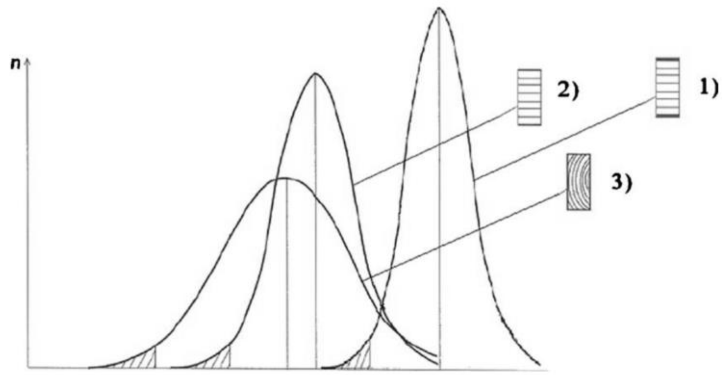

Figure 2-6 - Characteristics of Timber (3), Glulam (2), and Reinforced Glulam (1) (André & Johnsson, 2010)

2.2.1. Reinforcement

Already small amounts of reinforcement can increase significantly stiffness and strength of the cross-section. This improvement is achieved by the higher elastic modulus of the strengthening material and therefore its ability to absorb greater stresses for equal strain. Figure 2-1 was extended by reinforced timber (1), and Figure 2-6 shows impressively the further increase of average and characteristic design value for strength as well as the decrease in the variability spread of strength.

With a low degree of flexure reinforcement the use of low-grade glulam can be increased as well as the total volume of the cross-section reduced, 1% can result in wooden cross-section reduction by 30% to 50% (Rug & Mönck, 2008). Another effective method for strengthening is a further development of the combined glulam cross-section, while not only adding laminates with higher grade but laminated veneer lumber (LVL) which achieves even higher strengths.

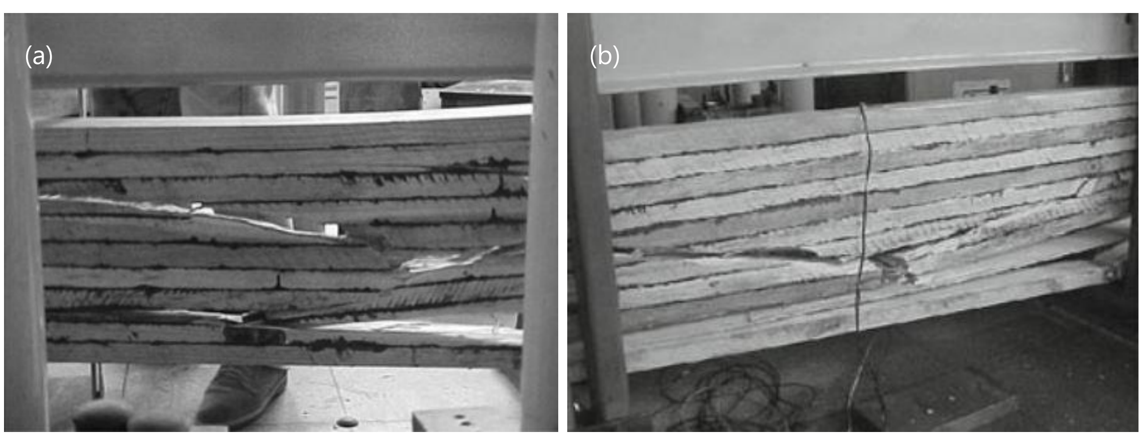

Figure 2-7 - Failure of an unreinforced and reinforced glulam beam (Fiorelli & Dias, 2003)

An unreinforced timber member mainly fails brittle in tension if exposed to flexural loading due to natural defects, as shown in Figure 2-7 (a). The collapse of a wooden member is commonly assumed if the yield strength is reached in the outmost fiber. Reinforcement has a similar purpose as for concrete structure although it does not replace the tensile strength. Timber has already appropriate tension strength in flexure but in combination with the bridging effect of flexure reinforcement, the expansion of propagating cracks around defects can be stopped (Persson & Wogelberg, 2011).

The result is a higher strength of the member as well as it can be taken advantages of the plasticisation of wood on the compression side, which is shown in Figure 2-8 (a). As demonstrated in Figure 2-7 (b) the failure mode can be change from the brittle and total collapse to ductile and more moderate failure mode.

Figure 2-8 – Full scale reinforced beams (a) with compression failure (Gentile, Svecova, & Rizkalla, 2002) and (b) with ductile behavior (Gilfillan, Gilbert, & Patrick, 2003)

Two modes for the stress and strain distribution of a reinforced timber cross-section are distinguished in Figure 2-9:

(1) The timber is linear-elastic
(2) The timber is plastic after yielding in compression

As long as the timber is linear the finale failure is in tension. After yielding in compression, plastic deformation occurs in the wood which leads to a shifting of the neutral axis of the internal forces. The following collapse can either occur in tension or in compression. Furthermore strengthening placed at the tension side is an efficient step for higher flexure strength. Several studies showed that an additional reinforcement on the compression side can contribute improving properties; these studies are summarized in chapter 2.3.1.

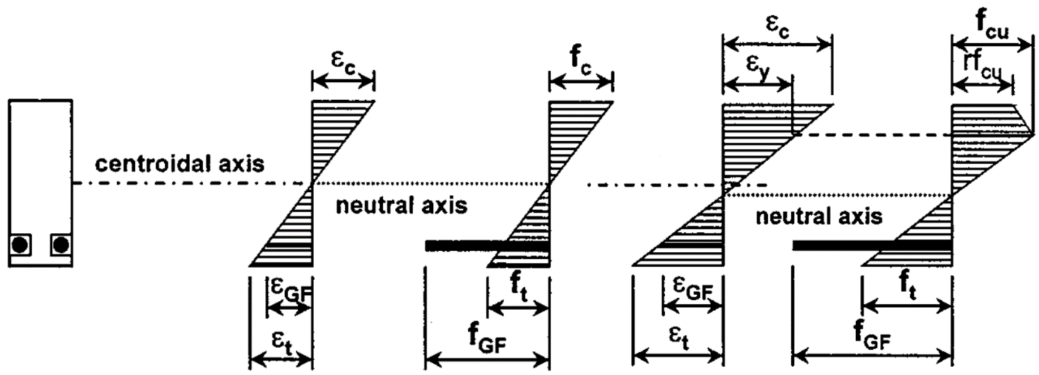

Figure 2-9 - Distribution of stress and strain for bilinear stress-strain relationship (Gentile, Svecova, & Rizkalla, 2002)

The flexure reinforcements covered in this thesis are either steel plate or bar. While the plates can be arranged horizontally or vertically into the wood, the bars only laid horizontally. Since the reinforcement is part of a firm structure of timber and adhesive, the ability of reinforcement buckling under compression load, as shown Figure 2-10, is not taking into calculations. It is assumed that the timber and adhesive bond are sufficient enough to hinder the buckling and absorb the stresses. If extensive compressive loads are applied, an additional verification is recommended.

Figure 2-10 – Rebar buckling under compression load (De Luca & Marano, 2012)

Since the tension strength of timber perpendicular to the grain is relatively low, as soon as these stresses occur there is a possibility for necessary reinforcement. This impact often emerges in notched beams, beams with openings or curved beams. As shown in Figure 2-11 curved beam are exposed to several different stresses, but especially the tension stress perpendicular to the grain in the curved section are significantly high.

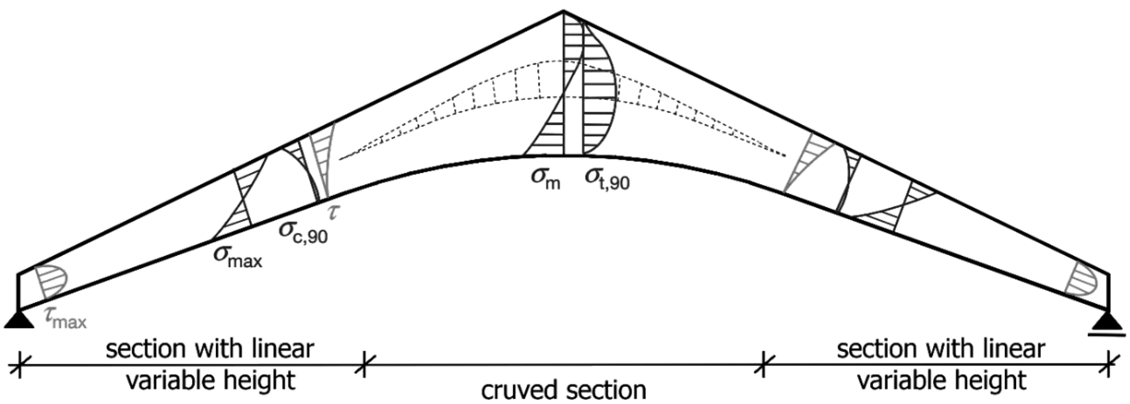

Figure 2-11 – Schematic course of stresses in a pitched cambered beam (Dietsch, 2012)

Similar to flexure reinforcement this reinforcement also provides bridging of cracks as well as carries the tension stress perpendicular to the grain. While the EC 5 provides the calculation method to determine the different stresses in curved beams, the German National Annex of the EC 5 presents dimensioning of reinforcement.

2.2.2. Connections

The architectural benefit and direct load transmission of glued-in fasteners were already discussed and reason for chosen connection types. The rigid connections need to be designed in a way that failure occurs in steel and not in the wood or adhesive in order to achieve ductile rather than brittle rupture.

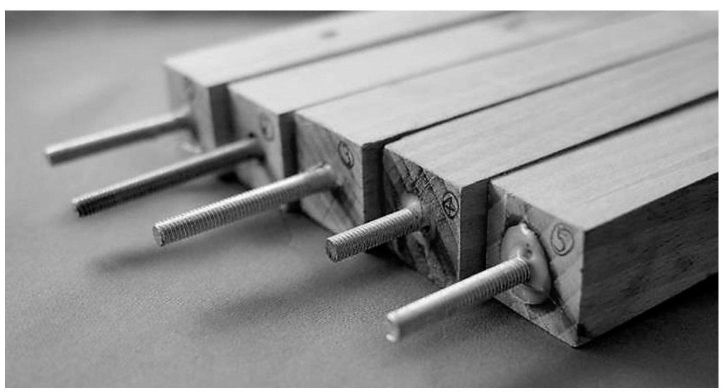

Figure 2-12 - Glued-in Rods[1]

The German National Annex of the Eurocode 5 standardized the design of connection with glued-in rods, shown in Figure 2-12. The design is based on the capability of the adhesive and the rod to withstand the stresses. The bonding between the adhesive and the bar is ensured by thread or ribs on the bar's surface.

[1] http://static-content.springer.com/image/art%3A10.1007%2Fs35145-015-0534-1/MediaObjects/35145_2015_534_Fig1_HTML.jpg

Perforated plates, pictured in Figure 2-13, are a newer method and have been mostly developed at the University of Applied Science in Wiesbaden (Bahmer, 2010). The approach of stress transmission is relatively similar to glued-in rods but the adhesive has an increased influence, since adhesive dowels form in the holes of the plates.

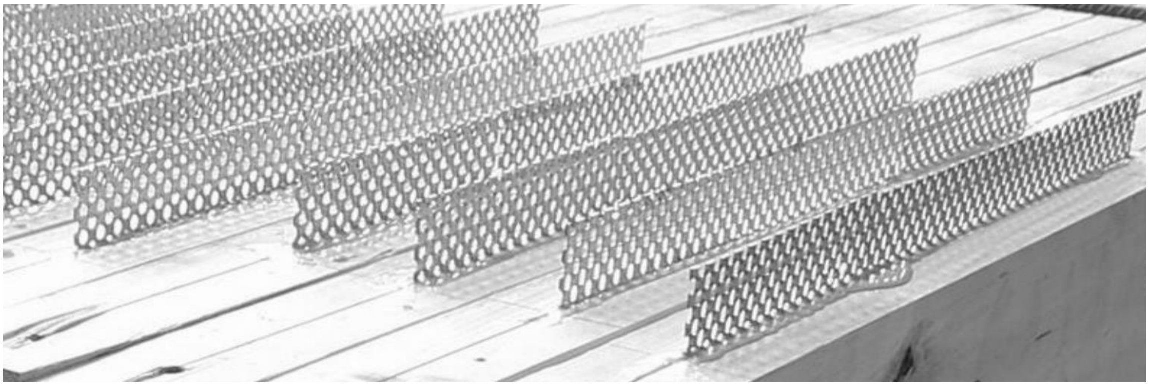

Figure 2-13 - Perforated plates glued into wood (Bathon L. , 2015)

The application of both systems is simple and quick while the full wooden cross section is mobilized for load transmission with just a minimal weakening.

2.3. Experimental Results

COLLECTION OF DATA

If new method is developed experimental studies need to be executed to gain more information and to establish a calculation model. The following chapter summarizes studies collection for reinforcement and connections.

2.3.1. Reinforcement

A lot of studies about reinforcement were done since the second half of the last century. While older studies often reinforce with steel, the newer concentrate on newer materials such as fiber reinforced polymers. Since this thesis focuses on steel, predominantly studies concerning this material are presented but to prove the efficiency for reinforcement in general some study concentrating on FRP were also included.

Since reinforcement for tension perpendicular to the grain is standardized by the German National Annex and very little number of studies has been performed on this topic, hence it is not included into the summary.

2.3.1.1. Flexure Reinforcement

In his dissertation (Alam, 2004) presents different approaches for reinforcement, such as the work of (Dziuba, 1985, pp. 115-119) who reinforced timber beams with steel rods in tension and used different degrees of reinforcement. While placing more and more reinforcement on the tension side until no tensile failure could be noticed, the rate of increasing effects reduced. But each of the series buckled more in compression. Another study made by (Borgin, Loedolff, & Saunders, 1968, S. 1681-1705) glulam was reinforced with 5% of reinforcement. The first test samples had evenly distributed reinforcement between the tension and compression side, shown in Figure 2-14 (a). All reinforcement was placed in the compression side for the other samples (Figure 2-14 (b)). Both reinforcement types improved the stiffness of the beam, showed a similar ductility but higher strength was achieved by only adding reinforcement in the top, whereas (Brunner & Schnüriger, 2002) discovered a higher ductility by only reinforcing the tension side of the beam.

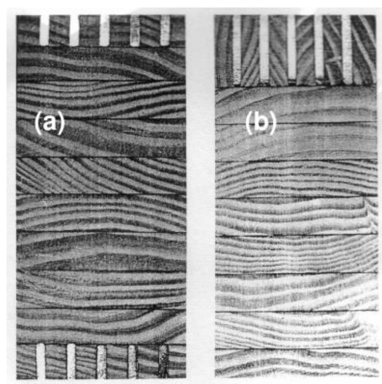

Figure 2-14 - Vertically laminated steel-timber composite beams as tested by Borgin et al. (Alam, Reinforcement of Timber for Structural Application and Repair, 2004)

(Alam, Ansell, & Smedley, 2009) first loaded the test beams until collapse, straightened these afterwards and reinforced them with different material. The authors discovered the importance of the reinforcement position and achieved the greatest efficiency when it was placed at top or bottom side. Reinforcement with steel increases the beam stiffness more effectively than FRP, discovered Alam and his team. Furthermore they found out that despite the weakening of the beam through reinforcement, the stiffness mostly improved to the cross-section without reinforcement.

Very high strength steel cords reinforcement was the material (Borri, Corradi, & Speranzini, 2013) used to improve the load-carrying capacity by 88% and the ultimate stiffness by 87%. (Bulleit, Sandberg, & Woods, 1989) investigated the influence of moisture cycles on strengthening effect. While the dry and wet beams experienced a similar stiffness increase of 24 to 32 %, moment capacity increased only for the dry beams over 30%, the moisture-cycled beams did not experienced any improvement.

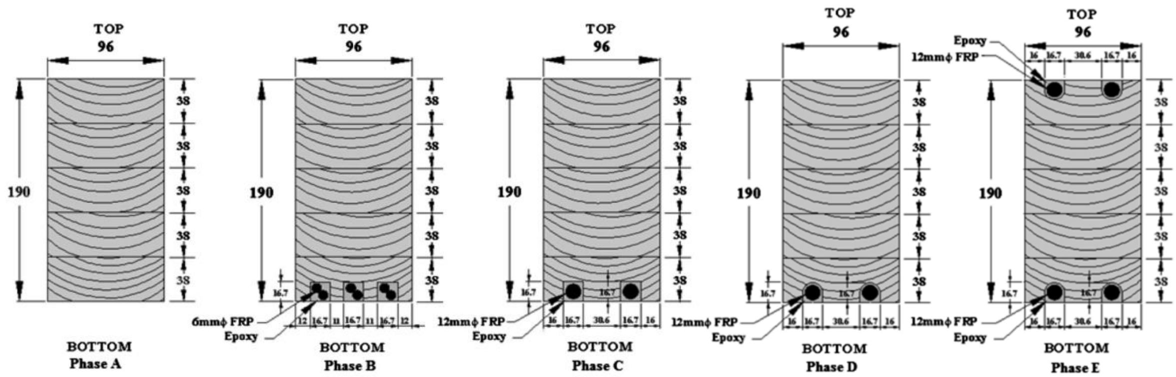

Figure 2-15 - Beam Configurations Tested by Raftery and Whelan (Raftery & Whelan, 2014)

(Raftery & Whelan, 2014) studied the effect between different grooves and variable rod diameters, as shown in Figure 2-15. Smaller bars did not serve with any advantage over larger ones but they discovered a different between the grooves since less adhesive is needed to fill circular grooves, the load transmitted more direct. A reinforcement degree of 1.4% in tension could achieve an increase of global stiffness and of moment of capacity by 13.9% and 68%, respectively. The specimen with a degree of 1.4% in tension and in compression improved the global stiffness and moment of capacity by 29.6% and 98.5%, respectively. Although the reinforcement material was FRP the high effectiveness of reinforcement is obvious. (Davalos, Qiao, & Trimble, 2000) conducted a study about the performance epoxy-FRP-wood interface and concluded that if suitable resin is used, failure will occur in the wood without experiencing delamination.

Figure 2-16 – Failure outgoing from the lamella above the reinforcement plate (Blaß, Krams, & Romani, 2002)

(Glišović, Stevanović, & Petrović, 2015) also strengthened the glulam beams with FRP and applied as a first improvement laminations with higher quality in the region with the greatest stresses. Afterwards horizontal plates were placed as reinforcement. With one plate the load-carrying capacity could be increased by 54.3% and the stiffness by 18.1%. Two plates enhanced the load-carrying capacity by 65.8% and the stiffness by 39.2%.

Vertical plates glued into wood were tested by (Alhayek & Svecova, 2012). Two different groups had been formed as can be seen in Figure 2-17. The increase was similar for both groups with about 30% and 3% in strength and stiffness, respectively, while the tension group had a small advantage. Overall they could increase the strength by up to 40 % for low-grade timber members and 15 % for high-grade.

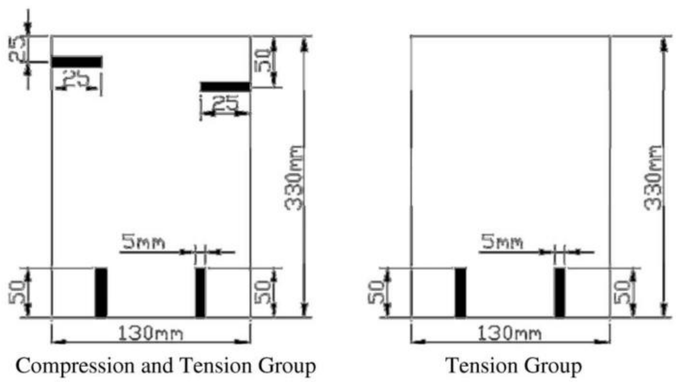

Figure 2-17 - Beam Cross Section tested by (Alhayek & Svecova, 2012)

A relevant variable is the time-dependent behavior which (Gilfillan, Gilbert, & Patrick, 2003) tested for. Even though the number tests were limited they discovered that tension reinforcement can reduce the creep deflection of the beam.

2.3.2. Connection

The following chapter summarizes the research concerning glued-in rods and perforated plates.

2.3.2.1. Glued-in rods

For full performance of connection with glued-in rods (Steiger, 2012) suggested focusing on the system as a whole and conducting quality control for all parts of this system

(1) Steel
(2) Timber
(3) Adhesive,
(4) Geometrical Parameters (spacing).

(Lippert, 2002)'s approach equals the load-carrying capacity of a group of rods and the sum of the capacity of one rod, which simplifies the verification of the connection. Since the adhesive fills the gap between rod and wood, the perfect fitting increases the load-bearing capacity against lateral loads compared to conventional fasteners.

2.3.2.2. Perforated Plate

Only few studies have researched on glued-in plates for timber-timber connections (Bathon L. , et al., 2014), but since Bathon worked with timber-concrete composite structures, experiences and knowledge about steel plates glued into wood were gained. Further research could be based on these results (Bathon L. , et al., 2014) and a parameter study identified the feasibility for steel plates as timber-timber-connections.

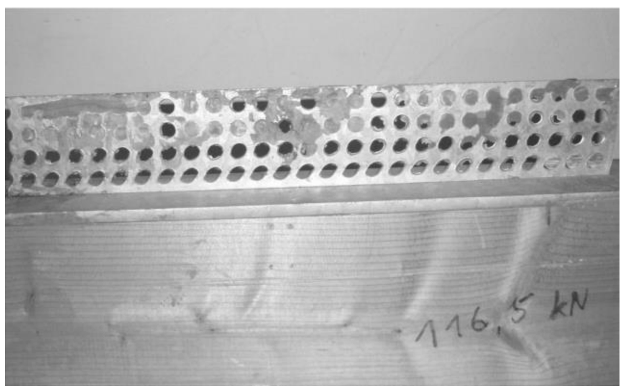

Figure 2-18 - Deformation of the lower row of holes of a perforated plate (Bahmer, 2010)

Therefore Bathon started researching on perforated plates with an outcome of efficient rigid connection method and a defined load-carrying capacity. In the course of this research the application for a building inspectorate approval was launched which was achieved by the end of 2014.

Figure 2-19 - "Flying Stairs" (UBC's Earth Sciences Building)[2]

The MPA (Material Testing Institute) Wiesbaden tested further on glued-in perforated plates (Bathon, Bletz, Schmidt, Weber, & Weil, 2009) and conducted for example test for tension under temperature load and compressive shear. The tension tests under temperature load shows that the functionality of the connection can be guaranteed at the necessary temperature level. The compression shear test showed that the ductile properties of the perforated plates are consistent (Figure 2-18) and it is possible to achieve fully ductile connection due to plastification of steel (Bahmer, 2010).

Bathon and his team are pioneers for perforated plates and consulted different projects for timber construction as for example the ‚Flying' Stair at the University of British Columbia's Earth Sciences Building, illustrated in Figure 2-19. Furthermore the first timber windmill-powered plant could be constructed with the help of perforated plates, shown in Figure 2-20.

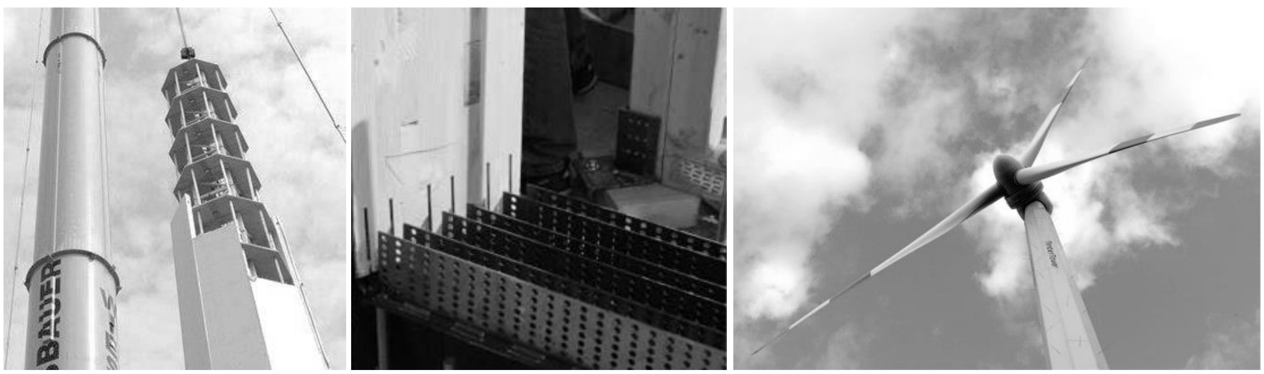

Figure 2-20 - TimberTower [3]

2.4. Theoretical results

DIFFERENT APPROACHES

2.4.1. Reinforcement

Since there is still need for research for flexural reinforcement several different design methods have been developed and are presented in the following chapter.

This is different for reinforcement for tension perpendicular to the grain since the calculation model is already approved and included into the EC 5, this thesis adapts this calculation model.

[2] http://www.eqcanada.com/projects/earth-science-building-esb-at-university-of-british-columbia/

[3] left photo: http://www.ndr.de/nachrichten/niedersachsen/timbertower113_v-contentgross.jpg; middle photo: http://www.goforwood.info/image.php/2010-10-19_11910s.jpg?width=450&image=/uploads/2010-10-19_11910s.jpg; right photo: http://www.timbertower.de/medien/

2.4.1.1. Flexure Reinforcement

Buchanan drafted the so called Bazan Buchanan Law to predict bending strength of wood, providing a foundation for following researchers and pursuing the work of (Bazan, 1980) who explained the relationship between tension, compression, and bending strength for clear wood. (Buchanan, 1990) sets three reasons for the difficulty to predict the bending strength of wood:

(1) Non-linear nature of the stress-strain relationship for wood in compression.
(2) Large variability in strength properties of wood.
(3) Major influence of size effects, results in failure stresses decreasing as stressed volume increases

He introduced formulae to calculate the position of the neutral axis after compression yielding and developed several modes of failure in bending which are relative to the relationship of tension and compressive strength, shown in Figure 2-21 and explained in the list below:

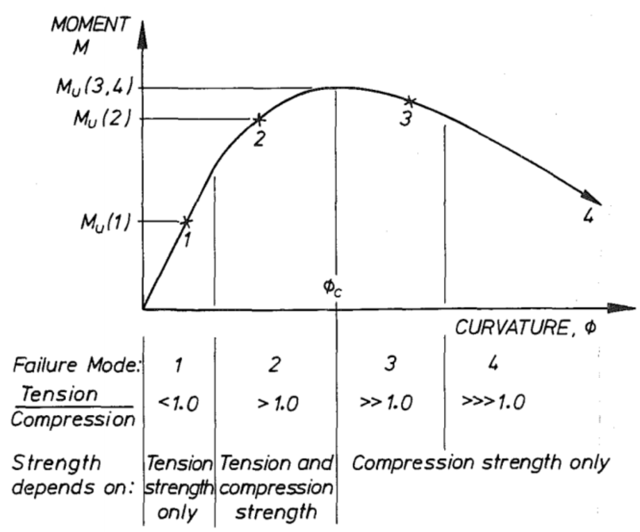

Figure 2-21 - Moment Curvature Relationship for Various Failure Modes (Buchanan, 1990)

- Mode 1: linear until failure which means it fails brittle in tension without compression yielding.
- Mode 2: still fails brittle but after some compression yielding
- Mode 3: can either fail in brittle tension or in compression, depending on the material; beam deforms ductile.
- Mode 4: fails in compression, tensile strength is much higher than compressive strength

Most approaches are based on statistical distribution and moment-curvature analysis to achieve the excellent results concerning accuracy compared to experimental tests. The methods consider the nonlinear behavior of wood in compression as (Lindyberg & Dagher, 2012)'s ReLAM model or (Gentile, Svecova, & Rizkalla, 2002)'s and (Lopez-Anido & Xu, 2002)'s models. The iterative process includes several solution steps which need to be repeated until ultimate failure is reached. These models use algorithm and computer programs to solve the equations.

Several other studies attempt to develop easier models to consider the nonlinearity of wood while avoiding iterative calculations to find the position of the neutral axis. These approaches are based on formulae adjusted to always only one special failure mode. The number of failure modes vary, some assume for example just tension and compression failure (Cai, 2009; Borri, Corradi, & Grazini, 2005; Fiorelli & Dias, 2003) while others divided the modes into linear-elastic and plastic phase with several sub modes (Jacob & Garzon Barragán, 2007).

Common calculation models for dimensioning timber cross-sections do not include the bilinearity of wood since in general wood can be assumed to fail in tension. The ductile potential in compression is only activated with a high tensile strength which can be the case if reinforcement is applied. The standard assumed wood as a linear material, neglecting the plastification, since it does not consider reinforcement for timber. This thesis is based on approved formulae, assuming also wood as a linear material and risking conservative results.

For linear analysis the transformed section method allows quick and consistent evaluation of the stress state (Borri, Corradi, & Grazini, 2005), since the stiffness differences of the materials are considered. As the initial response of reinforced timber is linear (Lopez-Anido & Xu, 2002) this method is legit for further calculations. And in the end it is a simplified version of the other approaches with satisfying results (Hernandez, Davalos, Sonti, Kim, & Moody, 1997). And assuming a rigid bond between timber and steel, the reinforced cross-section can be dimensioned when the transformed section method is applied as one material (Rug & Mönck, 2008).

For the design of flexure reinforcement the following assumptions are the basis (Lopez-Anido & Xu, 2002):

1. A perfect bond between wood and steel – longitudinal strains are continuous through the depth
2. The stress-strain-relationships of wood and steel are known.
3. The longitudinal strains are continuous over the depth of the cross-section
4. The equilibrium of internal forces in the cross section need to be satisfied.

2.4.2. Connections

Glued-in rods are already standardized in the German National Annex of the Eurocode 5, but there are some different approaches for dimensioning. Variable influence is attributed to density of wood or the diameter of the rod (Steiger, 2012).

The perforated plate has been tested by the MPA Wiesbaden and the DIBt and a building inspectorate approval (Zulassung Z-9.1-770, 2014) was achieved, this regulates of HSK ("Holz-Stahl-Komposit" – wood-steel-composite) systems and presents a calculation model to dimension the glue-wood-steel connection.

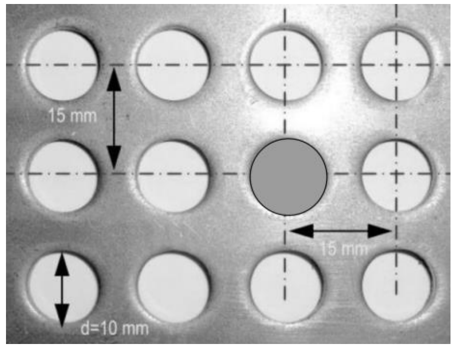

Figure 2-22 – Structure of a perforated plate (Bathon L. , et al., 2015)

The variability is very limited but the definitions of the building inspection approval (Zulassung Z-9.1-770, 2014) need to be followed otherwise an approval in the individual case is required. The properties of the plate including the distribution of holes are defined as follows:

- Plate thickness: 2.5 mm
- Steel grade: S235 or S355
- Hole diameter: 10 mm (± 1)
- Spacing between holes: 5 mm (± 0.2)
- Edge distance of holes: 2.5 mm (± 0.1).

The building inspection approval (Zulassung Z-9.1-770, 2014) also dictates the plate dimensions, allowing a width between 15 mm and 1260 mm and a length, which represents the penetration depth, between 55 mm and 300 mm. For effective stress transmission at least three adhesive dowels need to be glued into the timber, demonstrated in Figure 2-23 (a). In addition only adhesive dowels with a distance of at least 12.5 mm to the wooden edge can be included in the calculation.

Applied in a timber cross-section spacing between plates shall be at least 40 mm and the distance to the edge 20 mm (Figure 2-23 (b)).

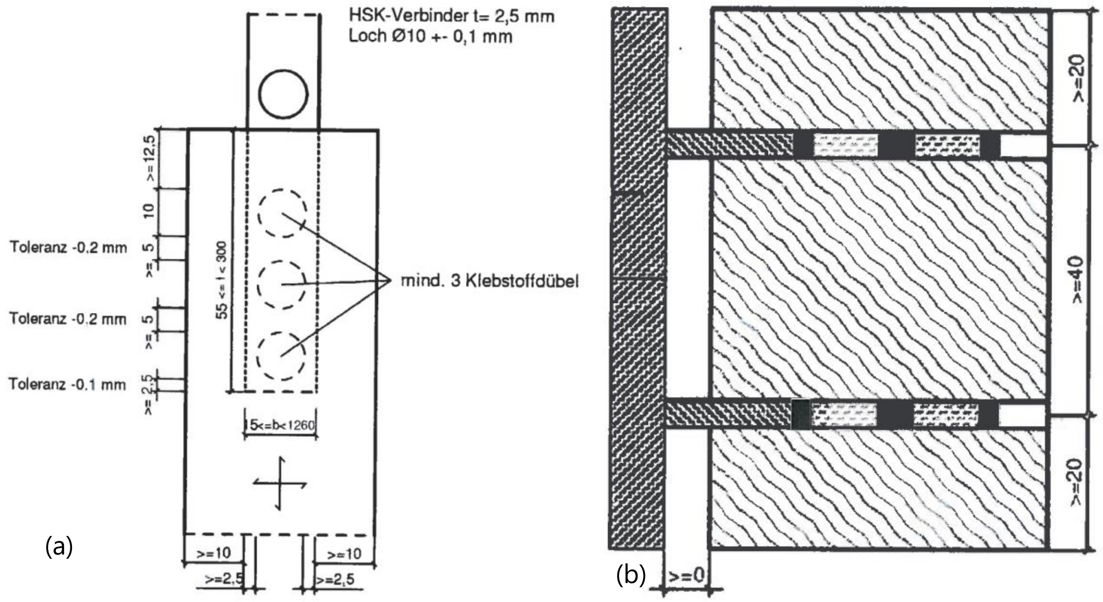

Figure 2-23 - Executive regulations for the HSK-System (Zulassung Z-9.1-770, 2014)

Since the connection consists of two members, under compression and bending loading these members press together. This fact can lead to significant improvement of the connection or lead to timber crushing. For simplicity reasons this stress is not included in the tool and further verifications of the cross-section may be needed.

3. Chapter: Methods – a closer look

With the general overview of experimental and theoretical results of several studies concerning reinforcement and connection methods, this chapter offers a deeper and more detailed presentation of those methods which are finally integrated into the tool.

Any cross-section which is approved by this thesis is only verified for this special case. No responsibility for further application is assumed. Instability problems of the beam may occur since this failure has not been taken into consideration for cross-section checks.

3.1. Reinforcement for Flexure

As mentioned in 2.4.1.1, the calculation model for dimensioning flexure reinforcement is based on the transformed section method. Herein the stress-strain relationship of wood is assumed as linear.

3.1.1. Types

The flexure reinforcement considered in this thesis are bar and plate strengthening made out of Steel.

Figure 3-1 - Reinforcing Bar[4] and Threaded Bolt[5]

3.1.1.1. Bar Reinforcement

There are two types of reinforcement bars

(1) Threaded bar
(2) Typical re-bar.

Both types of bar reinforcement are differently in their appearance, as seen in Figure 3-1. The reinforcing bar is covered with inclined transverse rips, while the threaded bolt has a threading.

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[4] https://www.schoeck.de/cache/schoeckmedia_Schoeck_Betonedelstahl%5B16327%5D_media_image_thumbnailscheme_360x542.jpg

[5] http://www.schraubennoxfasteners.com/__SCHRAUBEN_NOXFASTENERS_BILDER/TRAPEZ_GEWINDESTANGEN.jpg

The diameter of a threaded rod includes the thread but for calculating of the cross-section area, the thread is neglected. This leads to different cross-section area of a threaded rod and re-bar even though their diameter is the same. Another difference is the definitions of strength properties which are summarized in Table 7-1.

The layout of bar reinforcement is independent from the type. As flexure reinforcement the bars are laid horizontally into the wooden cross-section to carry tension and/or compression force.

An important definition to achieve effective reinforcement is rod spacing. The German National Annex provides values for glued-in rods, which will be adapted for reinforcement since the stress transmission is the same. The values are summarized in Table 7-2 and illustrated in Figure 7-1.

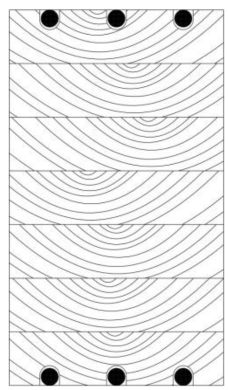


Figure 3-2 - Cross-Section with horizontally laid-in rods

Since reinforcement has the highest impact if located in the outmost fiber, bar set in grouts at the outside of wooden cross-section are preferred, see Figure 3-2. For this reason two distances to the edge of the beam can be chosen: the reinforcement is located directly at the edge of the beam or with the minimum distance defined in the German National Annex. It is not possible the select intermediate values to avoid timber failure due to tension perpendicular to the grain.

Furthermore the tool considers the possibility for up to three layers of reinforcement applied at the top and bottom.

3.1.1.2. Steel Plate Reinforcement

Steel plate strengthening is also divided into two different types. While the material is the same steel, the orientation of the plates may differ. The layout of the plates can be chosen either horizontal or vertical, as Figure 3-3 shows.

Since plates incorporated into wood are not included into any standards, the spacing definition needs to be imitated from another application. Because a general building inspectorate approval has been achieved for perforated plates their spacing values are assumed. With a 2.5 mm thickness of the perforated plate, end/edge distance of 20 mm and a spacing of 40 mm are allowed. This leads to a general assumption of end/edge distances of eight times the plate thickness and spacing with 16 times the thickness. Table 7-2 summarized the values clearly and comprehensively.

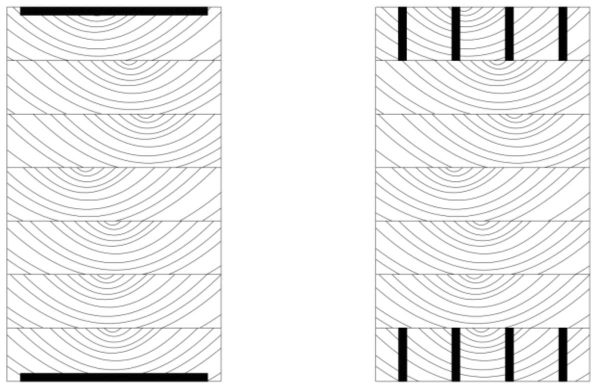


Figure 3-3 - Horizontal and vertical plate-formed reinforcement

Only one horizontal plate can be applied for each layer while its length is allowed to cover the whole beam width. If the plate is not placed on the outside of the beam, the edge distance need to be satisfied and between layers the minimum spacing. For vertical plates only one layer is possible, since the length of the plates is variable.

3.1.2. Calculation model

The design approach chosen is the transformed section method. Its approach is based on the Euler-Bernoulli bending theory, which assumes that for slender beams "plane surfaces remain plane" in bending. Therefore materials are assumed to be linear elastic and homogeneous. The idea is to transform the cross section of the composite beam into a beam with an equivalent cross section consisting of one material only. In the final step are the stresses converted from the transformed section to those from the original beam.

Since the calculation is based on the position of the neutral axis, this needs to be determined first. The neutral axis depends on the modular ratio n of the different materials E_1 and E_2 (Eq. 3-1). The calculation for the factored area A_{fact} is shown in Eq. 3-2; this area is multiplied by the modular ratio as Figure 3-4 (b) indicates.

$$n = \frac{E_2}{E_1}$$

Eq. 3-1 – modular ratio of elastic moduli

(Gere, 2002)

E_1 : elastic modulus of the weaker material
E_2 : elastic modulus of the stronger material

$$A_{fact,i} = n \cdot A_i$$

A_i : cross-section area of each material

Eq. 3-2 – factored cross-section area

(Gere, 2002)

The neutral axis of this one-material cross-section is in the centroid of the area; for this reason the areas A_i of every part of the composite beam is multiplied with the distance y_i between the top of the whole cross-section and its particular centroid. These accumulated individual values are related to the accumulated transformed section $\sum A_i$ to figure out the distance from the top to the neutral axis NA_{top} (Eq. 3-3).

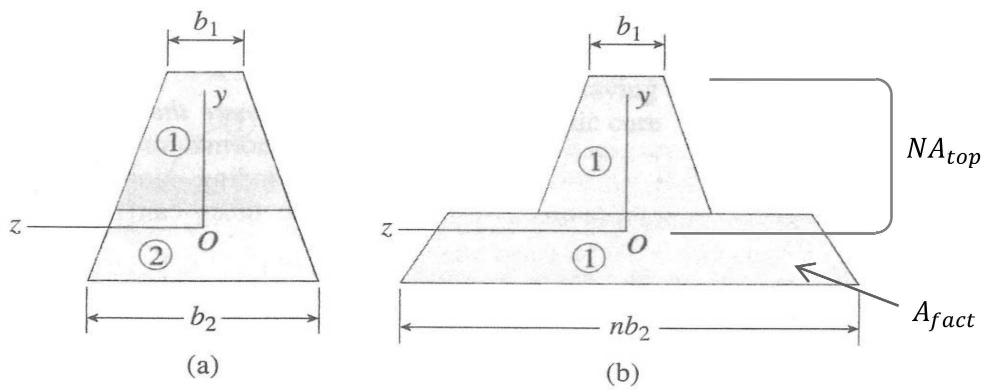


Figure 3-4 – Composite beam of two materials: (a) actual cross section and (b) transformed section consisting only material 1

The distance from the bottom of the member to the neutral axis is NA_{bot} (Eq. 3-4).

$$NA_{top} = \frac{\sum y_i A_i}{\sum A_i}$$

y_i : distance from the particular centroid to the neutral axis

Eq. 3-3 – distance to neutral axis from the top

(Gere, 2002)

$$NA_{bot} = h - NA_{top}$$

Eq. 3-4 – distance to neutral axis from the bottom

(Gere, 2002)

A short example in 7.2.1.1 demonstrates the determination of the neutral axis.

With the position of the neutral axis the stresses and strains of wood and steel can be calculated. The next step includes the computation of the moment of inertia of the transformed section. The quotation to calculate the moment of inertia of one element around the y-axis and z-axis is expressed in Eq. 3-5 and Eq. 3-6, respectively.

$$I_{y,T} = \sum \frac{1}{12} \cdot A_{fact,i} \cdot {h_i}^2 + A_{fact,i} \cdot z_{a,i}^2$$

Eq. 3-5 – moment of inertia about the y-axis of transformed section

(Gere, 2002)

$I_{y,T,i}$: transformed moment of inertia of one part (y-axis)
$A_{fact,i}$: factorised area of one part
h_i : height of one part
$z_{a,i}$: distance in z-direction from the edge of the beam to the centroid of the one part

$$I_{z,T} = \sum \frac{1}{12} \cdot A_{fact,i} \cdot {b_i}^2 + A_{fact,i} \cdot y_{a,i}^2$$

Eq. 3-6 – moment of inertia about the z-axis of transformed section

(Gere, 2002)

$I_{z,T,i}$: transformed moment of inertia of one part (z-axis)
b_i : width of one part
$y_{a,i}$: distance in y-direction from the edge of the beam to the centroid of the one area

With the moment of inertia of the transformed section for both axes, it is one more step to final stresses of the different material. The negative stresses are compressive while the positive determine tensile stress. Eq. 3-7 and Eq. 3-8 are equally useable for bending stresses around the y- and z-axis. The appropriate values for the bending stress, the distance to the neutral axis and the moment of inertia need to be inserted.

$$\sigma_w = -\frac{M \cdot d}{I_T}$$

Eq. 3-7 – bending stress in wood

(Gere, 2002)

M : applied bending moment
d : distance to the neutral axis; either y_a or z_a

$$\sigma_s = -\frac{M \cdot d}{I_T} n$$

Eq. 3-8 – bending stress in steel

(Gere, 2002)

After bending stresses, axial and shear stresses need to be determined. The basic equation for axial stresses is force divided by area. For a composite beam the axial force need to be divided between the materials depending on their elastic modulus. This is why the basic formula's numerator is extended by the total factored cross-section multiplied by the elastic modulus of the wood. This is same as if every single (normal) cross-section area was multiplied by its material specific elastic modulus. The normal stress is multiplied by the elastic modulus of the material whose stresses shall be identified. Thus the stress for each material can be identified with the equation presented as Eq. 3-9.

$$\sigma_{N,i} = -\frac{N \cdot E_i}{\sum A_{fact,i} \cdot E_w}$$

Eq. 3-9 – axial stress

N : applied axial load
E_i : elastic modulus of the particular material
$\sum A_i$: sum of all factored cross-section area
E_w : elastic modulus of wood

In addition, the materials needs be proven for shear stresses. Since shear stresses are also absorbed by the whole cross-section, this proof can follow the same principle as for axial stress. Steel can be calculated as Eq. 3-10 shows.

$$\tau_{d,s} = \frac{V \cdot E_s}{\sum A_{fact,i} \cdot E_w}$$

Eq. 3-10 – shear stress in steel

(DIN EN 1995-1-1, 2004)

V : applied shear load
E_s : elastic modulus of steel

For timber the (DIN EN 1995-1-1, 2004) has established a formula, which assumes that shear forces are only absorbed by timber. Therefore the extensions of the equations before need to be applied to calculate timber's share.

$$\tau_d = 1.5 \cdot \frac{V \cdot E_w}{k_{cr} \cdot \sum A_{fact,i} \cdot E_w}$$

Eq. 3-11 – shear stress in wood

(DIN EN 1995-1-1, 2004)

V : applied shear load
A_n : net cross-section area
k_{cr} : "crack coefficient"

softwood	glulam	hardwood
$k_{cr} = \frac{2.0}{f_{v,k}}$	$k_{cr} = \frac{2.5}{f_{v,k}}$	$k_{cr} = 0.67$

Table 3-1 - "crack coefficient "

(DIN EN 1995-1-1/NA, 2013, p. 42)

While designing timber construction it is advisable to avoid torsional stress since timber's torsional strength is relatively low compared to other structural material. Because of this reason this stress had not been included into the tool.

The final proof of the cross-section needs interaction of stresses. The important combinations for timber are biaxial bending stress with axial stress, meaning compression and tension, as well as the biaxial shear stresses. The following equations shall be satisfied.

$$(a)\frac{\sigma_{t,0,d}}{f_{t,0,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

Eq. 3-12 –biaxial bending and tension stresses in timber

(DIN EN 1995-1-1, 2004)

$$(b)\ \frac{\sigma_{t,0,d}}{f_{t,0,d}} + k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

k_m : factor for re-distribution of stresses and the effect of inhomogeneities (DIN EN 1995-1-1, 2004)

for rectangular section (solid timber, glulam and LVL) → $k_m = 0.7$

$$(a)\ \left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

$$(b)\ \left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

k_m : see Eq. 3-12

Eq. 3-13 –biaxial bending and compression stresses in timber

(DIN EN 1995-1-1, 2004)

$$\left(\frac{\tau_{y,d}}{f_{v,d}}\right)^2 + \left(\frac{\tau_{z,d}}{f_{v,d}}\right)^2 \leq 1$$

Eq. 3-14 –biaxial shear in timber

(DIN EN 1995-1-1, 2004)

For the resistance of steel there are different possible definitions depending on the purpose. The plastic behavior of gross cross-section is determined with the yielding strength. While rupture can occur in the crack line through the holes of bolted connection, the ultimate steel strength of the net cross-section is taken into account.

Since the reinforcement plates are gross cross-sections the yielding strength is decisive. For interaction of steel stresses the sum of the bending stresses around both axes with the axial stress need to be satisfied.

$$\sigma_{Rd} = \frac{f_y}{\gamma_{M,0}}$$

Eq. 3-15 – strength of steel

(DIN EN 1993-1-1, 2010, S. 53)

f_y : yield tensile strength of steel

$\gamma_{M,0}$: $= 1.1$ → Partial factor for steel properties

$$\frac{\sigma_{N,s}}{\sigma_{Rd}} + \frac{\sigma_{m,y,d}}{\sigma_{Rd}} + \frac{\sigma_{m,z,d}}{\sigma_{Rd}} \leq 1$$

Eq. 3-16 –biaxial bending and axial stress in steel

The shear strength of steel as well as the verification for biaxial shear is defined as follows.

$$\sigma_{V,Rd} = \frac{f_y/\sqrt{3}}{\gamma_{M,0}}$$

Eq. 3-17 – strength of steel

(DIN EN 1993-1-8, 2010)

$$\left(\frac{\tau_{y,d}}{\sigma_{V,Rd}}\right)^2 + \left(\frac{\tau_{z,d}}{\sigma_{V,Rd}}\right)^2 \leq 1$$

Eq. 3-18 –biaxial shear in steel

(DIN EN 1995-1-1, 2004)

All satisfaction of all equation the cross-section is held to be proven.

The following flowchart presents the whole calculation process for reinforcement in flexure.

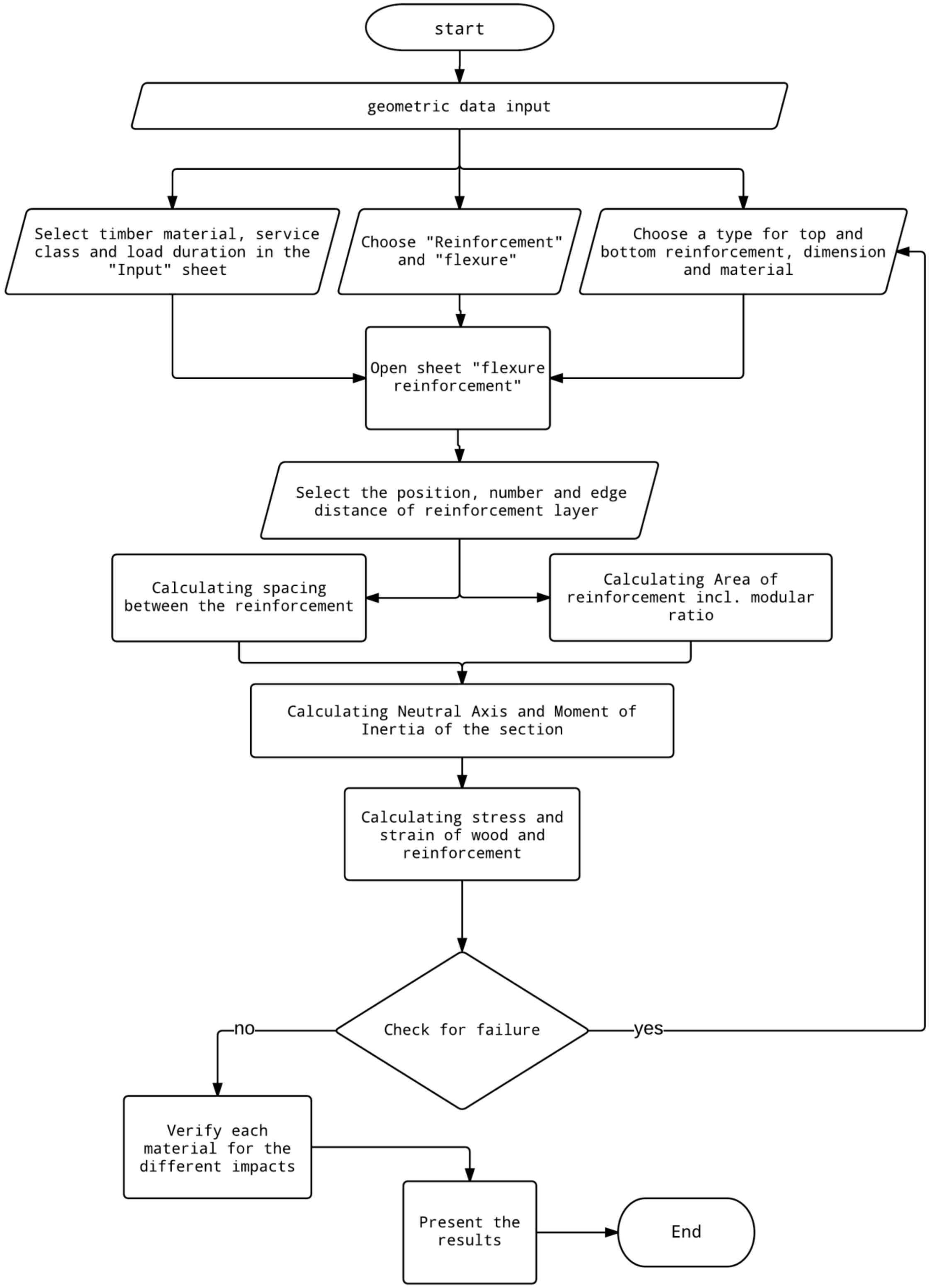


Figure 3-5 - Flowchart - calculation flexure reinforcement

3.1.3. Code

The full code is copied into the Appendix B chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**. In order to maintain variability in the tool, different arrangements have been made. The cross-section always remains rectangular the height can be changed by applying the reinforcement outside of the wood. Furthermore the shape of the reinforcement can be varied which involves adapting calculation.

The code consists of a lot of programming regarding spacing, since the distances change with shape and amount of reinforcement. Furthermore the calculation of the moment of inertia needs to be adjusted with different layout. The calculation itself and the output is also programmed.

3.1.4. Validation

3.1.4.1. Unreinforced Cross-Section

First a general wooden cross-section without reinforcement is validated to prove the basic formulae. The dimension of the cross-section with the defined stresses (Figure 7-3) was entered into the tool and the program Frilo. The results of the tool can be checked in Figure 7-4 and for Frilo in Figure 7-5, both can be found in the appendix.

The direct comparison between both programs can be found in Table 3-2.

Stress	Tool	Frilo (Module HO11)
σ_N	0.89	0.89
σ_{M_y}	5.93	5.93
σ_{M_z}	4.27	4.27
τ_{V_y}	1.22	0.80
τ_{V_z}	0.61	0.40

Table 3-2 – Comparison of results between Frilo and the tool

Since Frilo did not include the crack coefficient into their determination of shear stresses, the values are different. A correlation can be achieved by dividing these values with $k_{cr} = 0.6579$.

3.1.4.2. Reinforced Cross-Section

Furthermore the tool is validated for implementation of reinforcement into the wooden cross-section and the resulting stresses. A FE model of the cross-section was developed with Sofistik for validation with the same dimensions and stresses as the unreinforced beam.

Three different types of reinforcement were tested with horizontal plates, bars and vertical plates.

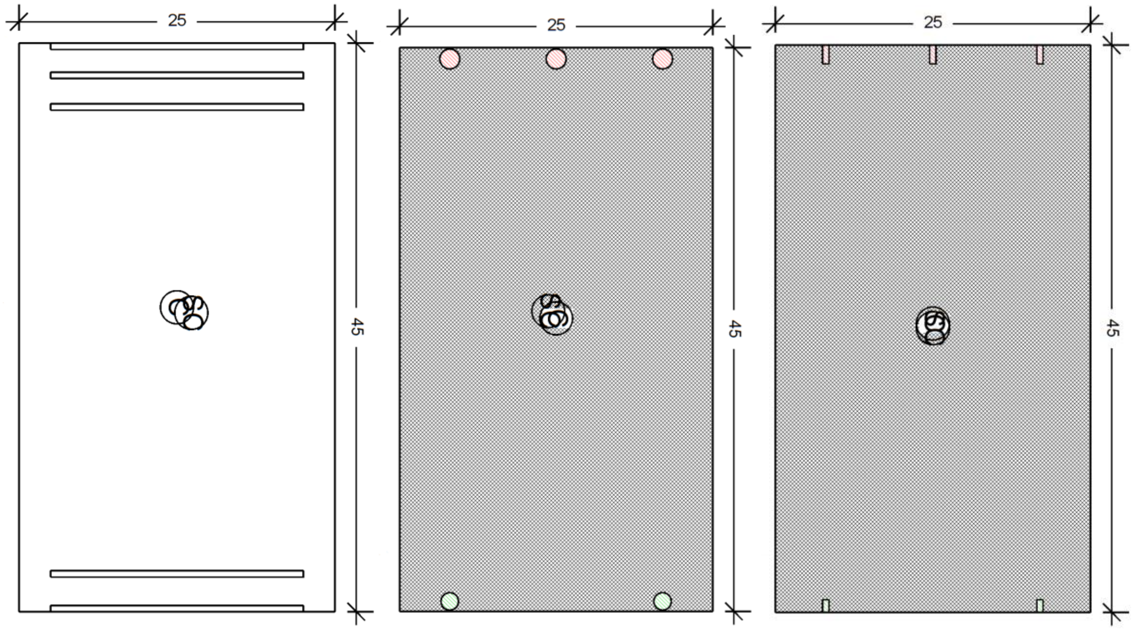


Figure 3-6 – Cross-section of three different validations

The final tables show the values evaluate with Sofistik as well as with the tool, associating screen shots can be found in the appendix.

(1) Validation of a reinforced cross-section with horizontal plates

Stress	Tool		Sofistik	
	Timber	Steel	Timber	Steel
σ_N	0.54	8.32	0.54	8.32
σ_{M_y}	2.74/-2.87	42.02/-44.01	2.18/-2.47	33.47/-37.89
σ_{M_z}	3.07	37.6	3.03	37.17

Table 3-3 - Validation of a reinforced cross-section with horizontal plates

(2) Validation of a reinforced cross-section with bars

Stress	Tool		Sofistik	
	Timber	Steel	Timber	Steel
σ_N	0.8	12.21	0.8	12.21
σ_{M_y}	4.28/-4.59	66.67/-70.37	4.35/-4.64	66.37/-70.81
σ_{M_z}	3.64	40.20/37,96	3.79	43.22/42.76

Table 3-4 – Validation of a reinforced cross-section with bars

(3) Validation of a reinforced cross-section with vertical plates

Stress	Tool		Sofistik	
	Timber	Steel	Timber	Steel
σ_N	0.85	13.08	0.85	13.08
σ_{M_y}	5.20/-5.37	79.73/-82.27	5.23/-5.39	80.19/-82.57
σ_{M_z}	3.81	39.71	3.79	43.84

Table 3-5 - Validation of a reinforced cross-section with vertical plates

While comparing the last three tables it is clearly that the tool is approved and also after comparison to Table 3-2 the increase in flexural strength of reinforcement is obvious.

Unfortunately Sofistik does not evaluate the shear stress of the reinforcement; therefore it has not been possible to prove the quality of the tool regarding shear strength. The Figure 3-7 (a) shows the shear stress showed by the result viewer when reinforcement is applied and Figure 3-7 (b) are the resulting shear stresses of an unreinforced cross-section, whose value does not agree with result of Frilo and the tool. The influence of reinforcement is not clear when consulting Sofistik and it may be considered wrong.

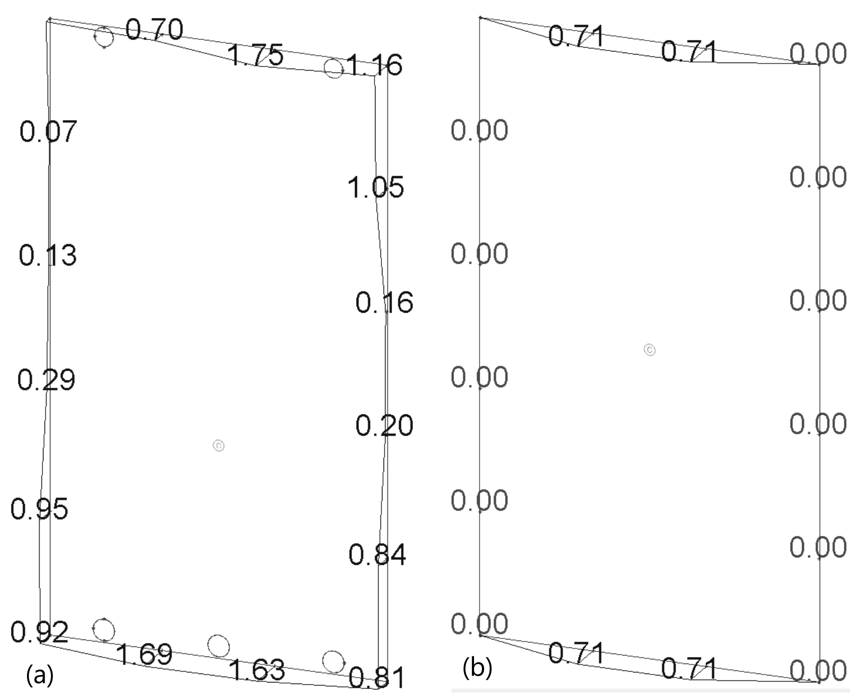


Figure 3-7 – Shear stress evaluated by Sofistik for an (a) reinforced cross-section with bars and (b) unreinforced

3.2. Reinforcement for Tension Perpendicular to the Grain

Tension stress perpendicular to the grain is develops in a beam with variable height or curved shape, notched beams or beams with openings.

This thesis' focus lies on curved beams.

3.2.1. Types

The EC 5 standardized three different types of beams with tension stress perpendicular to the grain: double tapered (Figure 3-9), curved (Figure 3-10) and pitched cambered (Figure 3-11) beams. The unsymmetrical versions of these beams will not be covered in this thesis. The stress itself can be determined by the EC 5, although if stresses are too high to be carried by the wooden cross-section alone only the German National Annex introduces calculation model to determine the strengthening.

In the cross-section at the apex deviation forces form due to the curved shape and/or the variable height of the cross-section and result in lateral stresses. The occurrence of tension stresses perpendicular to grain at the apex is shown in Figure 3-8.

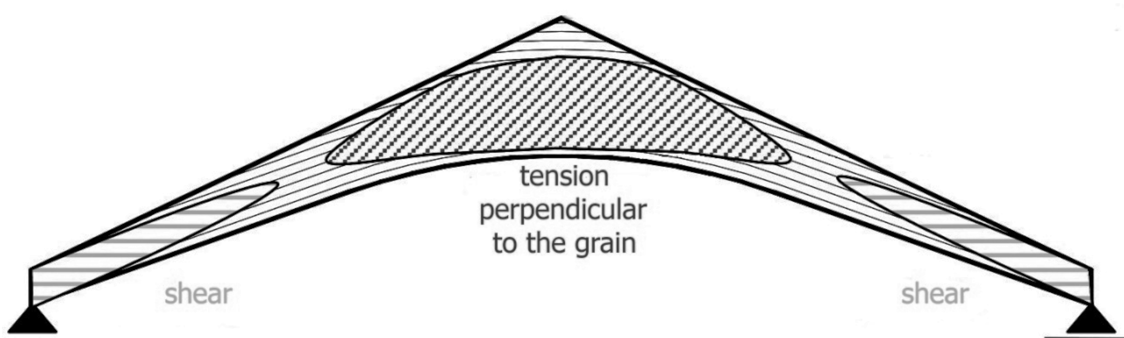


Figure 3-8 – Distribution of tension stress perpendicular to the grain and shear stress in a pitch cambered beam (Dietsch, 2012)

The striped area (1) shows the stressed area of the beam and is mainly exposed to tension stress perpendicular to the grain.

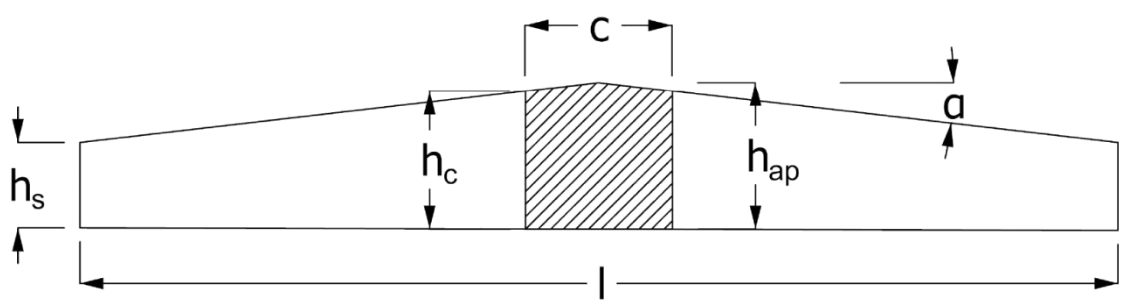


Figure 3-9 – Double tapered beam

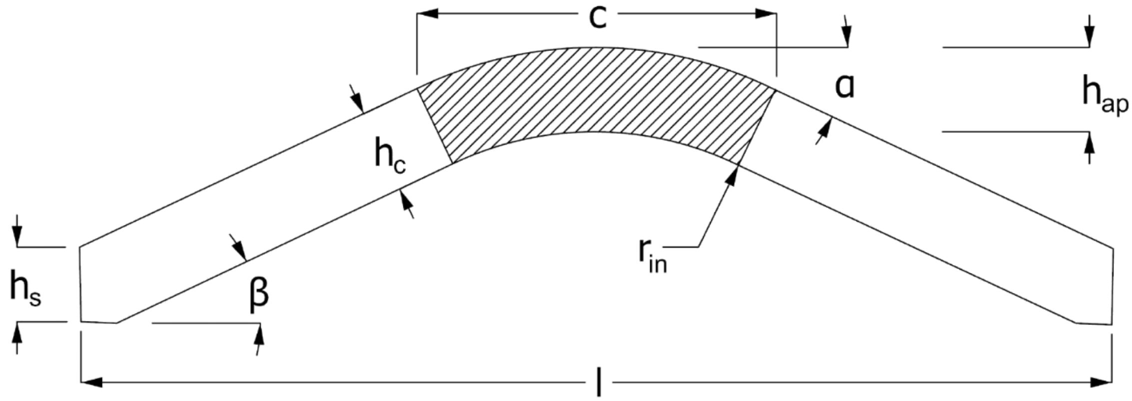


Figure 3-10 – Curved beam

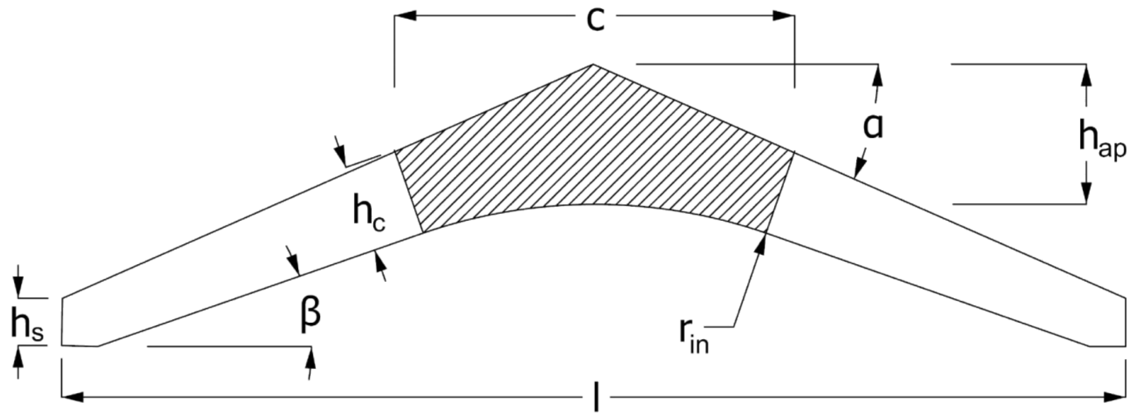


Figure 3-11 – Pitched cambered beam

The general calculation model of all three types is similar, though some values are determined differently for each type. The calculation of these values can be found in Table 3-6.

3.2.2. Calculation model

The calculation method is structured identically for all three beam types with differences in some values. For a clearer presentation the Table 3-6 summarizes the variable calculations of the following values:

(a) the height at the apex h_{ap},

(b) height at the beginning of stressed section h_c,

(c) volume of the stressed section V,

(d) the coefficient k_p.

double tapered	(a)[6]	$h_{ap} = h_s + \tan\alpha \cdot \frac{l}{2}$

[6] (Informationsdienst Holz, 1995, p. 20)

beam	(b)[7]		$h_c = h_s \cdot \cos\alpha$
	(c)[8]		$V = (1 - 0.25 \cdot \tan\alpha) \cdot b \cdot h_{ap}^2$
	(d)[9]		$k_p = 0.2 \cdot \tan\alpha$
curved beam	(a_1)	constant	$h_{ap} = h_s$
	(a_2)[10]	variable	$h_{ap} = h_s + \frac{l}{2} \cdot (\tan\alpha - \tan\beta) + r_{in} \cdot (\sin\beta - \tan\beta + \cos\beta - 1)$
	(b_1)[11]	constant	$h_c = h_s \cdot \cos\alpha$
	(b_2)[12]	variable	$h_c = \cos\alpha \cdot \left(h_s + \frac{l-c}{2} \cdot (\tan\alpha - \tan\beta)\right)$
	(c)[13]		$V = \frac{2 \cdot \beta}{360} \cdot \pi \cdot \left[\left(r + \frac{h_{ap}}{2}\right)^2 - \left(r - \frac{h_{ap}}{2}\right)^2\right] \cdot b$
	(d)[14]		$k_p = 0.25 \cdot \frac{h_{ap}}{r}$
pitched cambered beam	(a_1)[15]	constant	$h_{ap} = \frac{c}{2} \cdot \tan\alpha + \frac{h_s}{\cos\alpha} - r_{in} \cdot (1 - \cos\alpha)$
	(a_2)[16]	variable	$h_{ap} = h_s + \frac{l}{2} \cdot (\tan\alpha - \tan\beta) + \frac{c}{2} \cdot \tan\beta - r_{in} \cdot (1 - \cos\beta)$
	(b_1)[17]	constant	$h_c = h_s \cdot \cos\alpha$
	(b_2)[18]	variable	$h_c = \cos\alpha \cdot \left(h_s + \frac{l-c}{2} \cdot (\tan\alpha - \tan\beta)\right)$
	(c)[19]		$V = 2 \cdot \left[\frac{1}{2} \cdot \left(r + h_{ap}\right)^2 \cdot \frac{\sin\beta}{\sin\left(90 - (\alpha - \beta)\right)} \cdot \sin(90 - \alpha) - \frac{\beta}{360} \cdot \pi \cdot r_{in}^2\right] \cdot b$

[7] (Mönck & Rug, 2015, S. 677)

[8] (Boddenberg, 2015, p. 44)

[9] (Boddenberg, 2015, p. 44)

[10] (Informationsdienst Holz, 1995, p. 20)

[11] (Mönck & Rug, 2015, S. 677)

[12] (Mönck & Rug, 2015, S. 677)

[13] (Boddenberg, 2015, p. 50)

[14] (Boddenberg, 2015, p. 50)

[15] (Mönck & Rug, 2015, S. 677)

[16] (Mönck & Rug, 2015, S. 677)

[17] (Mönck & Rug, 2015, S. 677)

[18] (Mönck & Rug, 2015, S. 677)

[19] (Boddenberg, 2015, p. 57)

(d)[20]	$k_p = k_5 + k_6 \left(\frac{h_{ap}}{r}\right) + k_7 \left(\frac{h_{ap}}{r}\right)^2$

Table 3-6 – various calculations for the three different types

The bending moment around the strong axis is the main cause for tension stress perpendicular to the grain results. Since other loading have only very little influence on tension stress perpendicular to the grain, these will be disregarded for the upcoming process.

$$\sigma_{t,90,d} = k_p \cdot \frac{6 \cdot M_{ap,d}}{b \cdot h_{ap}^2}$$

Eq. 3-19 – Design tensile stress perpendicular to grain

(DIN EN 1995-1-1, 2004, p. 52)

k_p : factor according to Table 3-6 – calculation (d)

$M_{ap,d}$: design moment at apex resulting in tensile stresses parallel to the inner curved edge

$$k_5 = 0.2 \cdot \tan \alpha_{ap}$$

Eq. 3-20 – factor k_5

(DIN EN 1995-1-1, 2004, p. 52)

α_{ap} : angle of the upper taper

$$k_6 = 0.25 - 1.5 \cdot \tan \alpha_{ap} + 2.6 \cdot \tan^2 \alpha_{ap}$$

Eq. 3-21 – factor k_6

(DIN EN 1995-1-1, 2004, p. 52)

$$k_7 = 2.1 \cdot \tan \alpha_{ap} - 4 \cdot \tan^2 \alpha_{ap}$$

Eq. 3-22 – factor k_7

(DIN EN 1995-1-1, 2004, p. 52)

$$r = r_{in} + 0.5 \cdot h_{ap}$$

Eq. 3-23 – Radius

(DIN EN 1995-1-1, 2004)

r_{in} : inner radius

h_{ap} : height at the apex - according Table 3-6, calculation (a)

In order to check if the wooden cross-section can withstand the stress, the following condition needs to be satisfied. As part of the beam which is exposed to the tension stress perpendicular to the grain, the stress volume needs to be determined.

[20] (DIN EN 1995-1-1, 2004, p. 52)

k_{vol}	solid timber	glulam and LVL
①	1	$\left(\frac{V_0}{V}\right)^{0.2}$
②	$\left(\frac{600}{h_{ap}}\right)^{0.3}$	

Table 3-7 - factor k_{vol}

(DIN EN 1995-1-1, 2004, p. 50)

① : constructive reinforcement due to climate-induced stresses

② : full reinforcement to take all stresses

V_0 : $= 0.01\, m^3$: reference volume

V : stressed volume of apex zone – according Table 3-6 – calculation (c)

k_{dis}	double tapered beam	curved beam	pitched cambered beam
①	1.4	1.4	1.7
②	1.3	1.15	1.3

Table 3-8 - factor k_{dis}

(DIN EN 1995-1-1, 2004, p. 50)

$$\frac{\sigma_{t,90,d}}{k_{dis①} \cdot k_{vol①} \cdot f_{t,90,d}} \leq 1$$

Eq. 3-24 – Verification wood for tension perpendicular to the grain

(DIN EN 1995-1-1, 2004, p. 51)

If the Eq. 3-24 is not satisfied, the strength of the timber is not sufficient and it needs to be checked if the constructive reinforcement is adequate.

$$\frac{\sigma_{t,90,d}}{k_{dis②} \cdot k_{vol②} \cdot f_{t,90,d}} \leq 1$$

Eq. 3-25 – Verification constructive reinforcement for tension perpendicular to the grain

(DIN EN 1995-1-1, 2004, p. 51)

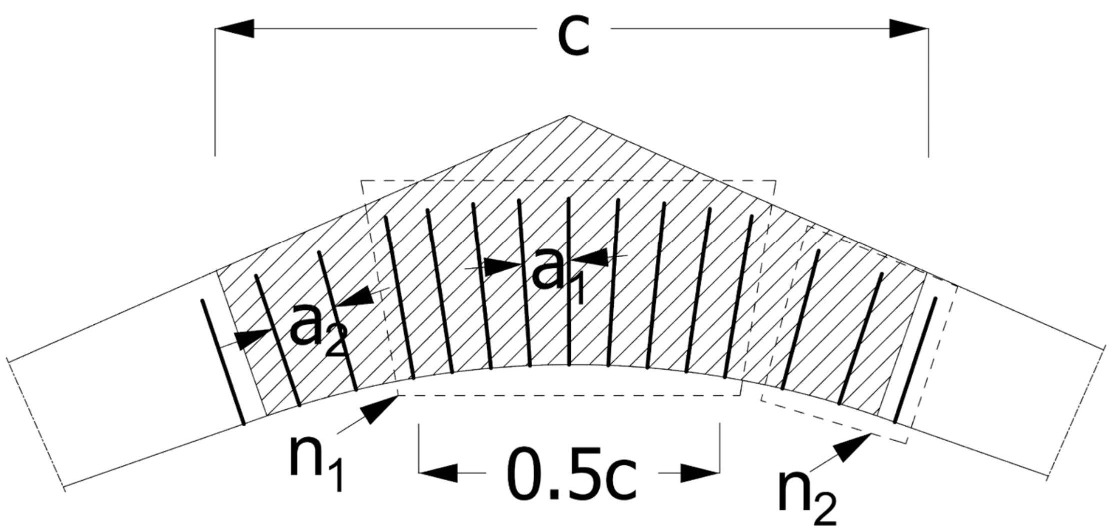


Figure 3-12 – Length of strengthening area and distance between strengthening

If Eq. 3-25 is not satisfied, thus the constructive reinforcement is not sufficient either. Therefore design of reinforcement is needed to withstand the total amount of tension stress perpendicular to the grain. The strength of timber is disregarded.

The value c is defined as the length of stressed area. Since the stresses are considerably higher towards the apex of the beam, the stressed area is divided into two outer parts and an inner part, seen in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

	double tapered beam	pitched cambered and curved beam
c	h_{ap}	$2 \cdot r_{in} \cdot \sin\beta$

Table 3-9 – Length of area for strengthening c

(DIN EN 1995-1-1, 2004)

The verification of reinforcement is based on sufficient steel bar and glue-line strength, whose calculation will be presented.

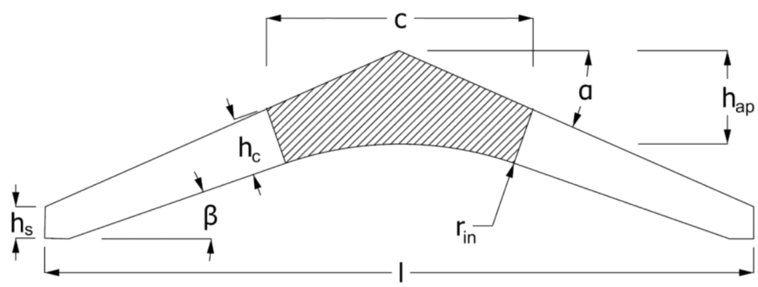


Figure 3-13 – Presentation of the dimensions

The strength of the glue-line is subject of the penetration length. In the (DIN EN 1995-1-1/NA, 2013) this length is defined to be the half of the beam height less the thickness of one lamella. For the inner and outer part different lengths of the reinforcement are defined, see Figure 3-12. The corresponding penetration depth for each case is determined based on the smallest height of the beam in the respective part.

$$l_{ad,i} = \frac{h_{c,i}}{2} - t$$

Eq. 3-26 – penetration depth of rods

(DIN EN 1995-1-1/NA, 2013)

$h_{c,i}$: height at the edge of c Table 3-6 – calculation (b)

t : thickness of the lamellae

$$\min l_{ad} = \max\begin{cases} 0.5 \cdot d^2 \\ 10 \cdot d \end{cases}$$

Eq. 3-27 – minimum penetration depth

(DIN EN 1995-1-1/NA, 2013)

In order to check which failure is dominating, the yield and ultimate tensile strength of the steel bar as well as the strength of the glue line are determined. The characteristic strength of the glue line can be assumed as 4.0 N/mm² as suggested by the (DIN EN 1995-1-1/NA, 2013, p. 57).

$$F_{t,90,Rd} = \min \begin{cases} \dfrac{f_{yk}}{1.1 \cdot \gamma_{M,0}} \cdot A \\ \dfrac{f_{uk}}{1.1 \cdot \gamma_{M,2}} \cdot A \\ 0.5 \cdot \pi \cdot d \cdot l_{ad,1} \cdot k_{mod} \cdot \dfrac{f_{k,1,k}}{\gamma_{M_W}} \end{cases}$$

Eq. 3-28 – minimum strength of tensile strength of one rod and its glue line

(Boddenberg, 2015)

$\gamma_{M,0}$: $= 1.1$: Partial factor for steel in wood
$\gamma_{M,2}$: $= 1.25$: Partial factor for steel in wood
γ_{M_W} : $= 1.3$: Partial factor for wood properties
$f_{k1,k}$: $= 4\ N/mm^2$: characteristic strength of glue line

Finally the definition of the bar layout needs to be determined including spacing and number of bars. The strength of the reinforcement is divided by the induced stress to find the spacing in the inner stressed area with higher stresses.

$$a_1 = \frac{F_{t,90,Rd} \cdot m}{\sigma_{t,90,d} \cdot b}$$

Eq. 3-29 – spacing between the rods in the inner section

(Boddenberg, 2015) Figure 3-12

b : width of the beam
m : number of rods transverse to beam axis

$$250\ mm \leq a_1 \leq 0.75 \cdot h_{ap}$$

Eq. 3-30 – restriction for the spacing

(DIN EN 1995-1-1/NA, 2013, p. 60)

Because of variable stresses and penetration lengths the inner and outer sections are designed separately. Due to lower stresses, the spacing between the bars in the outer section a_2 can be 50% higher as the spacing of the inner section a_1.

$$a_2 = 1{,}5 \cdot a_1$$

Eq. 3-31 – spacing between the rods in the outer sections

(DIN EN 1995-1-1/NA, 2013, p. 60)

$$n_1 = \frac{c/2}{a_1} + 1$$

Eq. 3-32 – number of reinforcement in the inner section

(Boddenberg, 2015)

$$n_2 = \frac{c/4}{a_2}$$

Eq. 3-33 – number of reinforcement in the outer sections

(Boddenberg, 2015)

If the constructive reinforcement is sufficient and Eq. 3-25 is satisfied, only the spacing number of rods and need to be computed. For simplicity reasons for calculation and construction the bars are laid with the same spacing, a determination of a_2 will be foregone.

$$a_1 = F_{t,90,d} * \frac{m \cdot 640}{\sigma_{t,90,d} \cdot b^2}$$

Eq. 3-34 - spacing between the rods

(Boddenberg, 2015, p. 65)

$$n_1 = \frac{c}{a_2} + 1$$

Eq. 3-35 – number of reinforcement in the inner section

(Boddenberg, 2015)

The following flowchart presents the whole calculation process for reinforcement for tension perpendicular to the grain.

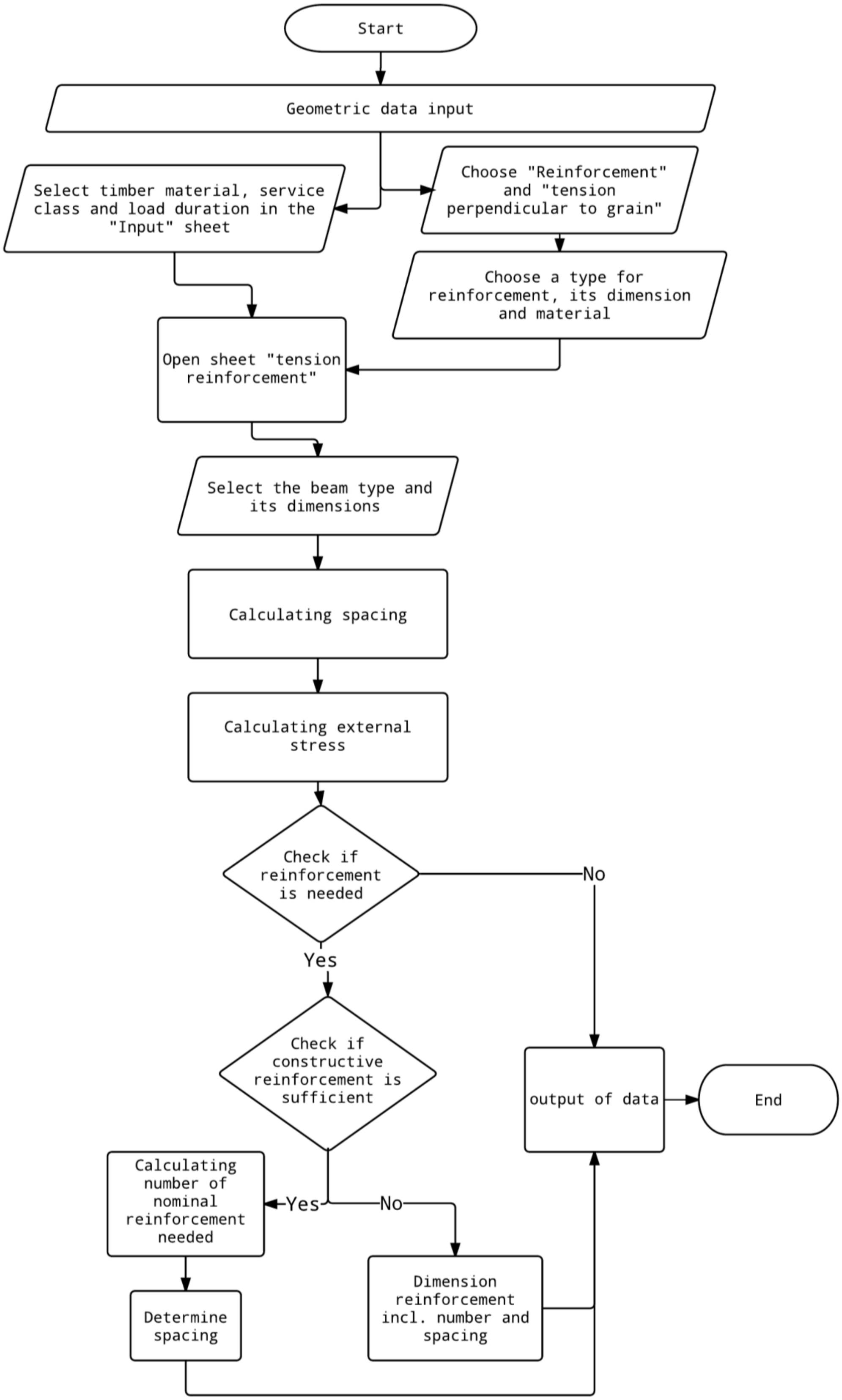


Figure 3-14 - Flowchart for calculation of reinforcement for tension perpendicular to the grain

3.2.3. Code

Since there are not many possible variations besides the different beam forms, the source concentrates on the calculation method shown in the previous chapter. This code can be referenced in chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**. It identifies the type of beam, checks if the height is constant or not and concludes how the dimensions need to be calculated. Further processes include the checking if reinforcement is needed and continues to design the layout.

3.2.4. Validation

For validation the examples of (Boddenberg, 2015) will be used since he included all three types in his script and presented his solution with high traceability. The screenshots of the tool results are included in the chapter 7.2.2.

It is safe to say that the tool is working sufficiently and is providing correct results.

3.2.4.1. Double Tapered Beam

For double tapered beams, the tool's capability was compared to an example of (Boddenberg, 2015). The Figure 3-15 shows the dimensions of the beam.

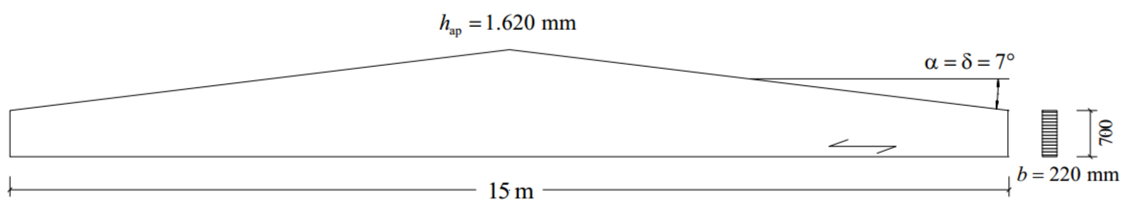


Figure 3-15 – Example of double tapered beam: dimensions (Boddenberg, 2015, p. 45)

Further information loading and timber grading are summarized in Table 3-10.

NKL	2
load duration	"short" (snow < 1000m)
M_{ap}	927.0 kNm
Timber grade	GL28h

Table 3-10 – Example of double tapered beam: further information (Boddenberg, 2015, p. 45ff)

The results of the example calculated by (Boddenberg, 2015) and the tool are presented in Table 3-11. The comparison between the results shows confirmations.

	(Boddenberg, 2015)	tool
h_{ap} [mm]	1620	1621

V [m³]	0.560	0.56
k_p [-]	0.024	0.02
$\sigma_{t,90,d}$ [N/mm²]	0.2365	0.24
$\eta_{t,90,d,1}$ [-]	1.21	1.21
$\eta_{t,90,d,2}$ [-]	0.79	0.79
$F_{t,90,Rd}$ [N]	12,700	12,721
a_1 [mm]	-	712
n_1 [-]	3	4

Table 3-11 – Validation of Double Tapered Beam

3.2.4.2. Curved Beam

Another example of (Boddenberg, 2015) lead to the validation of a curved beam. In Figure 3-16 the dimensions are presented.

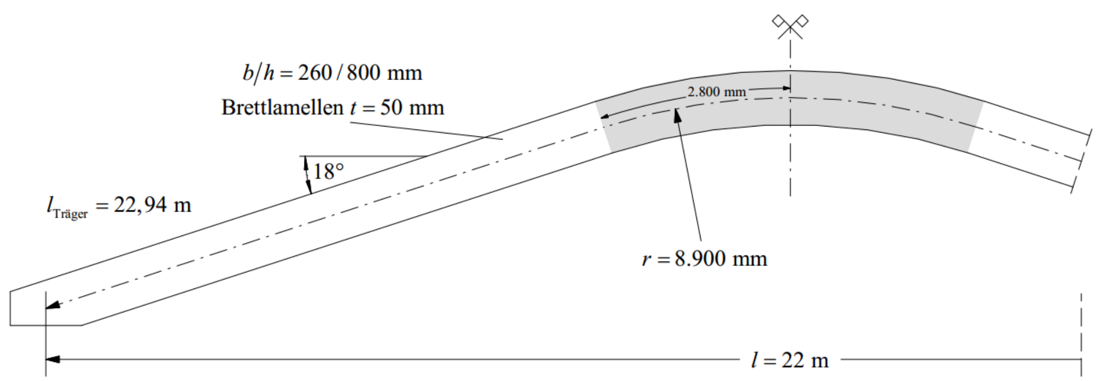


Figure 3-16 – Example of curved beam: dimensions (Boddenberg, 2015, p. 51)

Further information loading and timber grading are summarized in Table 3-12.

NKL	1
load duration	"short" (snow < 1000m)
M_{ap}	462.8 kNm
Timber grade	GL32h

Table 3-12 – Example of curved beam: further information (Boddenberg, 2015, p. 51ff)

The Table 3-13 clearly concludes the results of the tool as well; therefore it can be used to calculate the reinforcement for tension stress perpendicular to the grain of curved beams.

	(Boddenberg, 2015)	tool

h_{ap} [mm]	800	800
V [m³]	1.163	1.16
k_p [-]	0.0225	0.02
$\sigma_{t,90,d}$ [N/mm²]	0.376	0.37
$\eta_{t,90,d,1}$ [-]	2.01	2.00
$\eta_{t,90,d,2}$ [-]	1.029	1.03
$F_{t,90,Rd}$ [N]	12,300	12,194
a_1 [mm]	250	250
n_1 [-]	12	12
a_2 [mm]	370	375
n_2 [-]	4	5

Table 3-13 - Validation of Curved Beam

3.2.4.3. Pitched Cambered Beam

The example of the pitched cambered beam of (Boddenberg, 2015) lead to this validation. In Figure 3-17 the dimensions are presented.

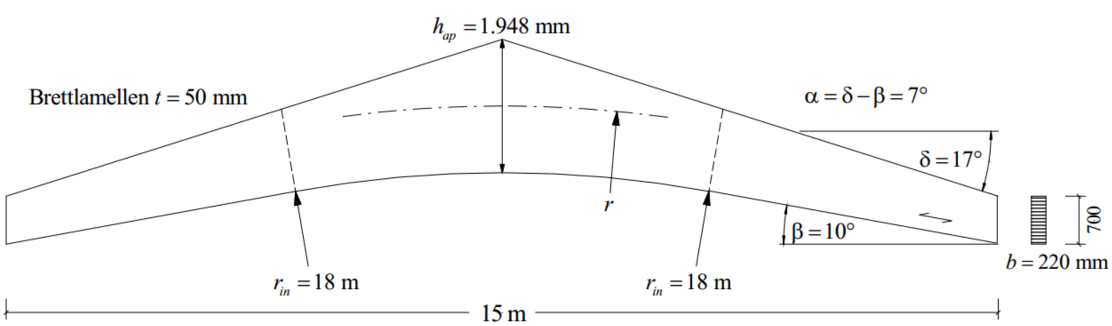


Figure 3-17 – Example of pitched cambered beam: dimensions (Boddenberg, 2015, p. 51)

Further information loading and timber grading are summarized in Table 3-14

NKL	1
load duration	"short" (snow < 1000m)
M_{ap}	874,7 kNm
Timber grade	GL32h

Table 3-14 – Example of pitched cambered beam: further information (Boddenberg, 2015, p. 51ff)

The Table 3-13 clearly concludes the results of the tool as well; therefore it can be used to calculate the reinforcement for tension stress perpendicular to the grain of curved beams.

Table 3-15 presents very similar values between the tool and the example of (Boddenberg, 2015), only besides differences for $F_{t,90,Rd}$. These mismatches are due to different definitions of γ_M. Since in this thesis the tensile yield strength is divided by $1.1 \cdot \gamma_{M,1}$, the increased partial factor for tensile strength. While in the example the tensile yield strength is divided by $\gamma_{M,2}$, although this is the partial factor for ultimate strength properties.

Since the tool is always providing the most efficient solution, there are differences between the spacing. (Boddenberg, 2015) chose a spacing of 400 but his calculated value was with 460 mm (variations due to different strengths of the reinforcement) relatively close to the tool.

	(Boddenberg, 2015)	tool
h_{ap} [mm]	1948	1948
V [m³]	2.21	2.21
k_p [-]	0.06751	0.07
$\sigma_{t,90,d}$ [N/mm²]	0.425	0.42
$\eta_{t,90,d,1}$ [-]	2.36	2.36
$\eta_{t,90,d,2}$ [-]	1.49	1.49
$F_{t,90,Rd}$ [N]	21,600	22,294
a_1 [mm]	400	470
n_1 [-]	9	8
a_2 [mm]	600	705
n_2 [-]	3	4

Table 3-15 - Validation of Pitched Cambered Beam

3.3. Connection – Glued-in Rod

Already in the German Standard DIN 1052 connections with glued-in rods have been part of and developed into a common type of fastener in Germany. The calculation model was derived by the German National Annex of the EC 5.

3.3.1. Types

Two types of rods are allowed: threaded rod and reinforcing bar. The property differences of these types have been discussed in chapter 3.1.1.1.

Figure 3-18 – Glued-in threaded rods[21]

3.3.2. Calculation model

Over time different calculation models considering variable influences of the involved materials such as wood density or steel bar diameter developed (Steiger, 2012). For example the preliminary EC 5 included larger influence of wood density and due to controversial discussion the final draft did not adapted this approach.

The steel bar is important for the connection to endure the loading but also the wood and the adhesive are crucial parts to be proven. Two load configurations are considered:

- loading parallel to the grain – axial loading
- loading perpendicular to the grain – lateral loading

3.3.2.1. Axial loading

The following failure modes can occur and need to be checked (Lippert, 2002):

[21] https://cdn.agrarverlag.at/imgsrv/to/mmedia/image//2013.08.23/1377263307714_1.jpg?_=1413300604

(1) Failure of steel bar

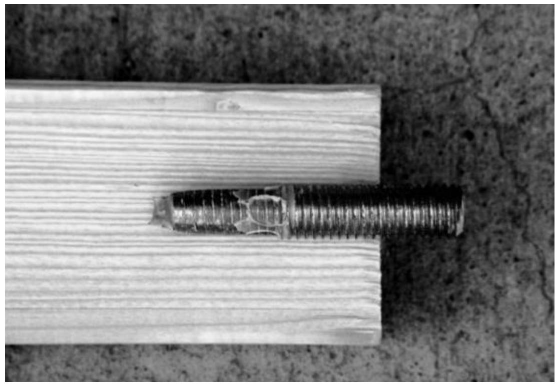


Figure 3-19 - Tension failure of the rod (Steiger, 2012)

The load-carrying capacity of a steel bar depends on the material strength. If the decisive design value is tensile yield strength, the connection is ductile. If the ultimate tensile strength is reached the bar ruptures.

$$F_{ax,S,Rd} = A_{ef,S} \cdot \min \begin{cases} \dfrac{f_{y,k}}{1.1 \cdot \gamma_{M,0}} \\ \dfrac{f_{u,k}}{1.1 \cdot \gamma_{M,2}} \end{cases}$$

Eq. 3-36 – load carrying-capacity of bar

(TiComTec, 2015, p. 9)

$\gamma_{M,0}$: = 1.1: Partial factor for steel in timber

$\gamma_{M,2}$: = 1.25: Partial factor for steel in timber

$A_{ef,S}$: stressed cross-section of the steel rod

(2) Failure of glue line

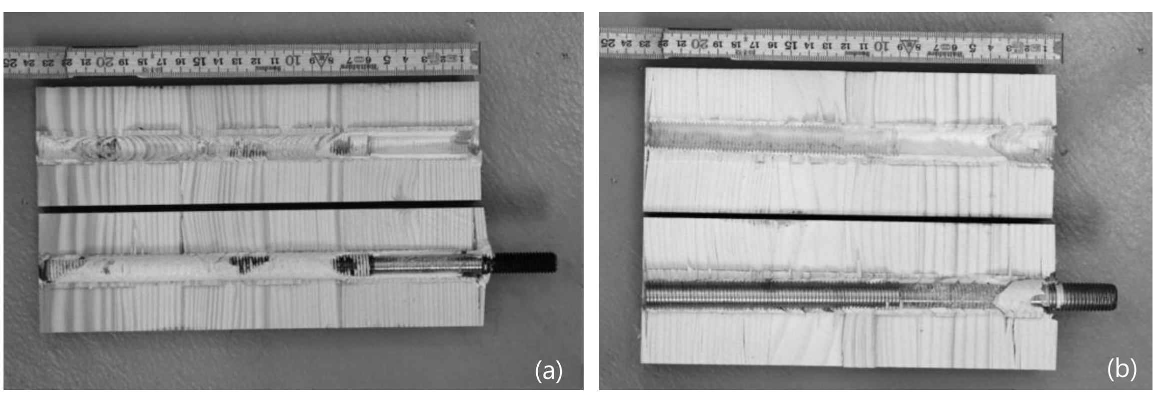


Figure 3-20 - Adhesion failure at the interface (a) adhesive – wood and (b) adhesive – steel (Steiger, 2012)

The glue line fails either due to adhesive or cohesive failure. Adhesion is the clinging of two different materials to each other, hence its failure, shown in Figure 3-20, takes place at the interface between the adhesive and (a) wood or (b) steel. While cohesive is the clinging of similar materials, therefore happens in the glue line or the timber close to the bond line.

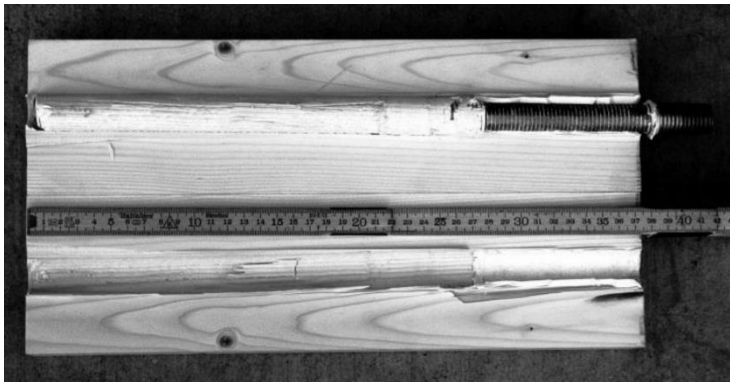


Figure 3-21 - Wood failure close to bond line (Steiger, 2012)

The design rules to determine failure of the glue line are controversial. The EC 5 assumes an independence of the glue line strength to the wood density while Swiss standards include it (Steiger, 2012). Since this thesis is based on the EC 5, its assumption will be adapted. Although the wood density seems to have an important influence while resisting shear forces at the adhesive interface.

The characteristic strength of the glue line is dependent on the critical anchoring length, which specifies length above which increase of load transfer stops (Johnsson, Blanksvärd, & Carolin, 2006). Since the load introduction becomes less effective the longer the bar is the corresponding shear strength of the glue line decreases.

$$\min l_{ad} = \max \begin{cases} 0{,}5 \cdot d^2 \\ 10 \cdot d \end{cases}$$

Eq. 3-37 – minimal penetration length

(DIN EN 1995-1-1/NA, 2013, p. 95)

Table 3-16 - Characteristic shear strength of glue line

(DIN EN 1995-1-1/NA, 2013)

l_{ad} [mm]	$f_{k1,k}$ [N/mm²]
≤ 250	4.0
$250 < l_{ad} \leq 500$	$5.25 - 0.005 \cdot l_{ad}$
$500 < l_{ad} \leq 1000$	$3.5 - 0.0015 \cdot l_{ad}$

$$f_{k1,d} = k_{mod} \cdot \frac{f_{k1,k}}{\gamma_{M_W}}$$

Eq. 3-38 – design shear strength of glue line

$f_{k1,k}$: characteristic strength of glue line, according Table 3-16

The load-carrying capacity of the glue line is based on the interfacial layer and the strength of the glue line.

$$F_{ax,A,Rd} = \pi \cdot d \cdot l_{ad} \cdot f_{k1,d}$$

d : fastener nominal diameter ($6mm \leq d \leq 30mm$)

l_{ad} : penetration depth ($l_{ad} \leq 1000mm$)

Eq. 3-39 – load-carrying capacity of glue line

(DIN EN 1995-1-1/NA, 2013, p. 94)

(3) Failure of wood: splitting

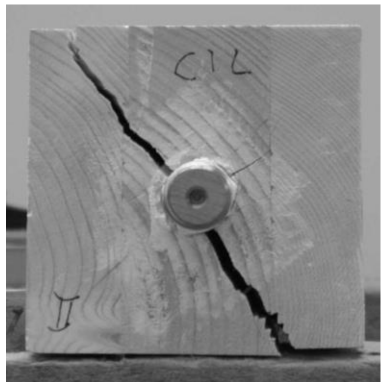


Figure 3-22 – Splitting of the wood (Steiger, 2012)

The failure of wood splitting can be avoided by compliance the wooden cover, hence design the connection with the minimal spacing.

(4) Failure of wood: tensile

As a result of high local axial stresses, failure of timber at the end of the bar is possible. Prove for the net cross-section is needed which is either defined as the net area or 36 times the diameter of the bar.

$$A_{net,W} = A_w - n_S \cdot A_{ef,S}$$

Eq. 3-40 – net cross-section

(Rug & Mönck, 2008)

$$A_{W,cal} = \min \begin{cases} A_{net,W} \\ n_S \cdot 36 \cdot d^2 \end{cases}$$

Eq. 3-41 – minimal net area of timber

(DIN EN 1995-1-1/NA, 2013, p. 95)

$$F_{ax,w,Rd} = \frac{A_{W,cal} \cdot f_{t,0,d}}{\mathrm{n_S}}$$

$f_{t,0,d}$: design tensile strength along the grain

Eq. 3-42 – resistance of timber

(DIN EN 1995-1-1/NA, 2013, p. 95)

The smallest of the calculated load-carrying capacities defines the decisive resistance and the failure mode.

$$F_{ax,Rd} = \min \begin{cases} F_{ax,S,Rd} \\ F_{ax,A,Rd} \\ F_{ax,w,Rd} \end{cases}$$

Eq. 3-43 – design value of axial withdrawal capacity

(DIN EN 1995-1-1/NA, 2013, p. 94)

The axial stresses affecting the cross-section are evenly distributed between all steel bars.

$$F_{ax,\mathrm{N},Ed} = \frac{N_d}{n_y \cdot n_z}$$

Eq. 3-44 – axial stress

n_y : number of rods in y-direction
n_z : number of rods in z-direction

The moment of inertia need to be calculated to determine the bending stress for the decisive glued-in rod in the connection layout.

$$I_{y,i} = \frac{1}{12} \cdot A_i \cdot {d_i}^2 + A_i \cdot z_{a,i}^2$$

Eq. 3-45 – moment of inertia about the y-axis of one rod

(Gere, 2002)

$I_{y,i}$: moment of inertia of one rod (y-axis)
A_i : area of one rod
d_i : diameter of one rod
$z_{a,i}$: distance in z-direction from beam's center of gravity to the one of the particular rod

$$I_{y,conn} = \sum I_{y,i}$$

Eq. 3-46 – moment of inertia about the y-axis of the connection (sum of rods)

$$I_{z,i} = \frac{1}{12} \cdot A_i \cdot {d_i}^2 + A_i \cdot y_{a,i}^2$$

Eq. 3-47 – moment of inertia about the z-axis of one rod

(Gere, 2002)

$I_{z,i}$: moment of inertia of one rod (z-axis)
$y_{a,i}$: distance in y-direction from beam's center of gravity to the one of the particular rod

$$I_{z,conn} = \sum I_{z,i}$$

Eq. 3-48 – moment of inertia about the z-axis of the connection (sum of rods)

The forces acting in the decisive glued-in rod resulting of bending stresses is calculated by determine the highest lever arm for each axis.

$$F_{ax,\mathrm{M_y},Ed} = \frac{M_y}{I_y} \cdot z_{max} \cdot A$$

Eq. 3-49 – bending stress around the y-axis

(Gere, 2002)

z_{max} : max. distance between the beam's center of gravity the decisive rod (z-direction)

$$F_{ax,\mathrm{M_z},Ed} = \frac{M_z}{I_z} \cdot y_{max} \cdot A$$

Eq. 3-50 – bending stress around the z-axis

(Gere, 2002)

y_{max} : max. distance between the beam's center of gravity the decisive rod (y-direction)

Since the decisive bar is affected by all influences equally, the total axial stress equals the sum of the separately determined ones.

$$F_{ax,Ed} = F_{ax,\mathrm{N},Ed} + F_{ax,\mathrm{M_y},Ed} + F_{ax,\mathrm{M_z},Ed}$$

Eq. 3-51 – combined axial stress

$$\frac{F_{ax,Ed}}{F_{ax,Rd}} \leq 1$$

Eq. 3-52 – verification axial loading

(DIN EN 1995-1-1/NA, 2013)

The connection is sufficient when the weakest link in the connection is capable to withstand the axial loading.

3.3.2.2. Lateral Loading

All resistances to lateral loading are based on the embedment strength which is dependent on the wood density and the bar diameter.

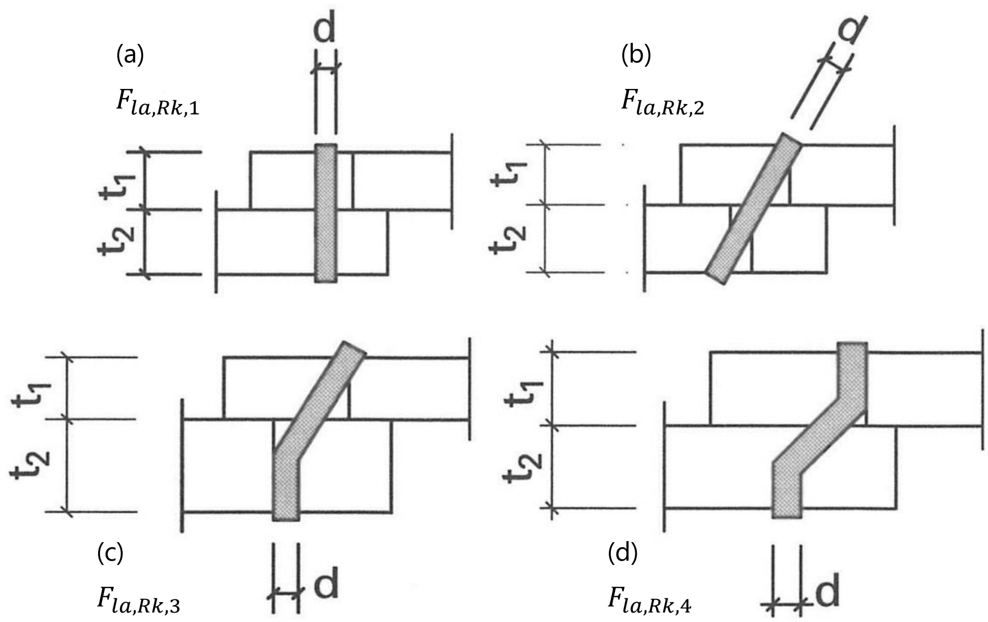


Figure 3-23 - Failure modes of timber connections (Rug & Mönck, 2008, p. 65)

The formulae for the characteristic embedment strength for glued-in rods set perpendicular to the grain can only be recognized with 10% since glued-in rod set parallel to the grain result in a less effective stress transmission between timber and bar.

$$f_{h,k} = 0.1 \cdot 1.25 \cdot 0.082 \cdot (1 - 0.01 \cdot d) \cdot \rho_k$$

Eq. 3-53 – characteristic embedment strength

(DIN EN 1995-1-1, 2004, p. 78)

The following four failure modes in Figure 3-23 can occur due to lateral stress and need to be checked (Lippert, 2002).

(1) Failure of wood: tension perpendicular to the grain

The loss of support for the bar due timber failure can be avoided with minimum wooden cover between bars.

(2) Failure of wood: bearing stress

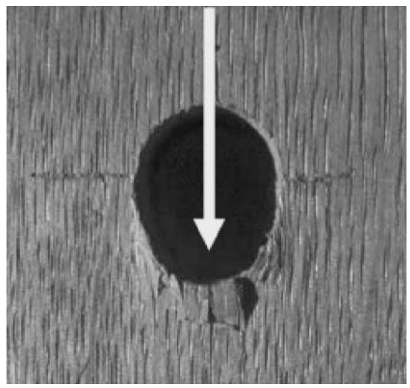


Figure 3-24 – Bearing stress exceeded (Bundesbildungszentrum des Zimmerer- und Ausbaugewerbes, 2015)

The bearing pressure of the glued-in rod exceeds the timber strength and timber crushing in loading direction occurs.

The first mode, shown in Figure 3-23 (a), is the failure of one timber members, while the second mode (b) is a failure in both members. In these situations the resistance is only based on the properties of timber.

$$F_{la,Rk,1} = f_{h,k} \cdot d \cdot l_{ad}$$

Eq. 3-54 –load-carrying capacity, as Figure 3-23 (a)

(DIN EN 1995-1-1, 2004, p. 63)

$$F_{la,Rk,2} = f_{h,k} \cdot l_{ad} \cdot d \cdot (\sqrt{2} - 1)$$

Eq. 3-55 –load-carrying capacity, as Figure 3-23 (b)

(DIN EN 1995-1-1, 2004, p. 63)

(3) Failure of bar: plastic hinge forming

If steel bars in connections yield, hinges are formed. The characteristic yield moment based on the ultimate tensile strength and bar diameter describes the resistance.

$$M_{y,Rk} = 0.3 \cdot f_{u,k} \cdot d^{2.6}$$

$f_{u,k}$: characteristic ultimate tensile strength of steel

Eq. 3-56 – characteristic fastener yield moment

(DIN EN 1995-1-1, 2004, p. 77)

The EC 5 suggests using slender glued-in rods, which results in less resistance and a higher possibility that slender bars yield in their ductile behaviour before the brittle failure of timber. The most ductile failure is achieved if $F_{la,Rk,4}$ governs.

The following failure modes are combinations of failure in timber and steel.

$$F_{la,Rk,3} = 1.05 \cdot \frac{f_{h,k} \cdot l_{ad} \cdot d}{3} \cdot \left[\sqrt{4 + \frac{12 \cdot M_{y,Rk}}{f_{h,k} \cdot d \cdot l_{ad}^2}} - 1\right]$$

Eq. 3-57 –load-carrying capacity, as Figure 3-23 (c)

(DIN EN 1995-1-1, 2004, p. 63)

$$F_{la,Rk,4} = 1.15 \cdot \sqrt{2 \cdot M_{y,Rk} \cdot f_{h,k} \cdot d}$$

Eq. 3-58 –load-carrying capacity, as Figure 3-23 (d)

(DIN EN 1995-1-1, 2004, p. 63)

After computing the four $F_{la,Rk,\mathrm{i}}$ the minimum value determines the material with the smallest resistant and therefore is responsible for failure.

$$F_{la,Rk} = \min \begin{cases} F_{la,Rk,1} \\ F_{la,Rk,2} \\ F_{la,Rk,3} \\ F_{la,Rk,4} \end{cases}$$

Eq. 3-59 – characteristic lateral load-carrying capacity

(DIN EN 1995-1-1/NA, 2013)

$$F_{la,Rd} = k_{mod} \cdot \frac{F_{la,Rk}}{\gamma_M}$$

Eq. 3-60 – design lateral load-carrying capacity

(DIN EN 1995-1-1, 2004)

The shear stresses of both axes distribute equally between the glued-in rods and the resultant presents the total lateral loading for each bar.

$$F_{la,\mathrm{V}_y,Ed} = \frac{V_y}{n_y \cdot n_z}$$

Eq. 3-61 – shear stress in y-direction

$$F_{la,\mathrm{V}_z,Ed} = \frac{V_z}{n_y \cdot n_z}$$

Eq. 3-62 –shear stress in z-direction

$$F_{la,Ed} = \sqrt{{F_{la,\mathrm{V}_y,Ed}}^2 \cdot {F_{la,\mathrm{V}_z,Ed}}^2}$$

Eq. 3-63 – shear stress

If Eq. 3-64 is satisfied the connection is able to withstand the lateral impact loads.

$$\frac{F_{la,Ed}}{F_{la,Rd}} \leq 1$$

Eq. 3-64 – verification lateral loading

(DIN EN 1995-1-1, 2004)

Since the properties and dimensions for both members of the connection are identically, the formulae for the resistances have been modified, the ratio for the embedment strength β and of the penetration lengths t_1/t_2 have been set to 1.

3.3.2.3. Interaction

For the case of a simultaneous axial and lateral load, the cross-section need to withstand an interaction of the stresses:

$$\left(\frac{F_{ax,Ed}}{F_{ax,Rd}}\right)^2 + \left(\frac{F_{la,Ed}}{F_{la,Rd}}\right)^2 \leq 1$$

Eq. 3-65 – verification of combined axial and lateral loading

(DIN EN 1995-1-1/NA, 2013, p. 95)

The following flowchart presents the whole calculation process for connection with glued-in rods.

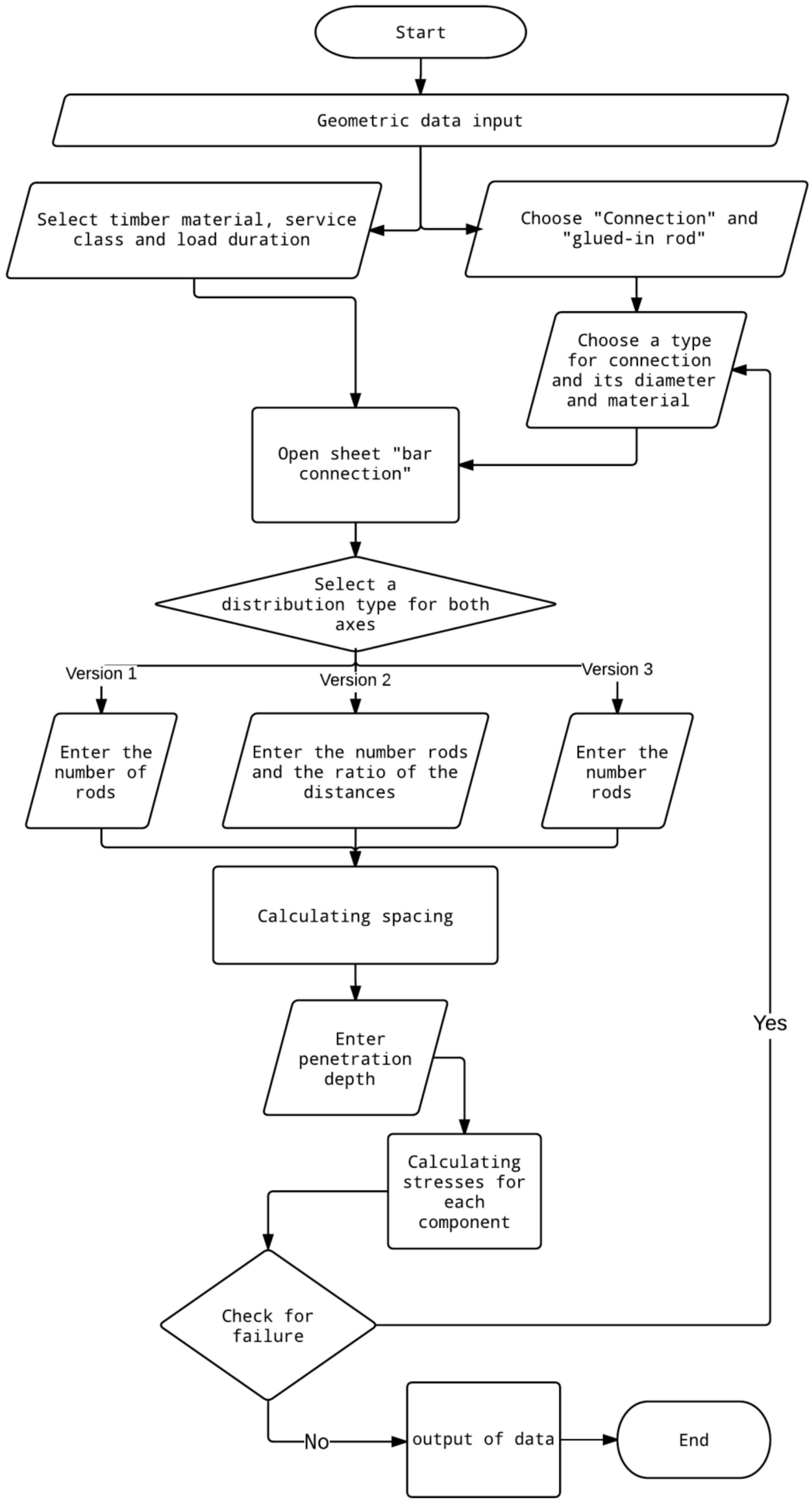


Figure 3-25 – Flowchart – calculation connection with glued-in rods

3.3.3. Code

The full code regarding connection with glued-in rods is copied into the Appendix B chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**.

It was important keeping variability in different distribution types of the rods; Figure 3-26 shows a selection of possible.

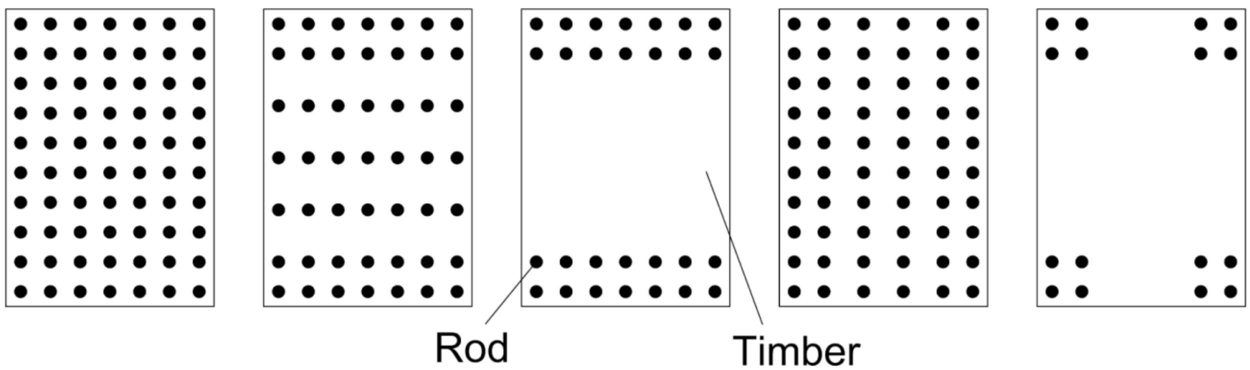


Figure 3-26 – A selection of different distribution types

3.3.4. Validation

The validation for glued-in rods is based on a comparison of stresses determined by this thesis' tool and a Sofistik© FE model of the cross-section. The cross-section is the same as used for flexure reinforcement although the elastic modulus of timber is set very low to achieve only stresses concerning the bars.

The outcome of the tool is defined in Newton and need to be converted to stress. Since the area of the reinforcement bars with a diameter of 14 mm (Figure 7-25) is 154 mm², the determined stresses summarized in Table 3-17.

	Tool		Sofistik
	Force [kN]	Stress [N/mm²]	Stress [N/mm²]
σ_N	5.56	36.08	36.08
σ_{M_y}	32.48	210.92	210.82
σ_{M_z}	19.91	129.31	129.34

Table 3-17 - Validation of connection with bars

The correlation between the values is obvious and acceptable for validation.

Unfortunately Sofistik does not evaluate the shear stress of the connection material; as already discussed for flexure reinforcement. A similar uneven and inappropriate stress distribution was the result of Sofistik.

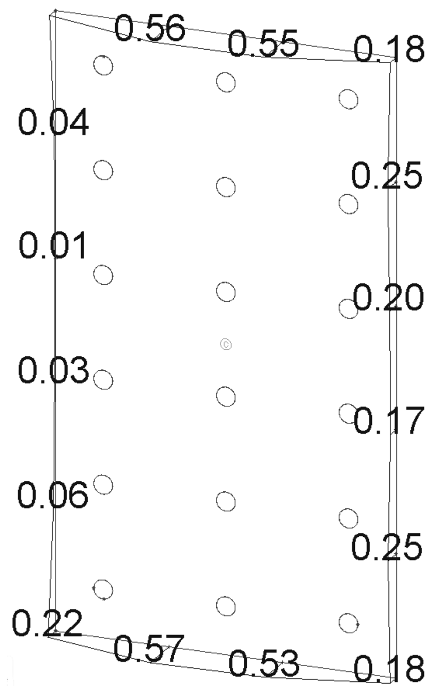


Figure 3-27 – Shear stress distribution of Sofistik for connection with glued-in rod

Since the strengths of the different components did not include complex evaluation a validation is not necessary.

3.4. Connection – Perforated Plate

Several studies concentrated on the idea to design a connection between two wooden members with a minimal cross-section reduction. The perforated plates are chosen for the tool due to their rigid and ductile connection.

3.4.1. Types

Due to the strict specifications the variability an adjustment to different occasions is very limited. If minimal permitted changes in plate thickness, steel grade or distance between the holes are allowed, it can be helpful to design an effective connection in a special situation.

3.4.2. Calculation model

The calculation method of building inspection approval (Zulassung Z-9.1-770, 2014) is generally based on the EC 5. Comparable to glued-in rods steel needs to be the weakest link in the chain under the motto "design in steel, build in wood" (Bathon L. , et al., 2015).

The three components of the connection are verified separately.

3.4.2.1. Steel plate

The axial force is distributed evenly between the steel plates.

$$F_{SP,N_d} = \frac{N_d}{n_{SP}}$$

Eq. 3-66 – normal stress of steel plate

n_{SP} : number of steel plates

The determination for moment of inertia is comparable to that for glued-in rods, since the steel plate is perforated the calculation are based on its net area.

$$A_{net,SP} = (b_{SP} \cdot t_{SP}) - n_{AD} \cdot (\pi \cdot \frac{d^2}{4})$$

Eq. 3-67 – net section area of steel plate

b_{SP} : steel plate width
t_{SP} : steel plate thickness
n_{AD} : total number of adhesive dowels
d : diameter of adhesive dowel

Since the plates are always placed symmetrical around one axis, the determination of the moment of inertia becomes easier because one parallel axis theorem does need to be included.

The basic calculations are comparable to that for glued-in rods.

$$I_{y,SP} = \sum \frac{1}{12} \cdot A_{net,SP} \cdot {t_{SP}}^2 + A_{net,SP} \cdot z_{a,i}^2$$

Eq. 3-68 – moment of inertia about the y-axis of the connection

(Gere, 2002)

A_{net} : net plate cross-section area

$z_{a,i}$: distance in z-direction from beam's center of gravity to the particular plate

$$I_{z,i} = \sum \frac{1}{12} \cdot A_{net,SP} \cdot {b_{SP}}^2 + A_{net,SP} \cdot y_{a,i}^2$$

Eq. 3-69 – moment of inertia about the z-axis of the connection

(Gere, 2002)

$y_{a,i}$: distance in y-direction from beam's center of gravity to the particular plate

The distribution of bending stresses depends on the plate layout. If the centers of the wooden cross-section and the steel plates are on the same axis, the applied bending moment is divided by the section modulus. For the moment around the other axis the decisive plate and its distance to center of the timber need be determined. Due to this fact the calculation are presented separately. The determination of the bending moments for vertical plates is presented first.

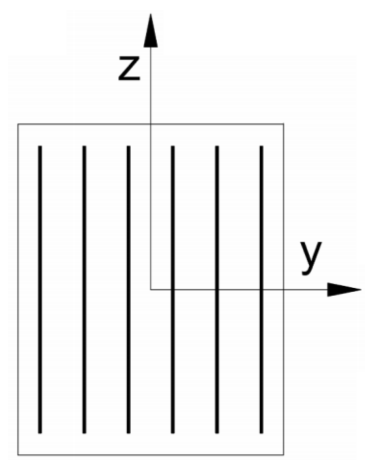


Figure 3-28 – Connection with vertical plates

$$w_{y,\text{ver},SP} = \frac{1}{6} \cdot A_{net,SP} \cdot t_{SP}$$

Eq. 3-70 – section modulus of vertical steel plate – y-axis

$$F_{SP,ver,M_y} = \frac{M_y}{n_{SP} \cdot w_{y,\text{ver},SP}} \cdot A_{net,SP}$$

Eq. 3-71 – bending stress of vertical steel plate – y-axis

$$F_{SP,ver,M_z} = \frac{M_z}{I_{z,SP}} \cdot y_{max} \cdot A_{net,SP}$$

Eq. 3-72 – bending stress of vertical steel plate – z-axis

y_{max} : Maximal distance in y-direction between the beam's center of gravity the outmost plate

The following formulae describe the determination the section modulus and bending moments about both axes for horizontal plates.

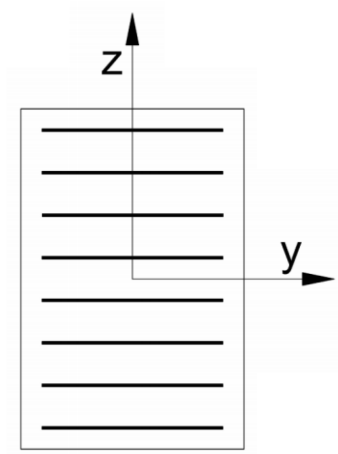


Figure 3-29 – connection with horizontal plates

$$F_{SP,hori,M_y} = \frac{M_y}{I_{y,SP}} \cdot z_{max} \cdot A_{net,SP}$$

Eq. 3-73 – section modulus of horizontal steel plate – y-axis

z_{max} : Maximal distance in z-direction between the beam's center of gravity the outmost plate

$$w_{z,\text{hori},SP} = \frac{1}{6} \cdot A_{net,SP} \cdot t_{SP}$$

Eq. 3-74 – section modulus of horizontal steel plate – z-axis

$$F_{SP,hori,M_z} = \frac{M_z}{n_{SP} \cdot w_{z,hori,SP}} \cdot A_{net,SP}$$

Eq. 3-75 – bending stress of horizontal steel plate – z-axis

The sum of forces induced by axial and bending loading represents the actual stress for the steel plates.

$$F_{SP,\text{Ed}} = F_{SP,N_d} + F_{SP,M_y} + F_{SP,M_z}$$

Eq. 3-76 – stress of steel plate

The shear forces are equally distributed between the plates.

$$F_{SP,V_y} = \frac{V_y}{n_{SP}}$$

Eq. 3-77 – design shear stress – y-axis

$$F_{SP,V_z} = \frac{V_z}{n_{SP}}$$

Eq. 3-78 – design shear stress – z-axis

The resultant of the shear forces equals the total shear force.

$$F_{SP,\text{V,Ed}} = \sqrt{{F_{SP,V_y}}^2 + {F_{SP,V_z}}^2}$$

Eq. 3-79 – shear stress

Since the connection is supposed to have ductile behavior, the resistance of the steel plate is based on yielding strength. Due to the holes in the plate a rupture failure is possible, hence for tensile axial loading this value needs to be considered if decisive.

$$F_{SP,Rd} = A_{net,SP} \cdot \min \begin{cases} \dfrac{f_{y,k}}{\gamma_{M,0}} \\ 0.9 \cdot \dfrac{f_{u,k}}{\gamma_{M,2}} \end{cases}$$

Eq. 3-80 – design resistance of the cross-section

(DIN EN 1993-1-1, 2010, S. 53)

$f_{y,k}$: yield strength of steel
$\gamma_{M,0}$: = 1.1: partial factor for steel
$f_{u,k}$: ultimate tensile strength of steel
$\gamma_{M,2}$: = 1.25: partial factor for steel

The shear resistance of the plates is also based on the ductile behavior, therefore dependent on yielding strength.

$$F_{SP,V,Rd} = A_{net,SP} \cdot \frac{f_{y,k} \cdot \sqrt{3}}{\gamma_{M,0}}$$

Eq. 3-81 – design plastic shear resistance of steel

(DIN EN 1993-1-1, 2010, S. 53)

The verification for axial and bending stresses can be provided separately to the verification for shear stresses.

$$\frac{F_{SP,\text{Ed}}}{F_{SP,Rd}} \leq 1$$

Eq. 3-82 – verification for biaxial bending and axial stresses

$$\frac{F_{SP,\text{V,Ed}}}{F_{SP,V,Rd}} \leq 1$$

Eq. 3-83 – verification for biaxial shear stresses

3.4.2.2. Adhesive Dowel

The improvement of perforated plates to normal steel plates are the holes and their filling with adhesive. The recess in the plate provides on the one hand more ductility since the area of the steel is reduced; on the other hand it increases the strength of the connection.

The following calculation method is based on building inspectorate approval (Zulassung Z-9.1-770, 2014) and on research of (Bathon L. , et al., 2015). The characteristic load-carrying capacity of an adhesive dowel is product of many studies and determined with:

$$F_{AD,Rk} = 800\ N$$

Eq. 3-84 – characteristic load-carrying capacity of an adhesive dowels

(Zulassung Z-9.1-770, 2014)

The Figure 3-30 demonstrates visually how the forces act on the plate and need to be distributed between the dowels. While axial and shear forces acting parallel to the perforated are evenly distributed between the dowels, the governing dowel for the bending moment acting parallel to the plate needs to be determined.

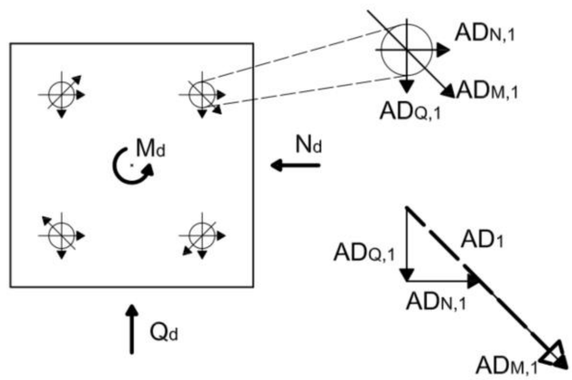


Figure 3-30 – Calculation concept for adhesive dowels (Bathon L. , et al., 2015)

The plate is subject to a moment which is not acting parallel to its plane, this moment can be divided into a tensile and compressive force couple which can be added to the axial force. For the horizontal plate, the force couple of the bending moment around the y-axis is added to the normal force. For the vertical plates the normal force is increased by the force in the plate due to bending moment around the z-axis.

$$F_{AD,hori,Ed,N} = \frac{N_d + F_{SP,hori,M_y}}{n_{AD}}$$

Eq. 3-85 – External normal force for each adhesive dowel

(Bathon L. , et al., 2015)

$F_{SP,hori,M_y}$: force in the decisive horizontal plate as a subject to moment around the y-axis - Eq. 3-74

n_{AD} : total number of adhesive dowels

$$F_{AD,ver,Ed,N} = \frac{N_d + F_{SP,ver,M_z}}{n_{AD}}$$

Eq. 3-86 – External normal force for each adhesive dowel

(Bathon L. , et al., 2015)

F_{SP,ver,M_z} : force in the decisive vertical plate as a subject to moment around the z-axis - Eq. 3-72

The adhesive dowels are only subject to one shear force, since the other one is not acting lateral and does not affect the dowels. For the horizontal plates the shear force in y-direction is taken into consideration and for the vertical plate it is the shear force in z-direction.

$$F_{AD,Ed,V} = \frac{V_d}{n_{AD}}$$

Eq. 3-87 – External shear force for each adhesive dowel

(Bathon L. , et al., 2015)

Following the approach for calculation of the polar moment of inertia for screws, the polar moment of inertia for the adhesive dowels is determined.

$$I_p = \frac{n_{AD}}{12} \cdot \left[\left({n_{AD,y}}^2 - 1 \right) \cdot {\Delta_y}^2 + \left({n_{AD,z}}^2 - 1 \right) \cdot {\Delta_z}^2 \right]$$

$n_{AD,y}$: number of AD in y-direction
Δ_y : $= 15\ mm$: distance of AD in y-direction
$n_{AD,z}$: number of AD in z-direction
Δ_z : $= 15\ mm$: distance of AD in z-direction

Eq. 3-88 – polar moment of inertia of the dowels

(Schneider, 2008, S. 8.78)

The force acting on the decisive adhesive dowel due to the bending moment in plate plane is calculated with the polar moment of inertia of the dowels and the distance to the outmost AD.

$$F_{AD,Ed,M} = \frac{M_d}{I_p} \cdot r_{max}$$

r_{max} : maximum distance to the outmost AD

Eq. 3-89 – External moment impact for each adhesive dowel

(Bathon L. , et al., 2015)

As Figure 3-30 illustrates the resultant of the axial and shear force which the dowel is subject to need to be added to the force due to the moment to get the total force for the governing dowel.

$$F_{AD,Ed} = \sqrt{(F_{AD,Ed,N}^2 + Ed_{AD,Ed,V}^2)} + F_{AD,Ed,M}$$

Eq. 3-90 – External force for each adhesive dowel

(Bathon L. , et al., 2015)

$$\frac{F_{AD,Ed}}{F_{AD,Rd}} \leq 1$$

Eq. 3-91 – External force for each adhesive dowel

(Bathon L. , et al., 2015)

3.4.2.3. Wood

The timber net cross-section has to withstand the loads at the end of the plates which are transferred by the connection. The building inspectorate approval reduces the tensile strength of timber to 80% which seems appropriate since the cross-section is influenced by the glued-in plates.

$$A_{net,W} = A_w - n_{SP} \cdot (b_{SP} \cdot t_{SP})$$

Eq. 3-92 – net cross-section area of timber

$$F_{ax,w,Rd} = A_{net,W} \cdot 0.8 \cdot f_{t,0,d}$$

$f_{t,0,d}$: design tensile strength along the grain

Eq. 3-93 – resistance of timber at the end of plates

(Zulassung Z-9.1-770, 2014)

$$\frac{F_{SP,Ed} \cdot n_{SP}}{F_{ax,w,Rd}} \leq 1$$

Eq. 3-94 – verification of wood at the end of the plate

(Zulassung Z-9.1-770, 2014)

$F_{SP,Ed}$: axial stress of steel plate - Eq. 3-76

Furthermore block shear failure in wood can occur if the connection is subjected to tensile axial loading. The (Zulassung Z-9.1-770, 2014) developed a procedure for determination the resistance of timber to this failure mode which is based on appendix A of (DIN EN 1995-1-1, 2004).

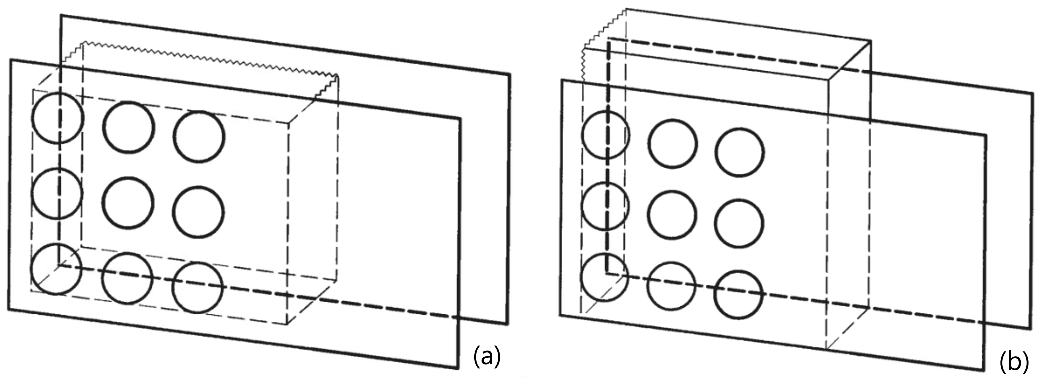


Figure 3-31 – Types of block shear failure (a) type A and (b) type B (Zulassung Z-9.1-770, 2014)

The block shear failure is divided into two types; the differences are illustrated in Figure 3-31.

If type A occurs the timber is teared out around the adhesive dowels and the block is pulled out of the cross-section, leaving a hole behind. The block has three fracture surfaces.

$$A_{net,t,a} = l_{net,t,bs} \cdot (n_{SP} - 1) \cdot t_2$$

$l_{net,t,bs}$: net width of the cross-section perpendicular to the grain

t_2 : dimension of connection see Figure 3-32

Eq. 3-95 – net cross-sectional area perpendicular to the grain – failure mode A

(Zulassung Z-9.1-770, 2014)

$$A_{net,v,a} = 2 \cdot l_{net,v,bs} \cdot (l_{net,t,bs} + (n_{SP} - 1) \cdot t_2)$$

$l_{net,v,bs}$: total net length of the shear fracture area

Eq. 3-96 – net shear area in the parallel to grain direction – failure mode A

(Zulassung Z-9.1-770, 2014)

If type B occurs the timber failed on only one side over the whole length and the block's height is identical to the cross-section's height. This failure mode results in a slit in the connection.

$$A_{net,t,b} = (l_{net,t,bs} + a_{2,1} + a_{2,2}) \cdot (n_{SP} - 1) \cdot t_2$$

Eq. 3-97 – net cross-sectional area perpendicular to the grain– failure mode B

(Zulassung Z-9.1-770, 2014)

$$A_{net,v,b} = 2 \cdot l_{net,v,bs} \cdot (l_{net,t,bs} + a_{2,1} + a_{2,2})$$

Eq. 3-98 – net shear area in the parallel to grain direction– failure mode A

(Zulassung Z-9.1-770, 2014)

a_1 :
a_2 : dimensions of connection see Figure 3-32

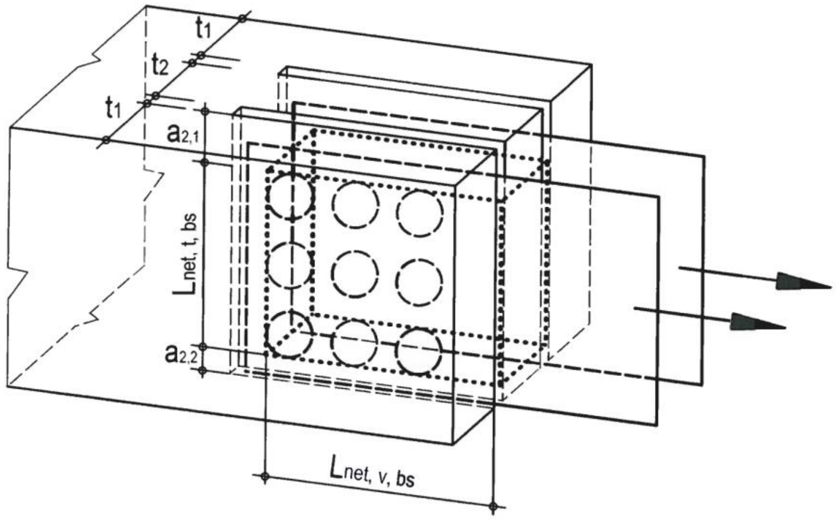


Figure 3-32 – Definition of distances for block shear failure (Zulassung Z-9.1-770, 2014)

Since both failure modes can occur, the minimum block shear capacity needs to be determined.

$$F_{bs,Rk} = \min \begin{cases} \max \begin{cases} 1.5 \cdot A_{net,t,a} \cdot f_{t,0,k} \\ A_{net,v,a} \cdot f_{v,k} \end{cases} \\ \max \begin{cases} 1.5 \cdot A_{net,t,b} \cdot f_{t,0,k} \\ A_{net,v,b} \cdot f_{v,k} \end{cases} \end{cases}$$

Eq. 3-99 – characteristic block shear capacity

$$F_{bs,Rd} = k_{mod} \cdot \frac{F_{bs,Rk}}{\gamma_M}$$

Eq. 3-100 –

Since this failure is mainly subjected to tension axial loading, the verification is based only on it as an external force.

$$\frac{N_d}{F_{bs,Rd}} \leq 1$$

Eq. 3-101 –

Both verifications for timber need to be satisfied separately.

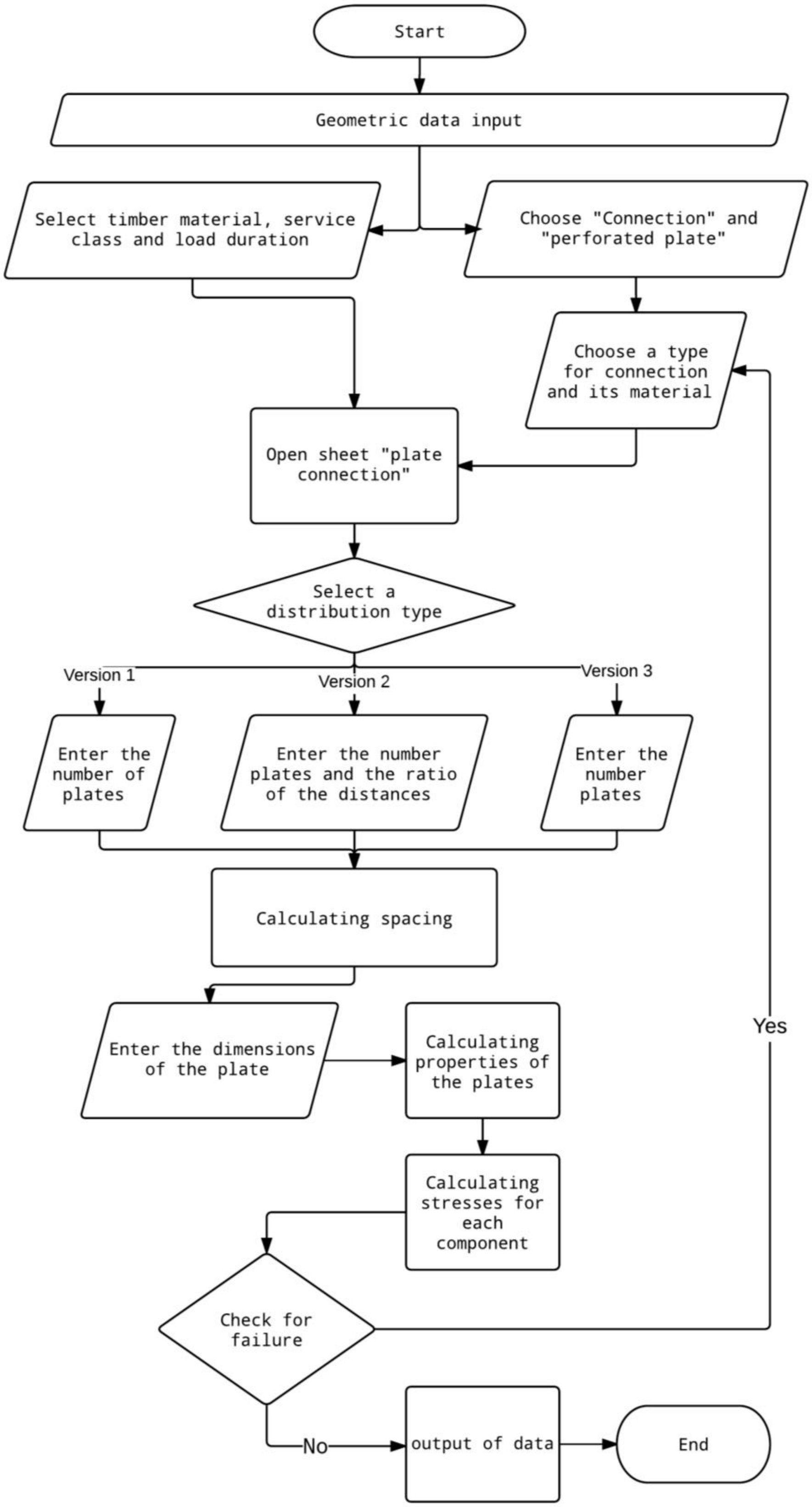


Figure 3-33 – Flowchart – calculation for connection with perforated plates

3.4.3. Code

The full code is copied into the Appendix B chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**. It was important keeping variability in different distribution types of the plates. An additional factor was the evaluation of the adhesive dowel number.

3.4.4. Validation

The validation for perforated plates was supposed to be based on a comparison with a Sofistik© FE model of the cross-section. Since the width of a plate is reduced by the number the adhesive dowels, an equivalent thickness was calculated. Unfortunately Sofistik does not calculate plates implemented into cross-section with a thickness less than a millimeter. Since the validation has been performed for glued-in rods and the calculation processes are similar, another validation will be neglected.

4. Chapter – tool manual

This tool for dimensioning wooden cross-sections for various situations is based on Excel© Visual Basic Application. Variable settings and opportunities are offered regarding dimensions and material of timber and steel. The following chapter is set to give instruction for using the tool.

4.1. General

The document opens with the entry page with an easily structured surface. Because of the boxes it is possible to understand where information is needed from the user. All general inputs such as timber dimensions or the loading are collected.

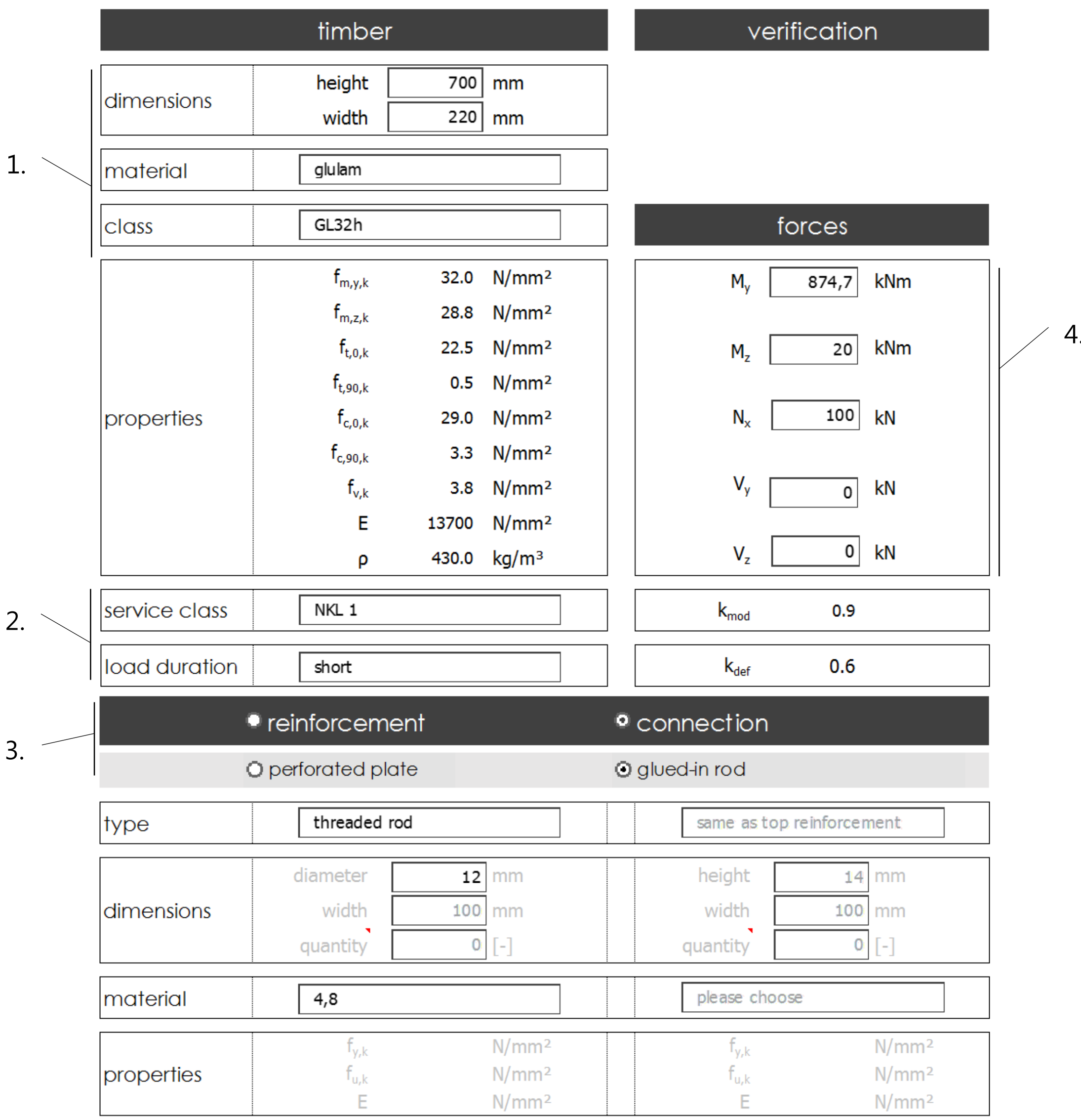


Figure 4-1 – Entry page

1. Please enter the dimension of the timber cross-section and its material.
2. Please choose the service class and load duration.
3. Please select in a first step between “reinforcement” and “connection”. In a second step it can between “reinforcement – flexure” and “reinforcement – tension perpendicular to the grain” or “connection – perforated plates” and “connection – glued-in rod”

Figure 4-2 – second step of choosing the calculation type for reinforcement

Figure 4-3 – second step of choosing the calculation type for connection

4. Please enter the external loads for further calculations.

After the selection of the type of calculation the dimension of the steel can be entered.

1. For reinforcement for flexure:

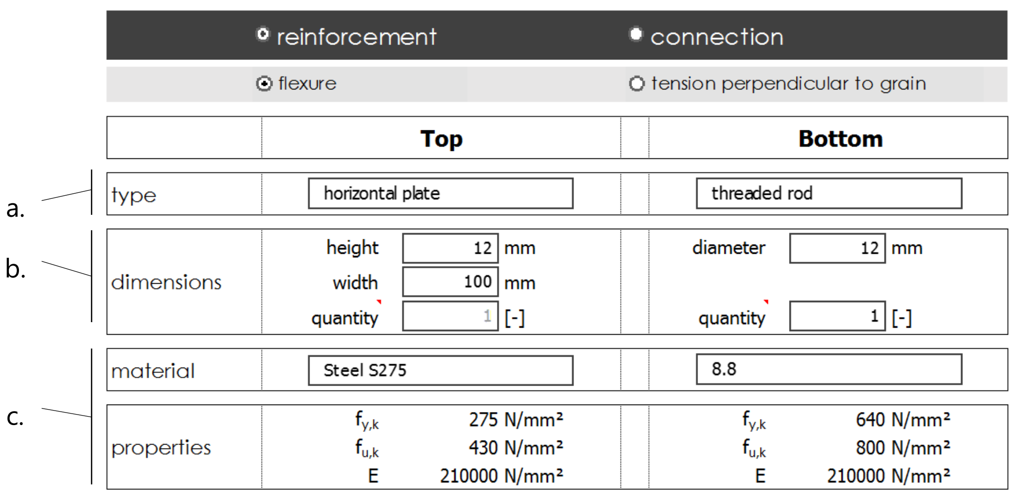


Figure 4-4 - Dimensions of reinforcement for flexure

a. Please choose the type of top and of bottom reinforcement. The possibilities are

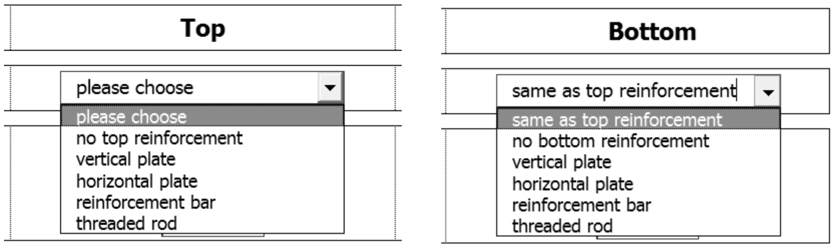


Figure 4-5 – Types of reinforcement for flexure

If "same as top reinforcement" is chosen for bottom reinforcement, every value (dimensions and steel properties) is copied from the top reinforcement.

b. Please enter the size of reinforcement and its quantity (amount of reinforcement side by side; an exception is "horizontal plate", in this case only the quantity "1" is possible)

c. Please select the material of the reinforcement.

2. For reinforcement for tension perpendicular to the grain

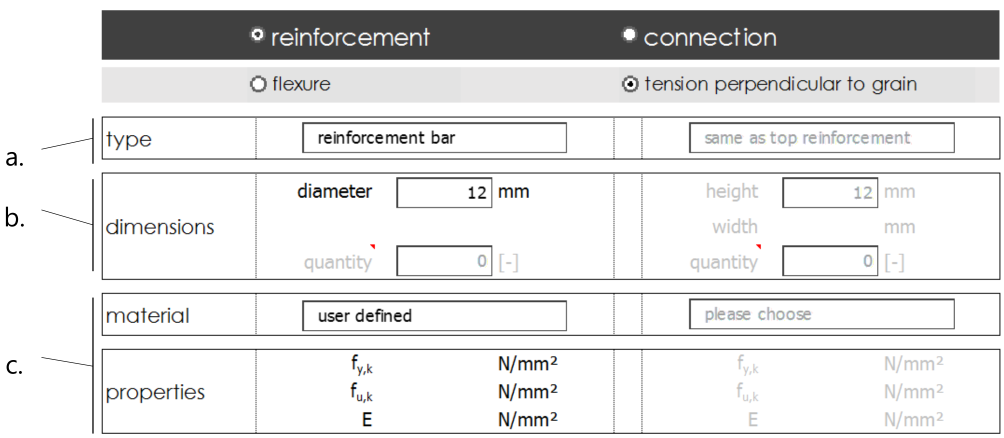


Figure 4-6 – Dimensions of reinforcement for tension perpendicular to the grain

a. Please choose the type of reinforcement. The possibilities are

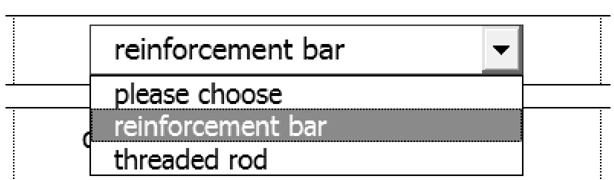


Figure 4-7 – Types of reinforcement for tension perpendicular to the grain

a. Please enter the size of reinforcement, the quantity will be calculated on the next sheet.

b. Please select the material of the reinforcement.

3. For connection with glued-in rods

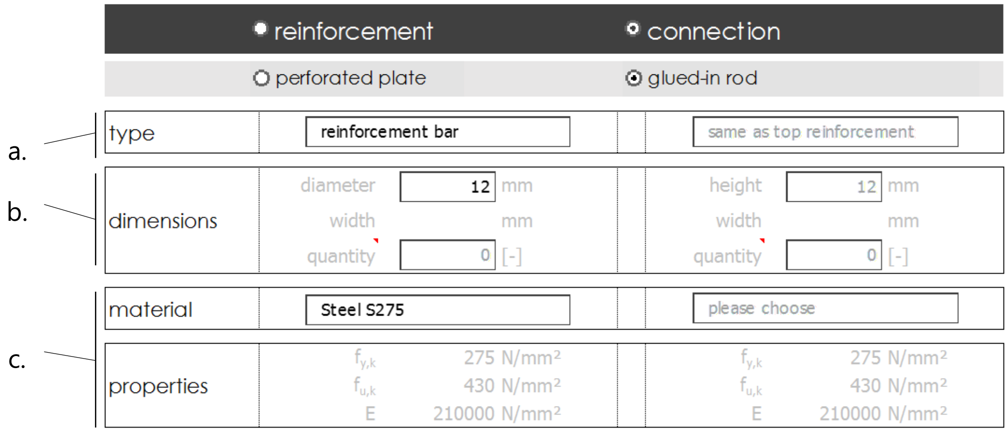


Figure 4-8 - Dimensions for connection with glued-in rods

a. Please choose for the type of glued-in rod

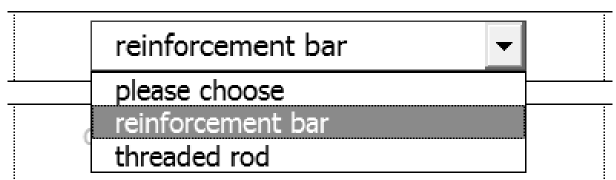


Figure 4-9 – Types of connections with glued-in rods

b. Please enter the size of reinforcement, the quantity will be chosen on the next sheet.

c. Please select the material of the reinforcement.

4. For connection with perforated plates

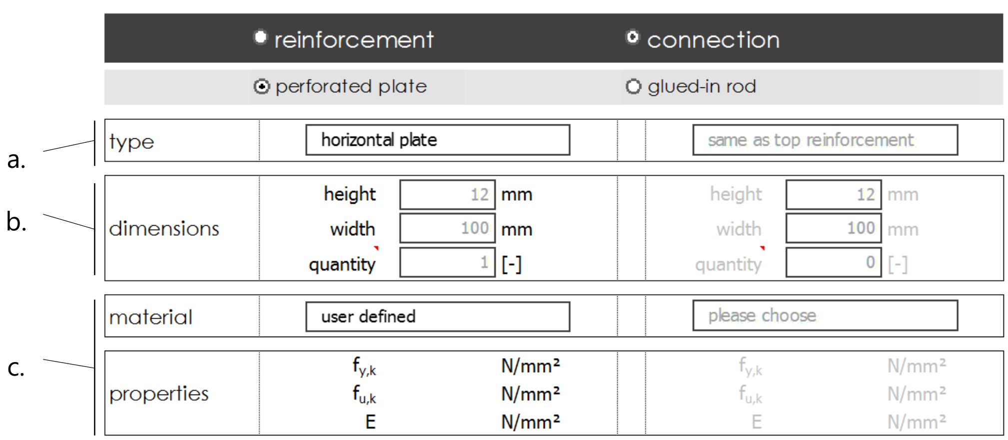


Figure 4-10 – Dimensions for connections with perforated plates

a. Please choose for the type of perforated plate.

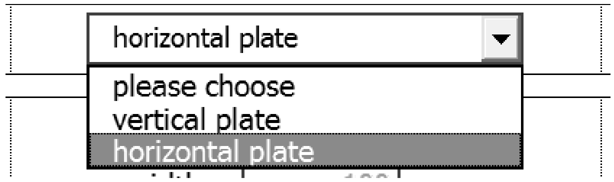


Figure 4-11 – Types of connection with perforated plates

b. Please enter size and quantity into the next sheet.

c. Please select the material of the reinforcement.

After filling all information into the entry side, the particular sheet for further calculations appears.

4.2. Reinforcement for Flexure

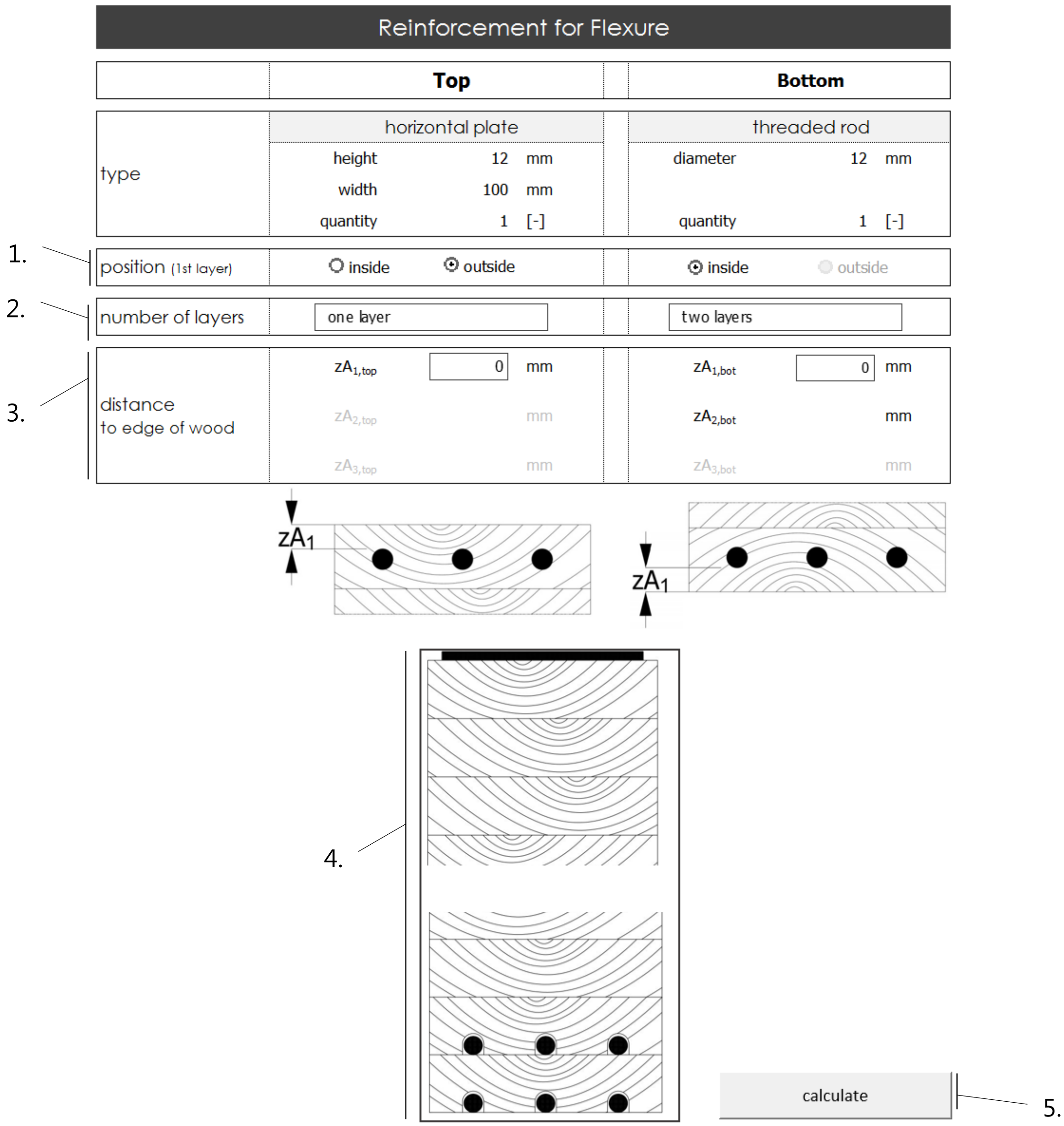


Figure 4-12 – Page of Reinforcement for Flexure

1. Please choose the position of the first layer, if the reinforcement type is chosen as "horizontal plate". If chosen outside, the most outer plate is glued to the outside of the wooden member.
2. Please select the number of layers for the top and bottom reinforcement. For vertical reinforcement only one layer is allowed.
3. Please select the distance of the first layer (top and bottom) to timber edge.
4. This is an schematic design of the reinforced cross-section.
5. Please start the calculation by clicking on "Calculate".

The verification output of the reinforcement of flexure:

verification						
	Top			Bottom		
wood cross-section	$\sigma_{w,axial,top}$	0.89	N/mm²	$\sigma_{w,axial,bot}$	0.89	N/mm²
	$\eta_{w,t0d,top}$	0.09		$\eta_{w,t0d,bot}$	0.09	
	$\sigma_{w,my,top}$	-23.70	N/mm²	$\sigma_{w,my,bot}$	23.70	N/mm²
	$\eta_{w,my,top}$	1.43		$\eta_{w,my,bot}$	1.43	
	$\sigma_{w,mz,top}$	-4.27	N/mm²	$\sigma_{w,mz,bot}$	4.27	N/mm²
	$\eta_{w,mz,top}$	0.39		$\eta_{w,mz,bot}$	0.39	
	interaction - axial and bending					
	$\eta_{w,top}$	1.79		$\eta_{w,bot}$	1.79	
	$\tau_{w,vy,top}$	0.00	N/mm²	$\tau_{w,vy,bot}$	0.00	N/mm²
	$\eta_{w,vy,top}$	0.00		$\eta_{w,vy,bot}$	0.00	
	$\tau_{w,vz,top}$	0.00	N/mm²	$\tau_{w,vz,bot}$	0.00	N/mm²
	$\eta_{w,vz,top}$	0.00		$\eta_{w,vz,bot}$	0.00	
	interaction - shear					
	$\eta_{w,v,top}$	0.00		$\eta_{w,v,bot}$	0.00	
steel reinforcement	$\sigma_{w,axial,top}$	0.00	N/mm²	$\sigma_{w,axial,bot}$	0.00	N/mm²
	$\eta_{w,t0d,top}$	0.00		$\eta_{w,t0d,bot}$	0.00	
	$\sigma_{w,my,top}$	0.00	N/mm²	$\sigma_{w,my,bot}$	0.00	N/mm²
	$\eta_{w,my,top}$	0.00		$\eta_{w,my,bot}$	0.00	
	$\sigma_{w,mz,top}$	0.00	N/mm²	$\sigma_{w,mz,bot}$	0.00	N/mm²
	$\eta_{w,mz,top}$	0.00		$\eta_{w,mz,bot}$	0.00	
	interaction - axial and bending					
	$\eta_{w,top}$	0.00		$\eta_{w,bot}$	0.00	
	$\tau_{w,vy,top}$	0.00	N/mm²	$\tau_{w,vy,bot}$	0.00	N/mm²
	$\eta_{w,vy,top}$	0.00		$\eta_{w,vy,bot}$	0.00	
	$\tau_{w,vz,top}$	0.00	N/mm²	$\tau_{w,vz,bot}$	0.00	N/mm²
	$\eta_{w,vz,top}$	0.00		$\eta_{w,vz,bot}$	0.00	
	interaction					
	$\eta_{w,v,top}$	0.00		$\eta_{w,v,bot}$	0.00	

Figure 4-13 – Verification output of reinforcement for flexure

4.3. Reinforcement for Tension Perpendicular to the Grain

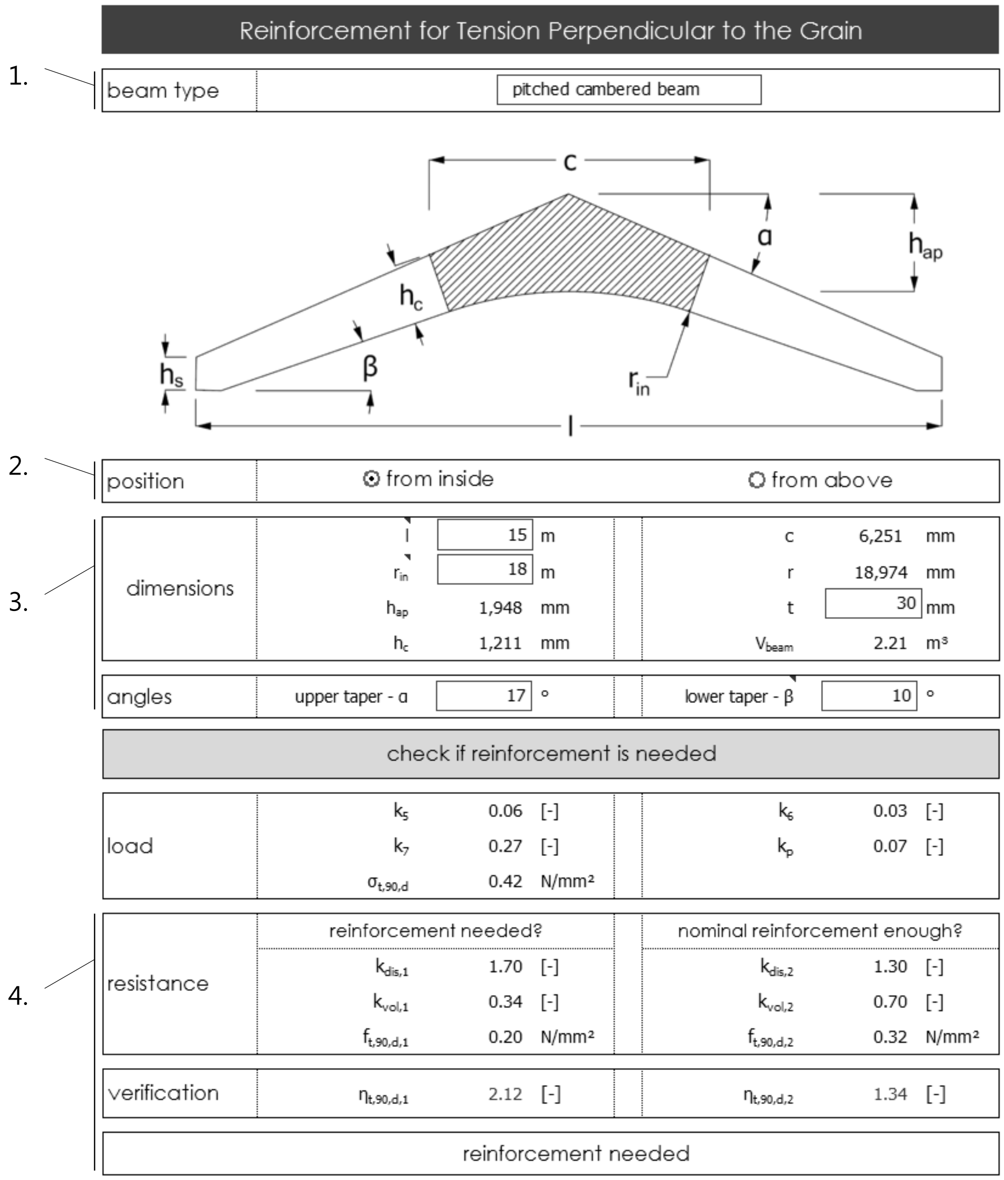


Figure 4-14 – Page for reinforcement for tension perpendicular to the grain

1. Please choose the beam type.

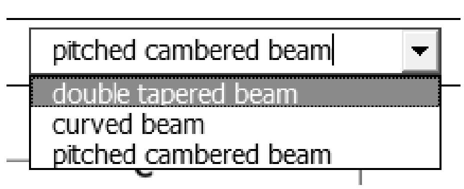
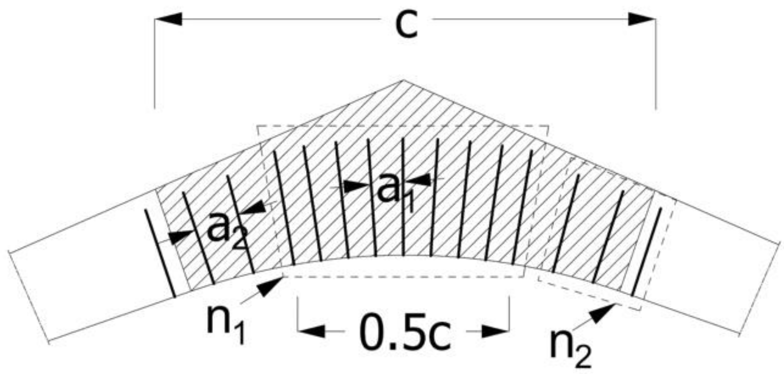


Figure 4-15 – Types of beam for tension perpendicular to the grain

2. Please choose if the reinforcement is applied from inside or from above.

3. Please enter the dimensions of the beam.
4. Results of the check if reinforcement is needed.



dimensioning of reinforcement							
number of rows	maximum	12	[-]	selected	2	[-]	5.
resistance of rod	f_{yd}	264	N/mm²	$F_{t,90,fyd,d}$	22,294	N	
	f_{ud}	291	N/mm²	$F_{t,90,fud,d}$	24,524	N	
resistance of glue line	inner two quarter			outer quarter			
	$f_{k,1,d}$	2.77	N/mm²	$f_{k,1,d}$	2.77	N/mm²	
	l_{ad}	672	mm	l_{ad}	575	mm	
	$F_{t,90,fk1d,d}$	35,081	N	$F_{t,90,fk1d,d}$	30,033	N	
decisive value	$\mathbf{F_{t,90,d}}$	**22,294**	**N**	$\mathbf{F_{t,90,d}}$	**22,294**	**N**	
spacing	a_1	470	mm	a_2	705	mm	6.
quantity of rods	n_1	8	[-]	n_2	4	[-]	

Figure 4-16 – Output of reinforcement for tension perpendicular to the grain

5. Please select the number of rows for the rods lateral to the axis.
6. Spacing between the reinforcement bars and their number.

4.4. Connection with Glued-in Rods

The structure of the sheet for connection with glued-in rods is a similar to one of reinforcement for flexure.The headline of the table is not divided into top and bottom but into z- and y-axis. The reason for this change is the difference in calculation since this tool offers the possibility to vary the spacing in both axes. The left side collects all the data about the z-axis including version of distribution, number of rods and spacing while on the right hand side these values correspond to the y-axis.

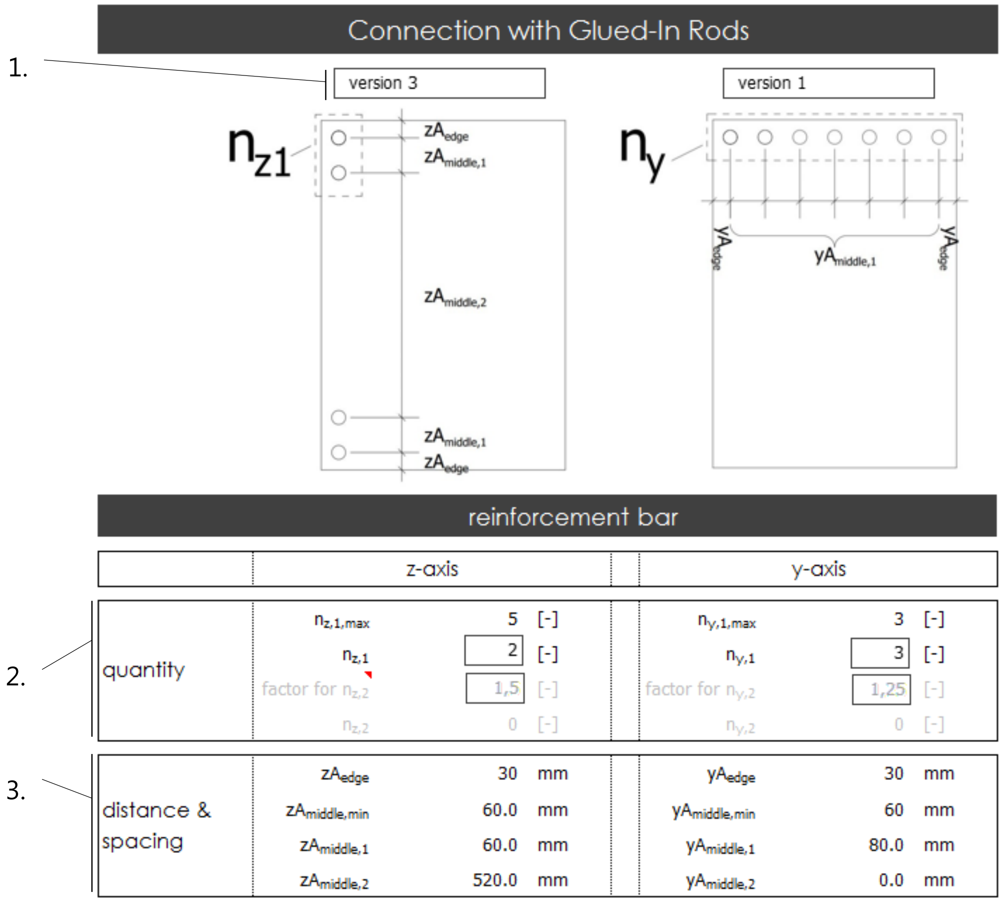


Figure 4-17 – Page for connection with glued-in rods

1. Please choose a version for the distribution of the rods for both axis, descriptive figures will appear.
2. Please choose the quantity of rods for both axis
    a. Please enter a value for n_1.
        i. Please choose a smaller value, if the value for $n_{1,max}$ appears in red.
    b. Please enter a value for the factor n_2 if "version 2" is selected.

       Distance $zA_{middle,1}$ (or $yA_{middle,1}$) is multiplied by this factor and determines maximal n_2.
3. The distances/spacing is depending on the size of the rod. The tool gives all values, there are not a matter to change.

The verification output of connection with glued-in rods:

verification						
4. moment of inertia	$I_{y,conn}$	69,487,003	mm^4	$I_{z,conn}$	2,901,399	mm^4
	$l_{ad,min}$	120	mm	l_{ad}	1000	mm
	$f_{k,1,k}$	2.00	N/mm²	$f_{h,1,k}$	3.88	N/mm²
	$M_{y,Rk}$	82,501	kNm			
5. axial load	$F_{ax,Rd,S}$	25,704	N	$F_{ax,Ed,N}$	16,667	N
	$F_{ax,Rd,S}$	35,369	N	$F_{ax,Ed,My}$	464,115	N
	$F_{ax,Rd,A}$	52,199	N	$F_{ax,Ed,Mz}$	67,046	N
	$F_{ax,Rd}$	25,704	N	$F_{ax,Ed}$	547,828	N
			η_{ax}	21.31		
6. lateral load	$F_{v,Rd}$	1,570,858	N	$F_{v,Ed}$	0	N
			η_v	0.00		
interaktion			η_{ax+v}	454.24		

Figure 4-18 – Verification of connections with glued-in rods

4. The moment of inertia of the connection.
5. The verification for the axial loading
    a. On the left side the resistances are summarized. First of each material (steel yielding, steel ultimate strength and adhesive) and the last value repeats the decisive value.
    b. On the right the loading forces are summarized with the total load at the end.
6. The verification for the lateral load.

4.5. Connection with Perforated Plates

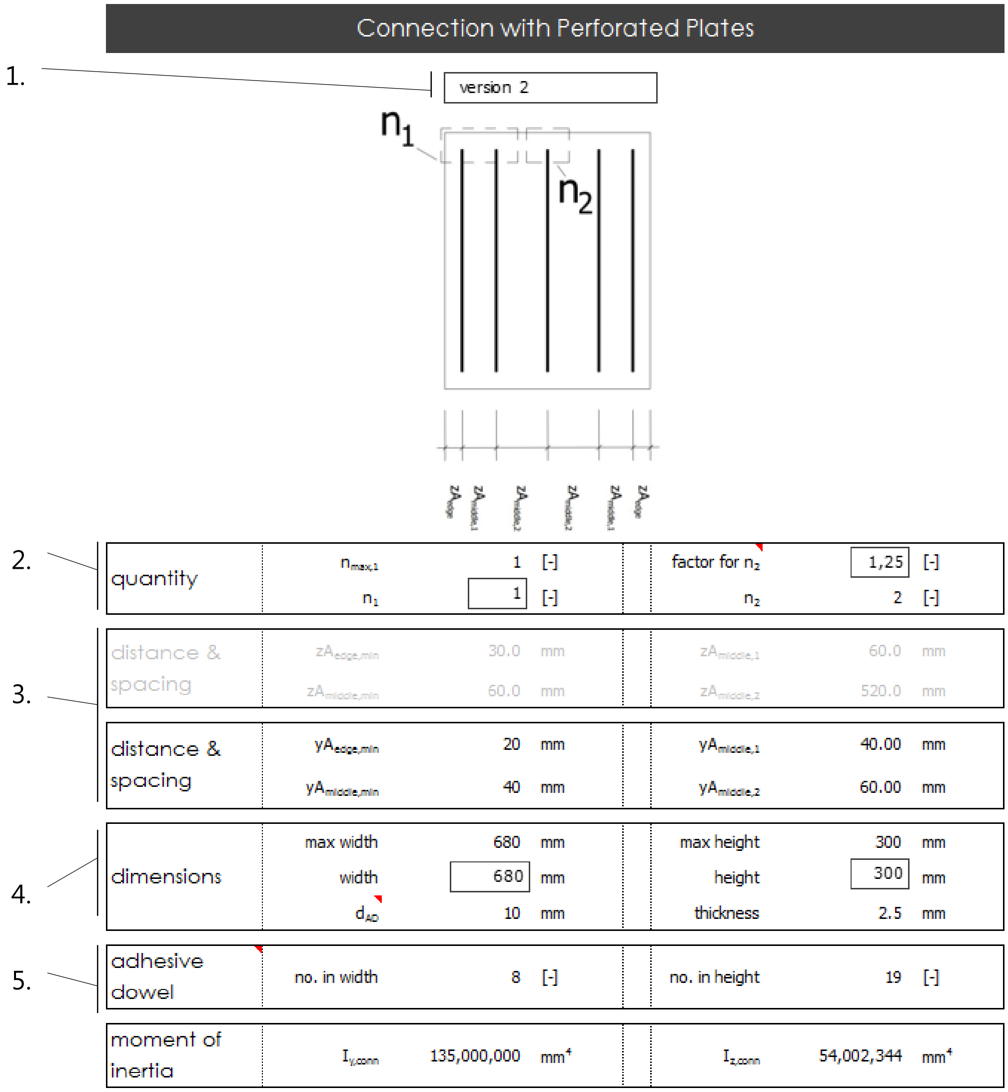


Figure 4-19 – Page of connection with perforated plates

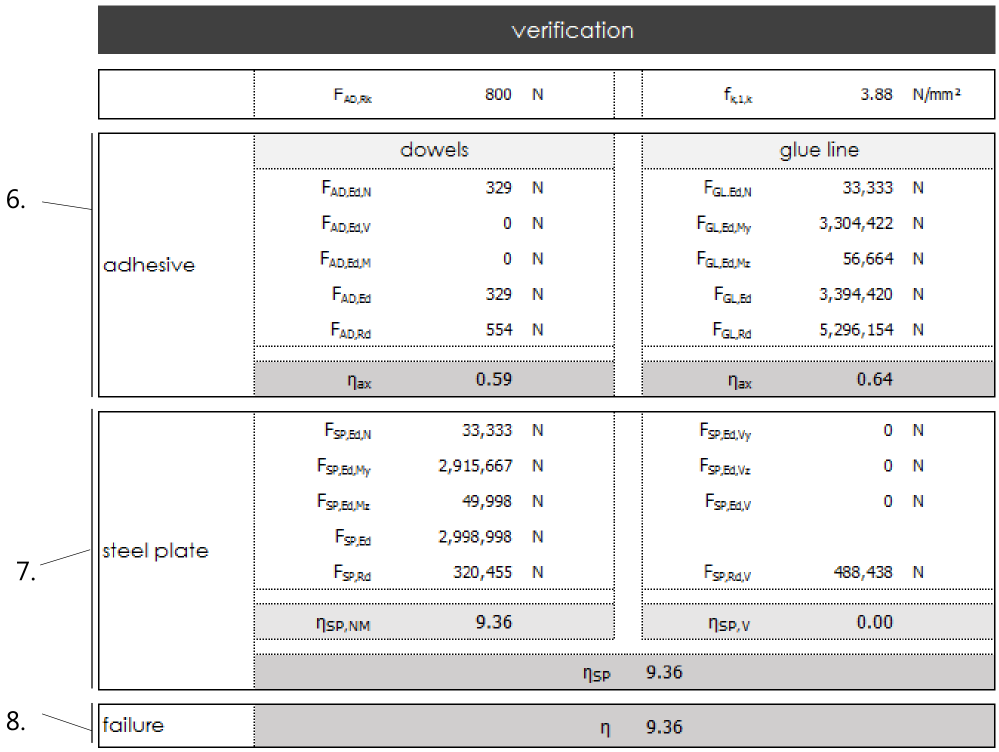
1. Please choose a version for the distribution of the plates.
2. Please choose the quantity of plates
    a. Please enter a value for n_1.
        i. Please choose a smaller value, if the value for $n_{1,max}$ appears in red.
    b. Please enter a value for the factor n_2 if "version 2" is selected.

       Distance $zA_{middle,1}$ (or $yA_{middle,1}$) is multiplied by this factor and determines maximal n_2.
3. The distances/spacing is depending on the size of the rod. The tool gives all values, there are not a matter to change.
4. Please enter the size of the plate

a. Please choose a smaller value than the maximum dimensions.

5. The properties of the adhesive dowels are not modifiable.

The verification output of connection with perforated plates:



verification						
	$F_{AD,Rk}$	800	N	$f_{k,1,k}$	3.88	N/mm²
adhesive (6.)	dowels			glue line		
	$F_{AD,Ed,N}$	329	N	$F_{GL,Ed,N}$	33,333	N
	$F_{AD,Ed,V}$	0	N	$F_{GL,Ed,My}$	3,304,422	N
	$F_{AD,Ed,M}$	0	N	$F_{GL,Ed,Mz}$	56,664	N
	$F_{AD,Ed}$	329	N	$F_{GL,Ed}$	3,394,420	N
	$F_{AD,Rd}$	554	N	$F_{GL,Rd}$	5,296,154	N
	η_{ax}	0.59		η_{ax}	0.64	
steel plate (7.)	$F_{SP,Ed,N}$	33,333	N	$F_{SP,Ed,Vy}$	0	N
	$F_{SP,Ed,My}$	2,915,667	N	$F_{SP,Ed,Vz}$	0	N
	$F_{SP,Ed,Mz}$	49,998	N	$F_{SP,Ed,V}$	0	N
	$F_{SP,Ed}$	2,998,998	N			
	$F_{SP,Rd}$	320,455	N	$F_{SP,Rd,V}$	488,438	N
	$\eta_{SP,NM}$	9.36		$\eta_{SP,V}$	0.00	
				η_{SP}	9.36	
failure (8.)				η	9.36	

Figure 4-20 – Verification output for connection with perforated plates

6. The verification of adhesive dowels and wood

7. The verification of steel plate

8. Final verification and indication which materials is the weakest link.

5. Chapter - Application

After discussing technique and their calculation method, it can be proceeded with the application on a project. The Figure 5-1 shows the structure of the project and marked the part which is exposed to the highest stresses and will be covered in this chapter.

Figure 5-1 – Relevant part of the construction marked

On one hand the connection of this particular part and the remaining of the leg is a crucial point in the design. Since the beam is curved, tension stress perpendicular to the grain occurs in the already highly stressed apex of the beam. The position of flexure reinforcement is not marked into Figure 5-2 because this technique can be applied in several different locations; it can either be placed on the top of the curved part of the beam or integrated in the beam over the whole length.

The following chapter presents the different design opportunities applied for this particular project.

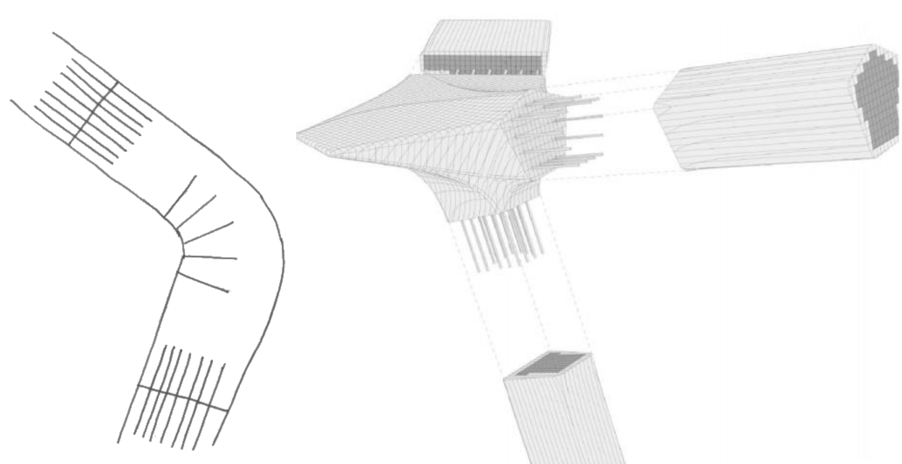


Figure 5-2 – sketch of possible application

5.1. Flexure Reinforcement

Since beam of the leg is exposed to high bending moments, flexural reinforcement is a logical conclusion. For an easier explanation of the results, the screeshots of the tool are included into this chapter.

The cross-section is designed with the dimensions showed in Figure 5-3, the applied loads are showed in the same figure. As can be seen in Figure 5-4 the verification is satisfied, the cross-section is suffienctly enough.

With reinforcement it is possible toreduce the cross-section to a size shown in Figure 5-5. The type and dimension of reinforcement is shown in Figure 5-6 and its distribution in Figure 5-7. As can be seen in Figure 5-8 the utilisation factors are very similar. As another prove of the efficiency of reinforcmeent, Figure 5-9 shows the utilisation factors of the same cross-section under the same applied loads but without reinforcement. As can be seen, the cross-section is utilizied with 130%.

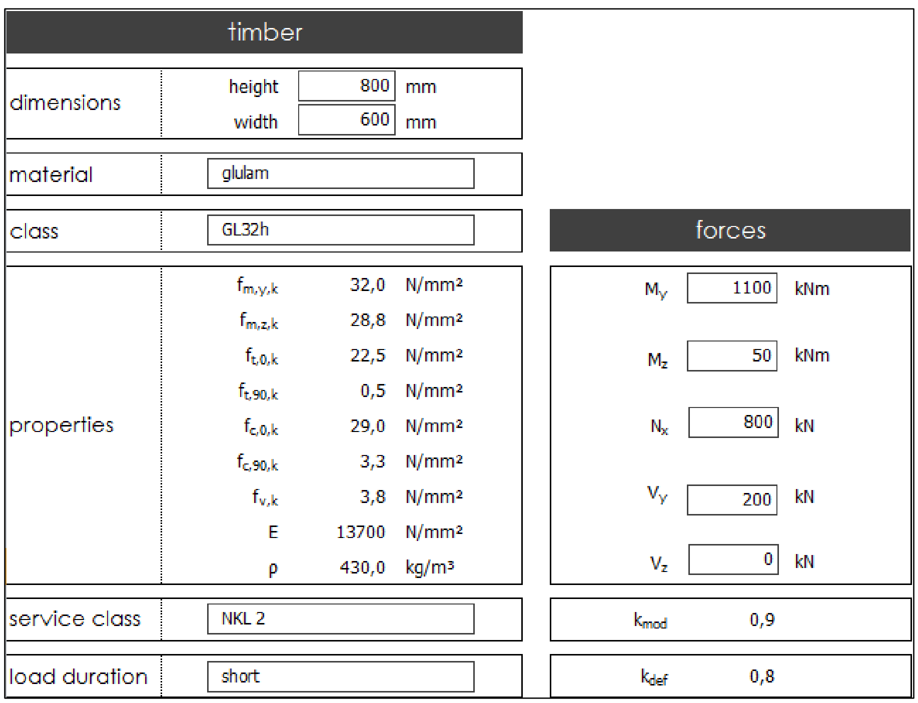


Figure 5-3 – Dimension and properties of the leg beam and applied loads for unreinforced cross-section

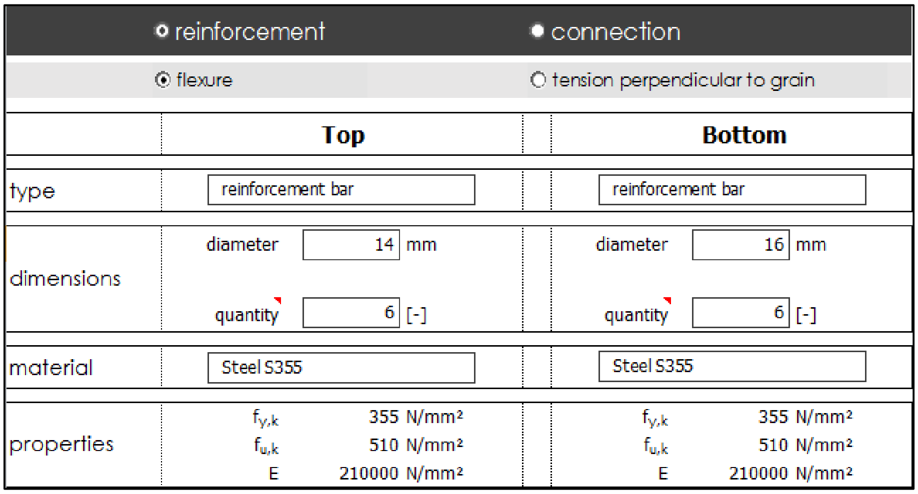
verification						
	Top			Bottom		
wood cross-section	$\sigma_{w,axial,top}$	1,67	N/mm²	$\sigma_{w,axial,bot}$	1,67	N/mm²
	$\eta_{w,t0d,top}$	0,11		$\eta_{w,t0d,bot}$	0,11	
	$\sigma_{w,my,top}$	-17,19	N/mm²	$\sigma_{w,my,bot}$	17,19	N/mm²
	$\eta_{w,my,top}$	0,78		$\eta_{w,my,bot}$	0,78	
	$\sigma_{w,mz,top}$	-1,04	N/mm²	$\sigma_{w,mz,bot}$	1,04	N/mm²
	$\eta_{w,mz,top}$	0,05		$\eta_{w,mz,bot}$	0,05	
	interaction - axial and bending					
	$\eta_{w,top}$	0,92		$\eta_{w,bot}$	0,92	
	$\tau_{w,vy,top}$	0,95	N/mm²	$\tau_{w,vy,bot}$	0,95	N/mm²
	$\eta_{w,vy,top}$	0,36		$\eta_{w,vy,bot}$	0,36	
	$\tau_{w,vz,top}$	0,00	N/mm²	$\tau_{w,vz,bot}$	0,00	N/mm²
	$\eta_{w,vz,top}$	0,00		$\eta_{w,vz,bot}$	0,00	
	interaction - shear					
	$\eta_{w,v,top}$	0,13		$\eta_{w,v,bot}$	0,13	

Figure 5-4 – Verification of unreinforced cross-section

timber			
dimensions	height	700	mm
	width	550	mm
material	glulam		
class	GL32h		
properties	$f_{m,y,k}$	32,0	N/mm²
	$f_{m,z,k}$	28,8	N/mm²
	$f_{t,0,k}$	22,5	N/mm²
	$f_{t,90,k}$	0,5	N/mm²
	$f_{c,0,k}$	29,0	N/mm²
	$f_{c,90,k}$	3,3	N/mm²
	$f_{v,k}$	3,8	N/mm²
	E	13700	N/mm²
	ρ	430,0	kg/m³
service class	NKL 2		
load duration	short		

forces		
M_y	1100	kNm
M_z	50	kNm
N_x	800	kN
V_y	200	kN
V_z	0	kN
k_{mod}	0,9	
k_{def}	0,8	

Figure 5-5 - Dimension and properties of the leg beam and applied loads for reinforced cross-section



reinforcement / connection

flexure / tension perpendicular to grain

	Top		Bottom	
type	reinforcement bar		reinforcement bar	
dimensions	diameter	14 mm	diameter	16 mm
	quantity	6 [-]	quantity	6 [-]
material	Steel S355		Steel S355	
properties	$f_{y,k}$	355 N/mm²	$f_{y,k}$	355 N/mm²
	$f_{u,k}$	510 N/mm²	$f_{u,k}$	510 N/mm²
	E	210000 N/mm²	E	210000 N/mm²

Figure 5-6 - Dimension and properties of reinforcement Part 1

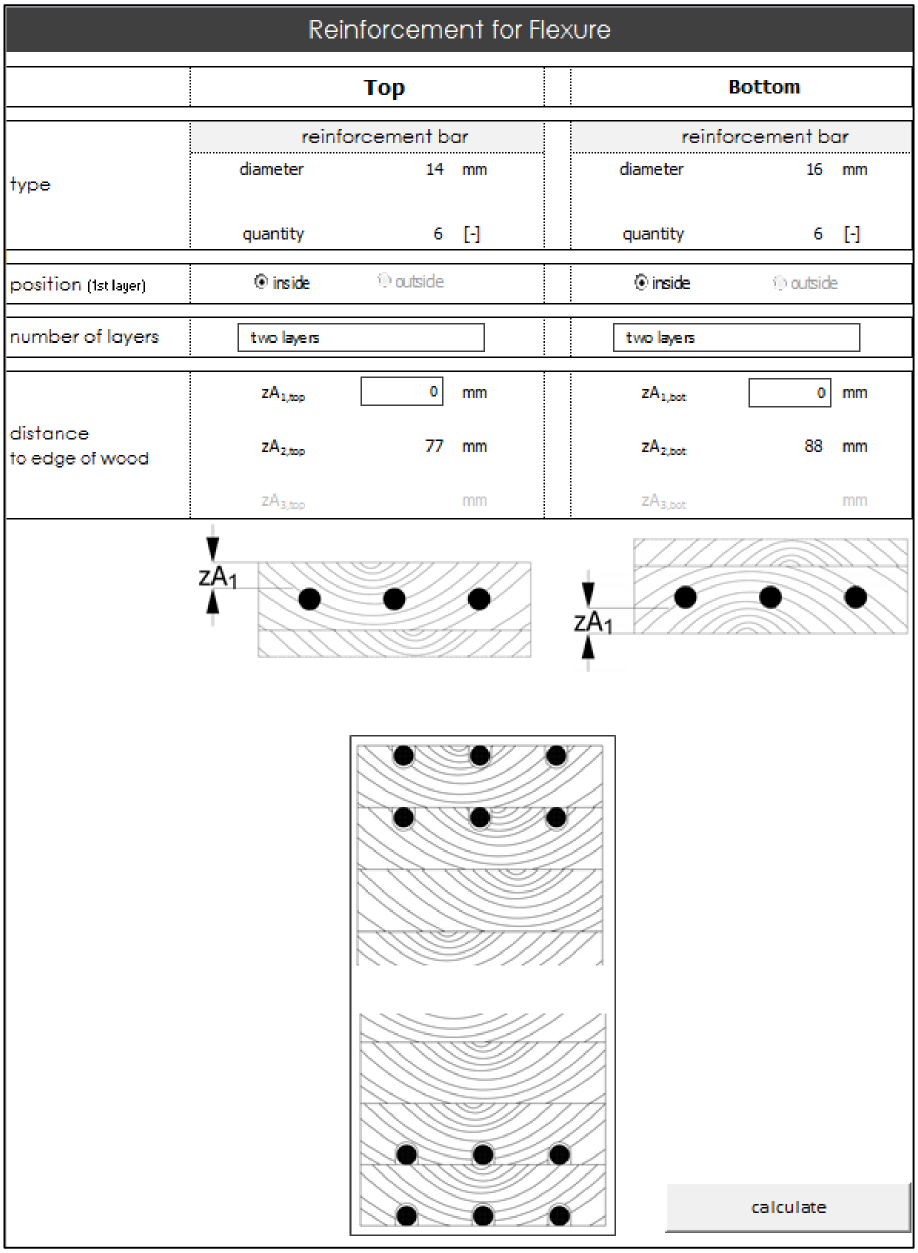


Figure 5-7 - Dimension and properties of reinforcement Part 2

verification						
	Top			**Bottom**		
wood cross-section	$\sigma_{w,axial,top}$	1,79	N/mm²	$\sigma_{w,axial,bot}$	1,79	N/mm²
	$\eta_{w,t0d,top}$	0,12		$\eta_{w,t0d,bot}$	0,12	
	$\sigma_{w,my,top}$	-18,03	N/mm²	$\sigma_{w,my,bot}$	17,47	N/mm²
	$\eta_{w,my,top}$	0,81		$\eta_{w,my,bot}$	0,79	
	$\sigma_{w,mz,top}$	-0,15	N/mm²	$\sigma_{w,mz,bot}$	0,15	N/mm²
	$\eta_{w,mz,top}$	0,01		$\eta_{w,mz,bot}$	0,01	
	interaction - axial and bending					
	$\eta_{w,top}$	0,93		$\eta_{w,bot}$	0,91	
	$\tau_{w,vy,top}$	1,02	N/mm²	$\tau_{w,vy,bot}$	1,02	N/mm²
	$\eta_{w,vy,top}$	0,39		$\eta_{w,vy,bot}$	0,39	
	$\tau_{w,vz,top}$	0,00	N/mm²	$\tau_{w,vz,bot}$	0,00	N/mm²
	$\eta_{w,vz,top}$	0,00		$\eta_{w,vz,bot}$	0,00	
	interaction - shear					
	$\eta_{w,v,top}$	0,15		$\eta_{w,v,bot}$	0,15	
steel reinforcement	$\sigma_{w,axial,top}$	27,49	N/mm²	$\sigma_{w,axial,bot}$	27,49	N/mm²
	$\eta_{w,t0d,top}$	0,09		$\eta_{w,t0d,bot}$	0,09	
	$\sigma_{w,my,top}$	-276,39	N/mm²	$\sigma_{w,my,bot}$	267,84	N/mm²
	$\eta_{w,my,top}$	0,86		$\eta_{w,my,bot}$	0,83	
	$\sigma_{w,mz,top}$	-1,96	N/mm²	$\sigma_{w,mz,bot}$	-1,92	N/mm²
	$\eta_{w,mz,top}$	0,01		$\eta_{w,mz,bot}$	0,01	
	interaction - axial and bending					
	$\eta_{w,top}$	0,95		$\eta_{w,bot}$	0,92	
	$\tau_{w,vy,top}$	6,87	N/mm²	$\tau_{w,vy,bot}$	6,87	N/mm²
	$\eta_{w,vy,top}$	0,04		$\eta_{w,vy,bot}$	0,04	
	$\tau_{w,vz,top}$	0,00	N/mm²	$\tau_{w,vz,bot}$	0,00	N/mm²
	$\eta_{w,vz,top}$	0,00		$\eta_{w,vz,bot}$	0,00	
	interaction					
	$\eta_{w,v,top}$	0,04		$\eta_{w,v,bot}$	0,04	

Figure 5-8 - Verification of reinforced cross-section

verification						
	Top			**Bottom**		
wood cross-section	$\sigma_{w,axial,top}$	2,08	N/mm²	$\sigma_{w,axial,bot}$	2,08	N/mm²
	$\eta_{w,t0d,top}$	0,13		$\eta_{w,t0d,bot}$	0,13	
	$\sigma_{w,my,top}$	-24,49	N/mm²	$\sigma_{w,my,bot}$	24,49	N/mm²
	$\eta_{w,my,top}$	1,11		$\eta_{w,my,bot}$	1,11	
	$\sigma_{w,mz,top}$	-1,42	N/mm²	$\sigma_{w,mz,bot}$	1,42	N/mm²
	$\eta_{w,mz,top}$	0,07		$\eta_{w,mz,bot}$	0,07	
	interaction - axial and bending					
	$\eta_{w,top}$	1,29		$\eta_{w,bot}$	1,29	
	$\tau_{w,vy,top}$	1,18	N/mm²	$\tau_{w,vy,bot}$	1,18	N/mm²
	$\eta_{w,vy,top}$	0,45		$\eta_{w,vy,bot}$	0,45	
	$\tau_{w,vz,top}$	0,00	N/mm²	$\tau_{w,vz,bot}$	0,00	N/mm²
	$\eta_{w,vz,top}$	0,00		$\eta_{w,vz,bot}$	0,00	
	interaction - shear					
	$\eta_{w,v,top}$	0,20		$\eta_{w,v,bot}$	0,20	
steel reinforcement	$\sigma_{w,axial,top}$	0,00	N/mm²	$\sigma_{w,axial,bot}$	0,00	N/mm²
	$\eta_{w,t0d,top}$	0,00		$\eta_{w,t0d,bot}$	0,00	
	$\sigma_{w,my,top}$	0,00	N/mm²	$\sigma_{w,my,bot}$	0,00	N/mm²
	$\eta_{w,my,top}$	0,00		$\eta_{w,my,bot}$	0,00	
	$\sigma_{w,mz,top}$	0,00	N/mm²	$\sigma_{w,mz,bot}$	0,00	N/mm²
	$\eta_{w,mz,top}$	0,00		$\eta_{w,mz,bot}$	0,00	
	interaction - axial and bending					
	$\eta_{w,top}$	0,00		$\eta_{w,bot}$	0,00	
	$\tau_{w,vy,top}$	0,00	N/mm²	$\tau_{w,vy,bot}$	0,00	N/mm²
	$\eta_{w,vy,top}$	0,00		$\eta_{w,vy,bot}$	0,00	
	$\tau_{w,vz,top}$	0,00	N/mm²	$\tau_{w,vz,bot}$	0,00	N/mm²
	$\eta_{w,vz,top}$	0,00		$\eta_{w,vz,bot}$	0,00	
	interaction					
	$\eta_{w,v,top}$	0,00		$\eta_{w,v,bot}$	0,00	

Figure 5-9 - Verification of unreinforced cross-section with the dimensions of reinforced cross-section

5.2. Connection with Glued-In Rods

As already mentioned the connection are a crucial point of the connection, these verification are important for the further process of the project.

Glued-in rods themselves are efficient reinforcement but due to the high bending and axial stresses, problems are evolving with the glue-line. This is the reason why either many small bars need to be chosen or the cross-section needs to be increased enable the possibility to place more rods. Since the first solution leads to very unpractical construction processes, the cross-section has been enlarged, Figure 5-10 shows these dimensions. The applied loads are identical with the ones for the flexural reinforcement. Figure 5-11 provides an overview of the dimensions and properties of the connection material.

The distribution of the rods is evenly over the cross-section as shown in Figure 5-12, 12 bars in z-direction and 11 in y-direction lead to 132 rods in total, still a very high number, considering they need to be drilled into the wood over a length of 1 m as Figure 5-13 presents. Furthermore this figure shows the verification, which shows that dominant strength is the yielding of steel, therefore the connection would fail ductile, the preferred failure mode.

timber			
dimensions	height	1000	mm
	width	900	mm
material	glulam		
class	GL32h		
properties	$f_{m,y,k}$	32,0	N/mm²
	$f_{m,z,k}$	28,8	N/mm²
	$f_{t,0,k}$	22,5	N/mm²
	$f_{t,90,k}$	0,5	N/mm²
	$f_{c,0,k}$	29,0	N/mm²
	$f_{c,90,k}$	3,3	N/mm²
	$f_{v,k}$	3,8	N/mm²
	E	13700	N/mm²
	ρ	430,0	kg/m³
service class	NKL 1		
load duration	short		

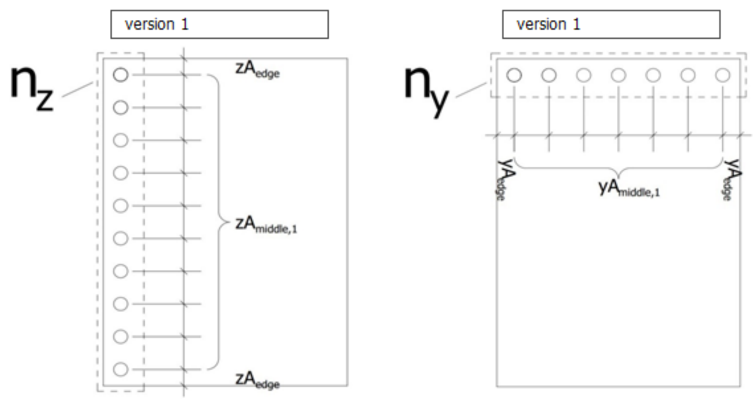
forces		
M_y	1100	kNm
M_z	50	kNm
N_x	800	kN
V_y	200	kN
V_z	0	kN
k_{mod}	0,9	
k_{def}	0,6	

Figure 5-10 – Dimension and properties of the timber cross-section and applied loads

	reinforcement			connection		
	perforated plate			glued-in rod		
type	reinforcement bar			same as top reinforcement		
dimensions	diameter	16	mm	height	14	mm
				width		mm
	quantity	0	[-]	quantity	1	[-]
material	Steel S355			please choose		
properties	$f_{y,k}$	355	N/mm²	$f_{y,k}$	355	N/mm²
	$f_{u,k}$	510	N/mm²	$f_{u,k}$	510	N/mm²
	E	210000	N/mm²	E	210000	N/mm²

Figure 5-11 - Dimension and properties of connection material

Connection with Glued-In Rods



reinforcement bar

	z-axis			y-axis		
quantity	$n_{z,1,max}$	12	[-]	$n_{y,1,max}$	11	[-]
	$n_{z,1}$	12	[-]	$n_{y,1}$	11	[-]
	factor for $n_{z,2}$	1,5	[-]	factor for $n_{y,2}$	1,25	[-]
	$n_{z,2}$	0	[-]	$n_{y,2}$	0	[-]
distance & spacing	zA_{edge}	40	mm	yA_{edge}	40	mm
	$zA_{middle,min}$	80,0	mm	$yA_{middle,min}$	80	mm
	$zA_{middle,1}$	83,6	mm	$yA_{middle,1}$	82,0	mm
	$zA_{middle,2}$	0,0	mm	$yA_{middle,2}$	0,0	mm

Figure 5-12 – Number and spacing of connection material

verification

moment of inertia	$I_{y,conn}$	2.212.324.626	mm^4	$I_{z,conn}$	1.784.985.992	mm^4
	$l_{ad,min}$	160	mm	l_{ad}	1000	mm
	$f_{k,1,k}$	2,00	N/mm²	$f_{h,1,k}$	3,70	N/mm²
	$M_{y,Rk}$	206.730	kNm	$A_{net,t}$	897.888	mm²
axial load	$F_{ax,Rd,S}$	58.989	N	$F_{ax,Ed,N}$	6.061	N
	$F_{ax,Rd,S}$	74.576	N	$F_{ax,Ed,My}$	46.786	N
	$F_{ax,Rd,A}$	69.598	N	$F_{ax,Ed,Mz}$	2.354	N
	$F_{ax,Rd,T}$	105.957	N			
	$F_{ax,Rd}$	58.989	N	$F_{ax,Ed}$	55.201	N
			η_{ax}	0,94		
lateral load	$F_{v,Rd}$	5.009.736	N	$F_{v,Ed}$	1.515	N
			η_v	0,00		
interaktion			η_{ax+v}	0,88		

Figure 5-13 - Verification of the connection with glued-in rods

5.3. Connection with Perforated Plates

The same connection needs to be proven with perforated plates, since the plates cover the whole length of the beam, the efficiency is higher as of glued-in rods. The cross-section does not need to be increased as much as Figure 5-14 shows. Still was an enlargement necessary to accomplish this connection.

Since the dimensions of the plates is not entered into the first sheet, Figure 5-15 only shows the chosen orientation of the plates as well as the properties.

In Figure 5-16 the missing properties have been entered, such as distribution of plates over the cross-section as well the size of the plates. The evaluated number of adhesive dowels is showed in this figure as well.

As Figure 5-17 shows is the connection sufficient and approved with a similar utilisation factor as for the connections with glued-in rods but with a smaller cross-section.

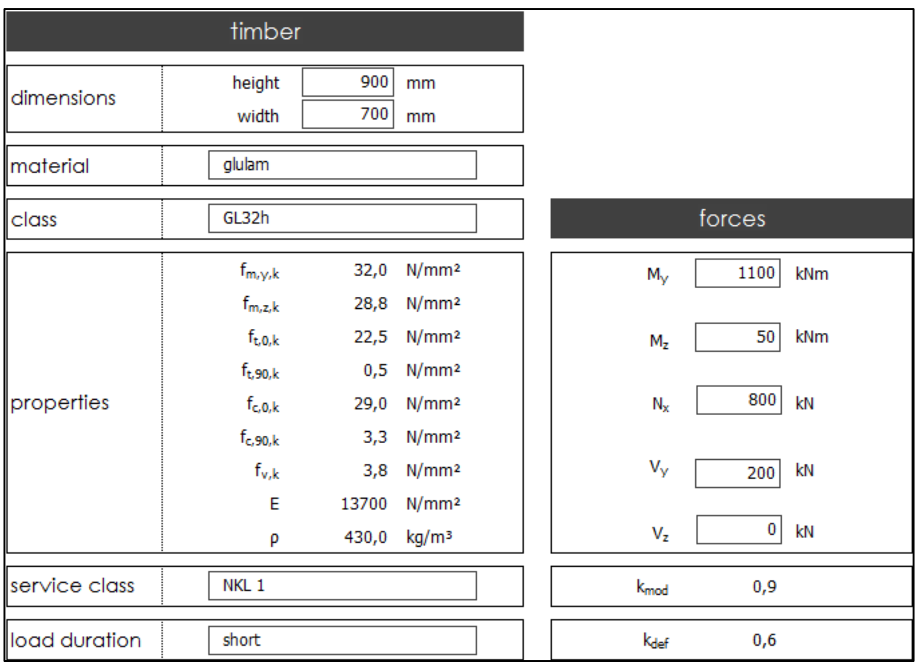


Figure 5-14 – Dimension and properties of the timber cross-section and applied loads

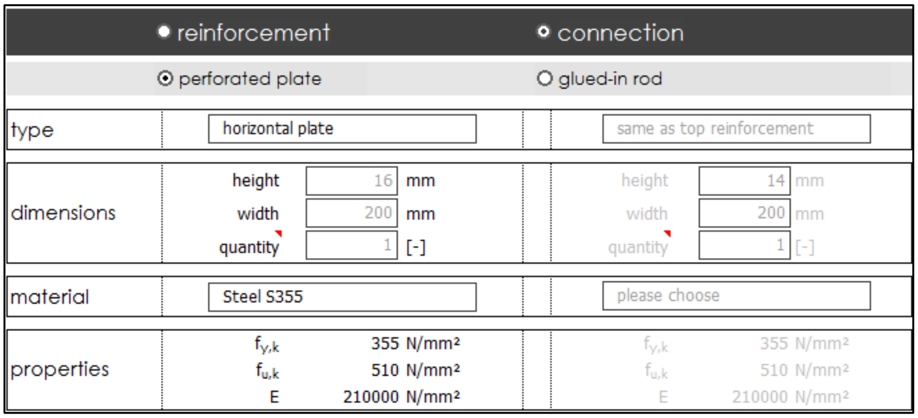


Figure 5-15 - Orientation and properties of connection material

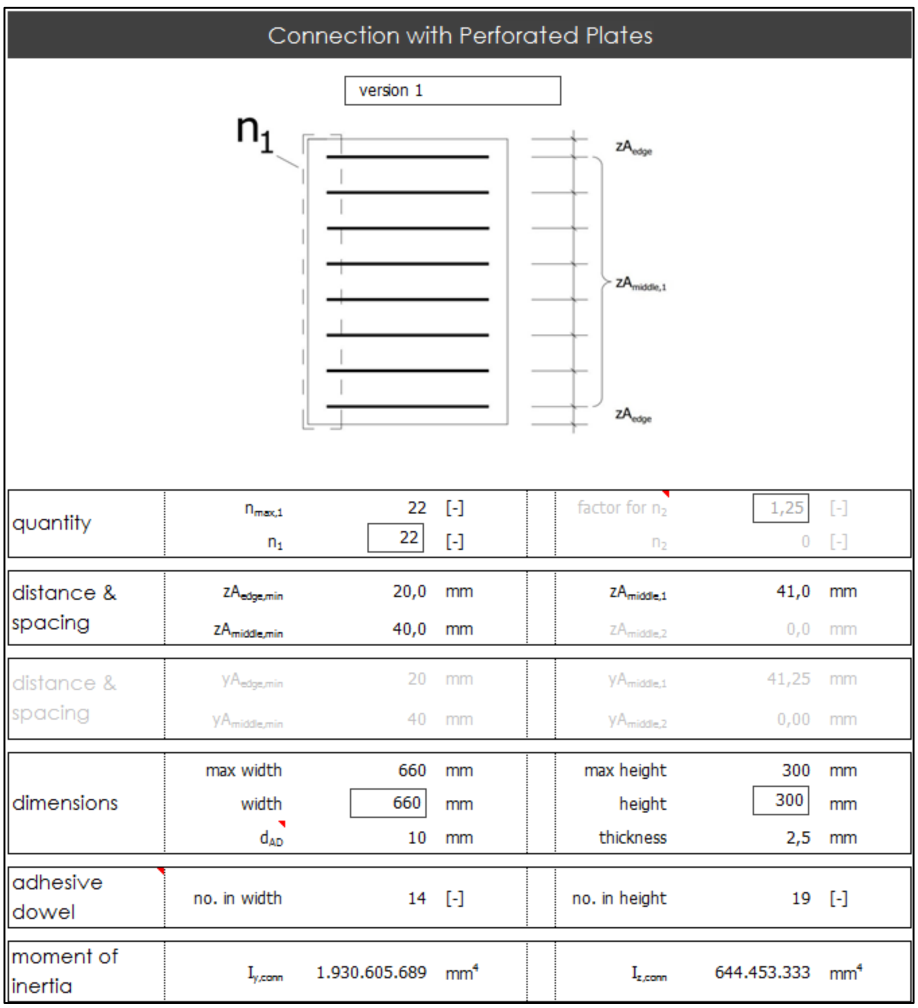


Figure 5-16 – Number and spacing of connection material

verification							
	$F_{AD,Rk}$	800	N	$f_{k,1,k}$	3,88	N/mm²
adhesive and timber	adhesive			timber		
	$F_{AD,Ed,N}$	191	N	$F_{t,Ed}$	381.088	N
	$F_{AD,Ed,V}$	0	N	$F_{t,Rd}$	8.031.025	N
	$F_{AD,Ed,M}$	0	N	η_w	0,05	
	$F_{AD,Ed}$	191	N	$F_{w,BS,Ed}$	36.364	N
	$F_{AD,Rd}$	554	N	$F_{w,bs,Rd}$	626.749	N
	η_{ax}	0,35		η_{ax}	0,06	
steel plate	$F_{SP,Ed,N}$	36.364	N	$F_{SP,Ed,Vy}$	9.091	N
	$F_{SP,Ed,My}$	318.501	N	$F_{SP,Ed,Vz}$	0	N
	$F_{SP,Ed,Mz}$	26.224	N	$F_{SP,Ed,V}$	9.091	N
	$F_{SP,Ed}$	381.088	N			
	$F_{SP,Rd}$	419.545	N	$F_{SP,Rd,V}$	639.473	N
	$\eta_{SP,NM}$	0,91		$\eta_{SP,V}$	0,01	
			η_{SP}	0,92		
failure			η	0,92		

Figure 5-17 - Verification of the connection with perforated plates

6. Chapter - Conclusion and recommendation

This thesis was developed with the purpose of developing a tool for dimensioning timber cross-sections this will be helpful in allowing timber constructions to be taken into consideration more often as a structure type. In times with growing interest in sustainability, wood as material is becoming more important. Since it is a natural material, in many processes to decide for a material, wood has too many arguments against it. Investigating these arguments and alleviating their criticality became the basis of this thesis.

One weakness of wood is its tensile strength despite a high strength to weight ratio. Firstly defects on the tension side lead to lower loading capacities. Several studies showed the effectiveness of bridging effect of reinforcement with significantly higher flexure strength or smaller cross-section. Secondly timber's lack in tensile strength perpendicular to the grain often requires reinforcement. For both cases this tool not only popularizes the techniques but also provides a rapid facility for a feasibility study. The second part of the tool does not tackle a weakness of timber itself but transportation limits. Effective connections are crucial if the structure is delivered in pieces, therefore glued-in fasteners are one of the best options. Their analysis with the individual parts is taken over by the tool, the convenient way allows fast setting changes and finding the best solution.

Certainly there are various FE programs providing more precise or detailed results. But these are missing a significant aspect; it needs time consuming adjustments in order to change certain aspects as the number of reinforcement or fasteners, their position or their shape. As a quick check while conducting a preliminary design to determine if using timber as structural material is a possibility, it is not sufficient. For consideration and comparison of several approaches the tool of this thesis is highly effective.

6.1. Areas for further studies

6.1.1. Potential of Reinforcement

As previously mentioned newer material such as fiber reinforced polymers can provide an even more effective reinforcement due to, for example, higher tensile strength and lower weight than steel. Particularly carbon fiber reinforced polymers are highly compatible with wood in terms of mechanical properties such as thermal expansion (Issa & Kmeid, 2005).

Another approach to making flexure reinforcement more effective is to prestress similar to concrete. The cross-section can be developed as a compression member to avoid high tensile stresses under service load. Several studies were performed to show the effectiveness such as of (De Luca & Marano, 2012), who prestressed glulam timbers with steel bars and (Guan, Rodd, & Pope, 2005) who used pultruded GFRP. The difference of 10% in flexural strength between normal and prestressed reinforcement was discovered by (Luggin & Bergmeister, 2001).

Another frequent failure mode of timber is shear failure which is already addressed in several studies with different methods including glued-in rods and glued-on plates of different material, for example GFRP sheets (Hay, Thiessen, Svecova, & Bakht, 2006) or wraps around the whole member (Gómez & Svecova, 2008). Attention should be paid also to a combination of reinforcement with laminated veneer lumber (LVL) in high-stress zones of the cross-section.

6.1.2. Potential of Connections

Due to the brittle failure mode of wood, connections need to be carefully designed. The consideration always needs to include the ductile behavior. The two discussed types are already effective versions but their efficiency can be increased as (Bathon L. , 2015) proved in several studies and projects. The Figure 6-1 shows a selection of versions developed. A combination of the glued-in rod with perforated plates is presented in (a), leading to a very ductile connection. The figure (b) is additionally able to absorb and transmit shear stresses. And the pipe device of figure (c) has twice the surface to transfer the load to the timber.

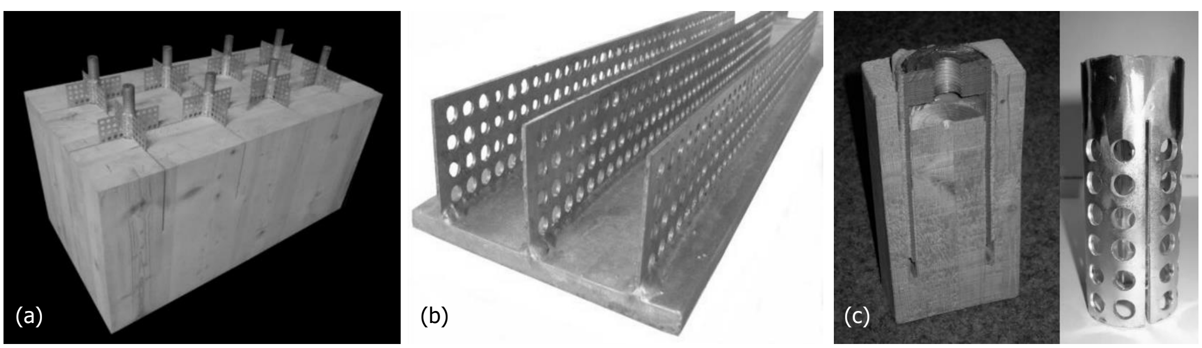


Figure 6-1 – multiple types of connections (Bathon L. , 2015)

Besides the common connection types with steel or FRPs, the research investigates glue. Similar to other structural fields, gluing is becoming more important as a connection without the use of fasteners. At the University of Applied Science in Trier and in Mainz (Becker, Schober, & Weber, 2015) researches timber joints with mineral cast, this material has excellent adhesion properties and easy to handle. Since this type of connection is casted, it can be applied for multiaxial loads and has high potential for example in structures as multi-storey buildings or long span beams. Even with complicated designs this mineral cast can act as an economic solution.

Luckily the diversity for implementation of timber as a natural, sustainable and economical solution as structural is increasing. Timber became not only a material similar appropriate but in many cases more convenient than conservative material for all types of structures. Fortunately the world can look forward to enjoy more timber in their environment.

7. Appendices

7.1. Appendix A: Tables

7.1.1. Material Properties Tables

type	steel grade	yield strength f_y	ultimate tensile strength f_u
Reinforcement bar	S 235	235	360
	S 275	275	430
	S 355	355	490
	B 500 A	500	525
	B 500 A	500	540
threaded rod	3.6	180	300
	4.6	240	400
	5.6	300	500
	8.8	640	800

Table 7-1 - yield strength f_y and ultimate tensile strength f_u of steel (DIN EN 1993-1-1, 2010, S. 28; DIN EN 1993-1-8, 2010, p. 24)

7.1.2. Distance and Spacing Tables

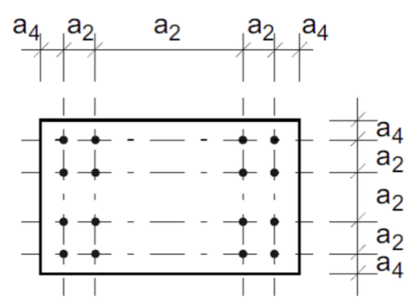


Figure 7-1 – Diagram for minimal spacing for glued-in rods (Steiger, 2012, p. 10)

type	a_2	a_4
steel bar parallel to the grain	$5d$	$2.5d$
perforated plates	$40\ mm$	$20\ mm$
glued-in steel plates	$16d$	$8d$

Table 7-2 - Minimal spacing or end/edge distances (DIN EN 1995-1-1/NA, 2013, pp. 93-94; Zulassung Z-9.1-770, 2014)

It is important to mention that these distances of bars do not include the distance between the bar and the loaded edge which is defined with $4d$ by the German National Annex of the EC 5. The tool will be adjusted to allow manually changing the edge distances.

7.2. Appendix B: Validation

7.2.1. Reinforcement for Flexure

7.2.1.1. Neutral Axis

This is example is adopted from Example 6-1 of (Gere, 2002, p. 414).

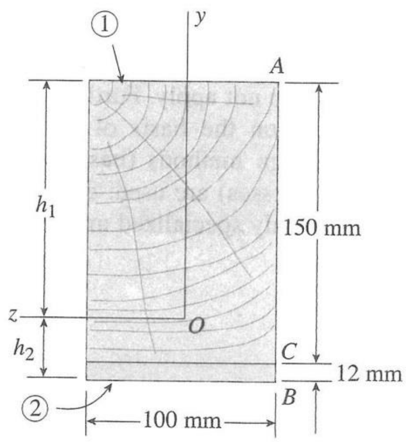


Figure 7-2 – Cross-section of a composite beam of wood and steel

The elastic moduli are defined as followed and result in the modular ratio n

$$E_1 = 10.5\ GPa \qquad E_2 = 210\ GPa$$

$$n = \frac{E_2}{E_1} = \frac{210}{10.5} = 20$$

Since the cross-section is transformed into an equivalent cross-section in wood, the timber area does not change but the steel does by the factor n.

$$A_1 = 100 \cdot 150 = 15000 \qquad A_{fact,2} = n \cdot A_2 = 20 \cdot 100 \cdot 12 = 24000$$

The neutral axis can be determined and agree exactly with the example of (Gere, 2002, p. 414)

$$NA_{top} = \mathrm{h}_1 = \frac{\sum y_i A_i}{\sum A_i} = \frac{y_1 A_1 + y_2 A_2}{\sum A_i} = \frac{75 \cdot 15000 + 156 \cdot 24000}{15000 + 24000} = 124.85$$

$$NA_{bot} = \mathrm{h}_2 = h - NA_{top} = 162 - 124.85 = 37.15$$

7.2.1.2. Unreinforced Cross-Section

timber

dimensions	height	450	mm
	width	250	mm
material	glulam		
class	GL32h		
properties	$f_{m,y,k}$	32,0	N/mm²
	$f_{m,z,k}$	28,8	N/mm²
	$f_{t,0,k}$	22,5	N/mm²
	$f_{t,90,k}$	0,5	N/mm²
	$f_{c,0,k}$	29,0	N/mm²
	$f_{c,90,k}$	3,3	N/mm²
	$f_{v,k}$	3,8	N/mm²
	E	13700	N/mm²
	ρ	430,0	kg/m³
service class	NKL 1		
load duration	short		

verification

forces

M_y	50	kNm
M_z	20	kNm
N_x	100	kN
V_y	60	kN
V_z	30	kN
k_{mod}	0,9	
k_{def}	0,6	

Figure 7-3 – input sheet

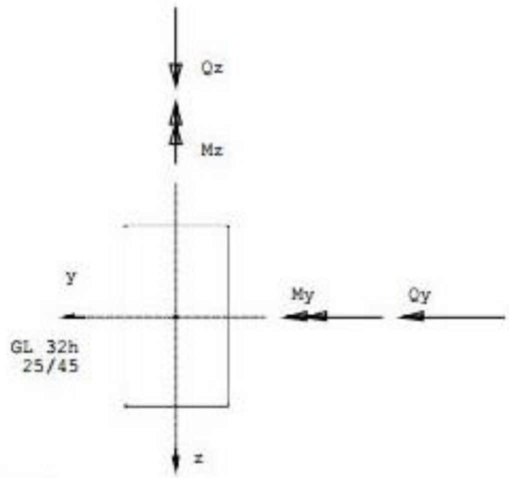
verification								
	Top				**Bottom**			
wood cross-section	$\sigma_{w,axial,top}$	0,89	N/mm²		$\sigma_{w,axial,bot}$	0,89	N/mm²
	$\eta_{w,t0d,top}$	0,06			$\eta_{w,t0d,bot}$	0,06	
	$\sigma_{w,my,top}$	-5,93	N/mm²		$\sigma_{w,my,bot}$	5,93	N/mm²
	$\eta_{w,my,top}$	0,27			$\eta_{w,my,bot}$	0,27	
	$\sigma_{w,mz,top}$	-4,27	N/mm²		$\sigma_{w,mz,bot}$	4,27	N/mm²
	$\eta_{w,mz,top}$	0,21			$\eta_{w,mz,bot}$	0,21	
	interaction - axial and bending						
	$\eta_{w,top}$	0,47			$\eta_{w,bot}$	0,47	
	$\tau_{w,vy,top}$	1,22	N/mm²		$\tau_{w,vy,bot}$	1,22	N/mm²
	$\eta_{w,vy,top}$	0,46			$\eta_{w,vy,bot}$	0,46	
	$\tau_{w,vz,top}$	0,61	N/mm²		$\tau_{w,vz,bot}$	0,61	N/mm²
	$\eta_{w,vz,top}$	0,23			$\eta_{w,vz,bot}$	0,23	
	interaction - shear						
	$\eta_{w,v,top}$	0,27			$\eta_{w,v,bot}$	0,27	

Figure 7-4 – verification sheet

Holzbemessung HO11 02/2015 (Frilo R-2015-2/P10)

Rechenteil mit BemHo901 (9.0.3.1)

Maßstab 1 : 20



NORMEN: DIN EN 1995-1-1/NA:2013-08
basierend auf EN 1995-1-1/A2:2014

BAUSTOFF: Brettschichtholz GL32h
Nutzungsklasse: 1 (geschlossen, beheizt; LF<65%; GLWF<15%)

E_{0mean} [N/mm2]	E_{005} [N/mm2]	G_{mean} [N/mm2]	G_{005} [N/mm2]	ρ_k [kg/m3]	γ [kN/m3]
13700	11100	850	708	430	5.0

f_{c0k} [N/mm2]	f_{c90k} [N/mm2]	f_{t0k} [N/mm2]	f_{t90k} [N/mm2]	f_{myk} [N/mm2]	f_{mzk} [N/mm2]	f_{vk} [N/mm2]	f_{Rk} [N/mm2]
29.0	3.3	22.5	0.5	32.9	32.0	3.5	0.0

SYSTEM:

L [m]	l_x [m]	l_{efcy} [m]	l_{efcz} [m]	l_{efmy} [m]	l_{efmz} [m]
0.10	0.00	0.10	0.10	0.10	0.10

lx=Abstand vom Hirnholzende

QUERSCHNITT: 25* 45

A [cm2]	A_{vy} [cm2]	A_{vz} [cm2]	I_y [cm4]	I_z [cm4]	W_y [cm3]	W_z [cm3]	W_T [cm3]
1125.0	750.0	750.0	189844	58594	8438	4688	6819

i_y [cm]	i_z [cm]	i_{my} [cm]	i_{mz} [cm]	U [cm]
13.0	7.2	11.3	36.7	140.0

BEIWERTE:

k_{cy}	k_{cz}	k_{crity}	k_{critz}	λ_{relCy}	λ_{relCz}	λ_{relMy}	λ_{relMz}	k_{cr}
1.00	**1.00**	**1.00**	**1.00**	**0.35**	**0.69**	**0.05**	**0.02**	**0.71**

EINWIRKUNGEN:

	Bezeichnung	γ_{sup}	γ_{inf}	ψ_0	ψ_1	ψ_2	k_{mod}	k_{def}
E	Bemessungslastfall	1.00	0.00	1.00	1.00	1.00	0.01	0.60

CHARAKTERISTISCHE EINWIRKUNGEN:

Nr	N_x [kN]	M_y [kNm]	V_z [kN]	M_z [kNm]	V_y [kN]	M_T [kNm]	NG%	EW	LED
1	100.0	50.00	30.0	20.00	60.0	0.00	0	E	mittel

KOMBINATIONEN FÜR TRAGFÄHIGKEIT:

LF	γ_M	Kombination
1 :	**1.30**	**1*b1 (P/T)**
2 :	**1.00**	**1*b1 (acci.,fi)**

BEMESSUNGS-EINWIRKUNGEN:

LF	N_{xd} [kN]	M_{yd} [kNm]	V_{zd} [kN]	M_{zd} [kNm]	V_{yd} [kN]	M_{Td} [kNm]	NG%	k_{mod}	k_{def}
1	**100.0**	**50.00**	**30.0**	**20.00**	**60.0**	**0.00**	**0**	**0.80**	
2	**65.0**	**32.50**	**19.5**	**13.00**	**39.0**	**0.00**	**0**	**0.80**	

SPANNUNGEN:

LF	σ_{Nd}	σ_{Myd}	τ_{Vzd}	σ_{Mzd}	τ_{Vyd}	τ_{MTd}	[je N/mm2]
1	**0.89**	**5.93**	**0.40**	**4.27**	**0.80**	**0.00**	

TRAGFÄHIGKEITSNACHWEISE: kalt

LF	ηSpng	ηStab	ηSchb	$\sigma_{ob,li}$	$\sigma_{ob,re}$	$\sigma_{un,li}$	$\sigma_{un,re}$
1	**0.51**	**0.51**	**0.58**	-0.77	-9.30	11.08	2.55

Figure 7-5 - Output sheet of Frilo for the unreinforced cross-section

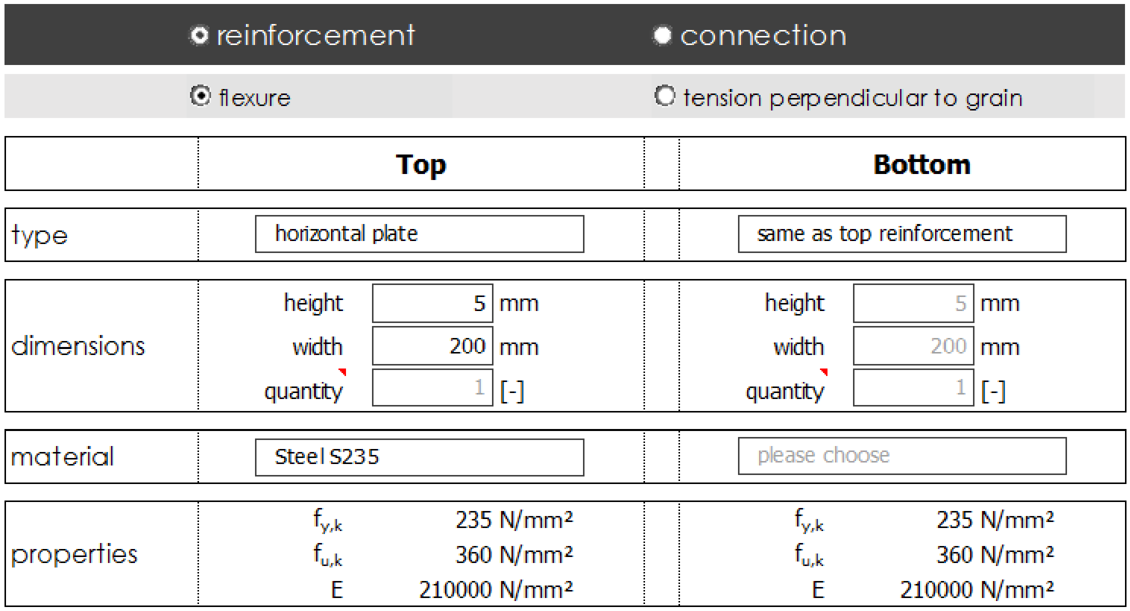
7.2.1.3. Reinforced cross-section

timber			
dimensions	height	450	mm
	width	250	mm
material	glulam		
class	GL32h		
properties	$f_{m,y,k}$	32,0	N/mm²
	$f_{m,z,k}$	28,8	N/mm²
	$f_{t,0,k}$	22,5	N/mm²
	$f_{t,90,k}$	0,5	N/mm²
	$f_{c,0,k}$	29,0	N/mm²
	$f_{c,90,k}$	3,3	N/mm²
	$f_{v,k}$	3,8	N/mm²
	E	13700	N/mm²
	ρ	430,0	kg/m³
service class	NKL 1		
load duration	short		

verification		
forces		
M_y	50	kNm
M_z	20	kNm
N_x	100	kN
V_y	60	kN
V_z	30	kN
k_{mod}	0,9	
k_{def}	0,6	

Figure 7-6 – General input sheet for all reinforcement types

7.2.1.3.1. *Reinforcement with Horizontal Plates*



reinforcement		connection	
flexure		tension perpendicular to grain	
	Top		Bottom
type	horizontal plate		same as top reinforcement
dimensions	height 5 mm		height 5 mm
	width 200 mm		width 200 mm
	quantity 1 [-]		quantity 1 [-]
material	Steel S235		please choose
properties	$f_{y,k}$ 235 N/mm²		$f_{y,k}$ 235 N/mm²
	$f_{u,k}$ 360 N/mm²		$f_{u,k}$ 360 N/mm²
	E 210000 N/mm²		E 210000 N/mm²

Figure 7-7 – input sheet of reinforcement with horizontal plates

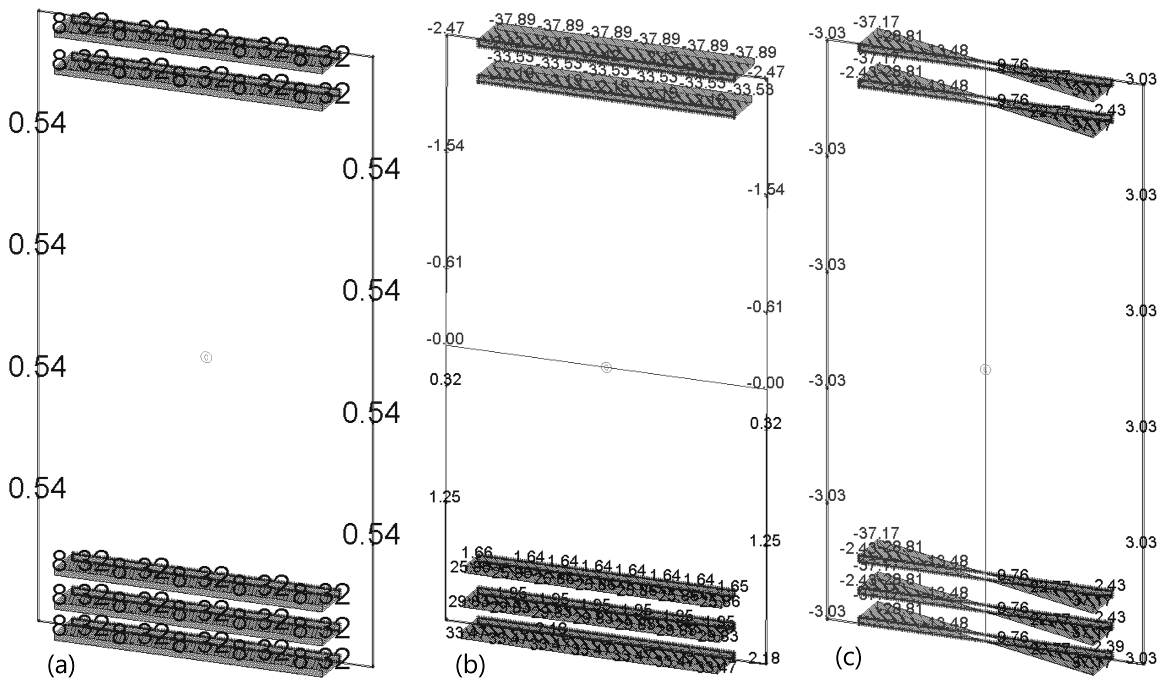


Figure 7-8 - Stress Diagram of Sofistik for (a) normal stresses, (b) bending stress around y-axis and (c) bending stress around z-axis for reinforcement with horizontal plates

verification						
	Top			**Bottom**		
wood cross-section	$\sigma_{w,axial,top}$	0,54	N/mm²	$\sigma_{w,axial,bot}$	0,54	N/mm²
	$\eta_{w,t0d,top}$	0,03		$\eta_{w,t0d,bot}$	0,03	
	$\sigma_{w,my,top}$	-2,87	N/mm²	$\sigma_{w,my,bot}$	2,74	N/mm²
	$\eta_{w,my,top}$	0,13		$\eta_{w,my,bot}$	0,12	
	$\sigma_{w,mz,top}$	-3,07	N/mm²	$\sigma_{w,mz,bot}$	3,07	N/mm²
	$\eta_{w,mz,top}$	0,15		$\eta_{w,mz,bot}$	0,15	
	interaction - axial and bending					
	$\eta_{w,top}$	0,28		$\eta_{w,bot}$	0,28	
	$\tau_{w,vy,top}$	0,00	N/mm²	$\tau_{w,vy,bot}$	0,00	N/mm²
	$\eta_{w,vy,top}$	0,00		$\eta_{w,vy,bot}$	0,00	
	$\tau_{w,vz,top}$	0,00	N/mm²	$\tau_{w,vz,bot}$	0,00	N/mm²
	$\eta_{w,vz,top}$	0,00		$\eta_{w,vz,bot}$	0,00	
	interaction - shear					
	$\eta_{w,v,top}$	0,00		$\eta_{w,v,bot}$	0,00	
steel reinforcement	$\sigma_{w,axial,top}$	8,32	N/mm²	$\sigma_{w,axial,bot}$	8,32	N/mm²
	$\eta_{w,t0d,top}$	0,04		$\eta_{w,t0d,bot}$	0,03	
	$\sigma_{w,my,top}$	-44,01	N/mm²	$\sigma_{w,my,bot}$	42,02	N/mm²
	$\eta_{w,my,top}$	0,21		$\eta_{w,my,bot}$	0,17	
	$\sigma_{w,mz,top}$	-37,60	N/mm²	$\sigma_{w,mz,bot}$	-37,60	N/mm²
	$\eta_{w,mz,top}$	0,18		$\eta_{w,mz,bot}$	0,15	
	interaction - axial and bending					
	$\eta_{w,top}$	0,42		$\eta_{w,bot}$	0,35	
	$\tau_{w,vy,top}$	0,00	N/mm²	$\tau_{w,vy,bot}$	0,00	N/mm²
	$\eta_{w,vy,top}$	0,00		$\eta_{w,vy,bot}$	0,00	
	$\tau_{w,vz,top}$	0,00	N/mm²	$\tau_{w,vz,bot}$	0,00	N/mm²
	$\eta_{w,vz,top}$	0,00		$\eta_{w,vz,bot}$	0,00	
	interaction					
	$\eta_{w,v,top}$	0,00		$\eta_{w,v,bot}$	0,00	

Figure 7-9 - Verification sheet of the tool for reinforcement with horizontal plates

7.2.1.3.2. *Reinforcement with bars*

◉ reinforcement		○ connection
◉ flexure		○ tension perpendicular to grain
	Top	**Bottom**
type	reinforcement bar	reinforcement bar
dimensions	diameter 14 mm quantity 2 [-]	diameter 16 mm quantity 3 [-]
material	Steel S275	Steel S235
properties	$f_{y,k}$ 275 N/mm² $f_{u,k}$ 430 N/mm² E 210000 N/mm²	$f_{y,k}$ 235 N/mm² $f_{u,k}$ 360 N/mm² E 210000 N/mm²

Figure 7-10 - Input sheet of reinforcement with bars

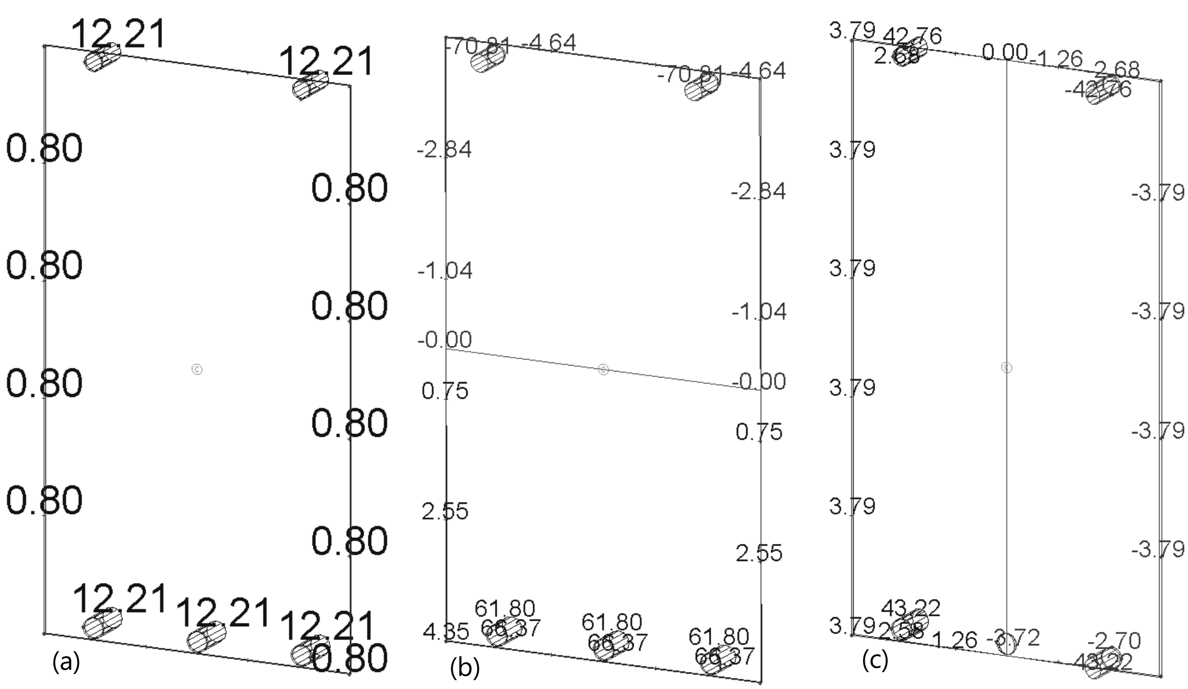


Figure 7-11 - Stress Diagram of Sofistik for (a) normal stresses, (b) bending stress around y-axis and (c) bending stress around z-axis for reinforcement with bars

verification						
	Top			**Bottom**		
wood cross-section	$\sigma_{w,axial,top}$	0,80	N/mm²	$\sigma_{w,axial,bot}$	0,80	N/mm²
	$\eta_{w,t0d,top}$	0,05		$\eta_{w,t0d,bot}$	0,05	
	$\sigma_{w,my,top}$	-4,59	N/mm²	$\sigma_{w,my,bot}$	4,28	N/mm²
	$\eta_{w,my,top}$	0,21		$\eta_{w,my,bot}$	0,19	
	$\sigma_{w,mz,top}$	-3,64	N/mm²	$\sigma_{w,mz,bot}$	3,64	N/mm²
	$\eta_{w,mz,top}$	0,18		$\eta_{w,mz,bot}$	0,18	
	interaction - axial and bending					
	$\eta_{w,top}$	0,39		$\eta_{w,bot}$	0,37	
	$\tau_{w,vy,top}$	0,00	N/mm²	$\tau_{w,vy,bot}$	0,00	N/mm²
	$\eta_{w,vy,top}$	0,00		$\eta_{w,vy,bot}$	0,00	
	$\tau_{w,vz,top}$	0,00	N/mm²	$\tau_{w,vz,bot}$	0,00	N/mm²
	$\eta_{w,vz,top}$	0,00		$\eta_{w,vz,bot}$	0,00	
	interaction - shear					
	$\eta_{w,v,top}$	0,00		$\eta_{w,v,bot}$	0,00	
steel reinforcement	$\sigma_{w,axial,top}$	12,21	N/mm²	$\sigma_{w,axial,bot}$	12,21	N/mm²
	$\eta_{w,t0d,top}$	0,05		$\eta_{w,t0d,bot}$	0,06	
	$\sigma_{w,my,top}$	-70,37	N/mm²	$\sigma_{w,my,bot}$	65,67	N/mm²
	$\eta_{w,my,top}$	0,28		$\eta_{w,my,bot}$	0,31	
	$\sigma_{w,mz,top}$	-40,20	N/mm²	$\sigma_{w,mz,bot}$	-37,96	N/mm²
	$\eta_{w,mz,top}$	0,16		$\eta_{w,mz,bot}$	0,18	
	interaction - axial and bending					
	$\eta_{w,top}$	0,49		$\eta_{w,bot}$	0,54	
	$\tau_{w,vy,top}$	0,00	N/mm²	$\tau_{w,vy,bot}$	0,00	N/mm²
	$\eta_{w,vy,top}$	0,00		$\eta_{w,vy,bot}$	0,00	
	$\tau_{w,vz,top}$	0,00	N/mm²	$\tau_{w,vz,bot}$	0,00	N/mm²
	$\eta_{w,vz,top}$	0,00		$\eta_{w,vz,bot}$	0,00	
	interaction					
	$\eta_{w,v,top}$	0,00		$\eta_{w,v,bot}$	0,00	

Figure 7-12 – Verification sheet of the tool for reinforcement with bars

7.2.1.3.3. *Reinforcement with Vertical Plates*

◉ reinforcement		● connection	
◉ flexure		○ tension perpendicular to grain	

	Top		Bottom	
type	vertical plate		vertical plate	
dimensions	height	10 mm	height	15 mm
	width	5 mm	width	5 mm
	quantity	2 [-]	quantity	3 [-]
material	Steel S235		Steel S235	
properties	$f_{y,k}$	235 N/mm²	$f_{y,k}$	235 N/mm²
	$f_{u,k}$	360 N/mm²	$f_{u,k}$	360 N/mm²
	E	210000 N/mm²	E	210000 N/mm²

Figure 7-13 - Input sheet of reinforcement with vertical plates

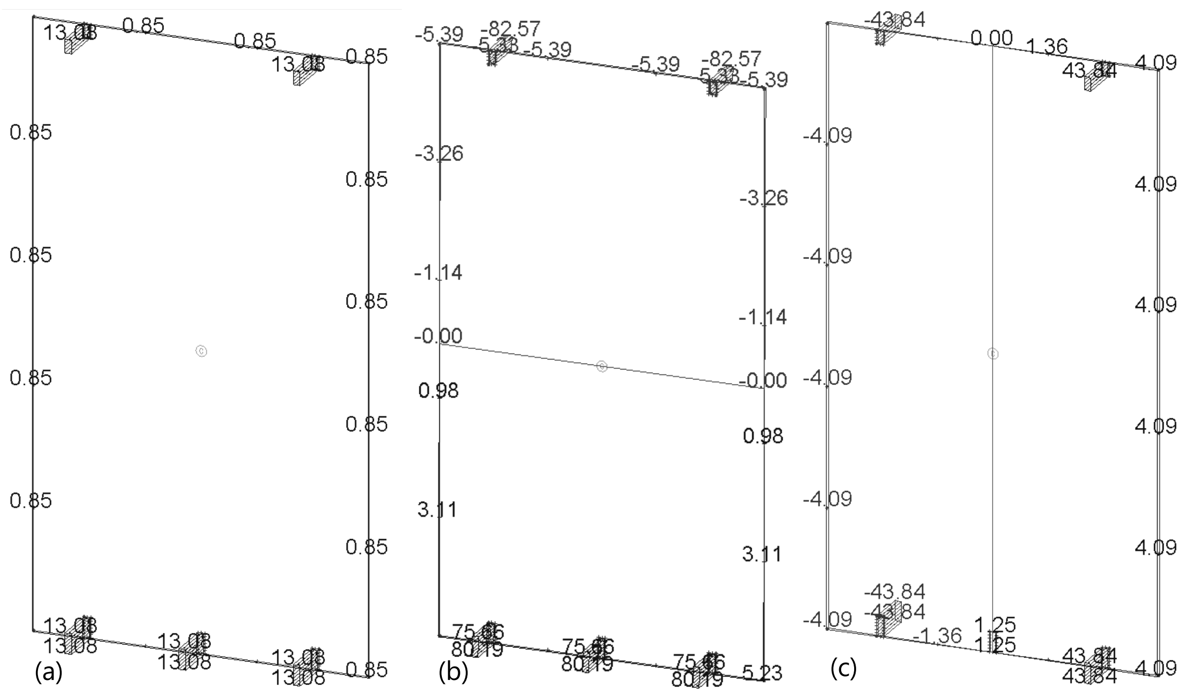


Figure 7-14 - Stress Diagram of Sofistik for (a) normal stresses, (b) bending stress around y-axis and (c) bending stress around z-axis for reinforcement with vertical plates

verification						
	Top			**Bottom**		
wood cross-section	$\sigma_{w,axial,top}$	0,85	N/mm²	$\sigma_{w,axial,bot}$	0,85	N/mm²
	$\eta_{w,t0d,top}$	0,05		$\eta_{w,t0d,bot}$	0,05	
	$\sigma_{w,my,top}$	-5,37	N/mm²	$\sigma_{w,my,bot}$	5,20	N/mm²
	$\eta_{w,my,top}$	0,24		$\eta_{w,my,bot}$	0,23	
	$\sigma_{w,mz,top}$	-3,81	N/mm²	$\sigma_{w,mz,bot}$	3,81	N/mm²
	$\eta_{w,mz,top}$	0,19		$\eta_{w,mz,bot}$	0,19	
	interaction - axial and bending					
	$\eta_{w,top}$	0,43		$\eta_{w,bot}$	0,42	
	$\tau_{w,vy,top}$	0,00	N/mm²	$\tau_{w,vy,bot}$	0,00	N/mm²
	$\eta_{w,vy,top}$	0,00		$\eta_{w,vy,bot}$	0,00	
	$\tau_{w,vz,top}$	0,00	N/mm²	$\tau_{w,vz,bot}$	0,00	N/mm²
	$\eta_{w,vz,top}$	0,00		$\eta_{w,vz,bot}$	0,00	
	interaction - shear					
	$\eta_{w,v,top}$	0,00		$\eta_{w,v,bot}$	0,00	
steel reinforcement	$\sigma_{w,axial,top}$	13,08	N/mm²	$\sigma_{w,axial,bot}$	13,08	N/mm²
	$\eta_{w,t0d,top}$	0,06		$\eta_{w,t0d,bot}$	0,06	
	$\sigma_{w,my,top}$	-82,27	N/mm²	$\sigma_{w,my,bot}$	79,73	N/mm²
	$\eta_{w,my,top}$	0,39		$\eta_{w,my,bot}$	0,37	
	$\sigma_{w,mz,top}$	-39,71	N/mm²	$\sigma_{w,mz,bot}$	-39,71	N/mm²
	$\eta_{w,mz,top}$	0,19		$\eta_{w,mz,bot}$	0,19	
	interaction - axial and bending					
	$\eta_{w,top}$	0,63		$\eta_{w,bot}$	0,62	
	$\tau_{w,vy,top}$	0,00	N/mm²	$\tau_{w,vy,bot}$	0,00	N/mm²
	$\eta_{w,vy,top}$	0,00		$\eta_{w,vy,bot}$	0,00	
	$\tau_{w,vz,top}$	0,00	N/mm²	$\tau_{w,vz,bot}$	0,00	N/mm²
	$\eta_{w,vz,top}$	0,00		$\eta_{w,vz,bot}$	0,00	
	interaction					
	$\eta_{w,v,top}$	0,00		$\eta_{w,v,bot}$	0,00	

Figure 7-15 – Verification sheet for reinforcement with vertical plates

7.2.2. Reinforcement for Tension perpendicular to the Grain

7.2.2.1. Double Tapered Beam

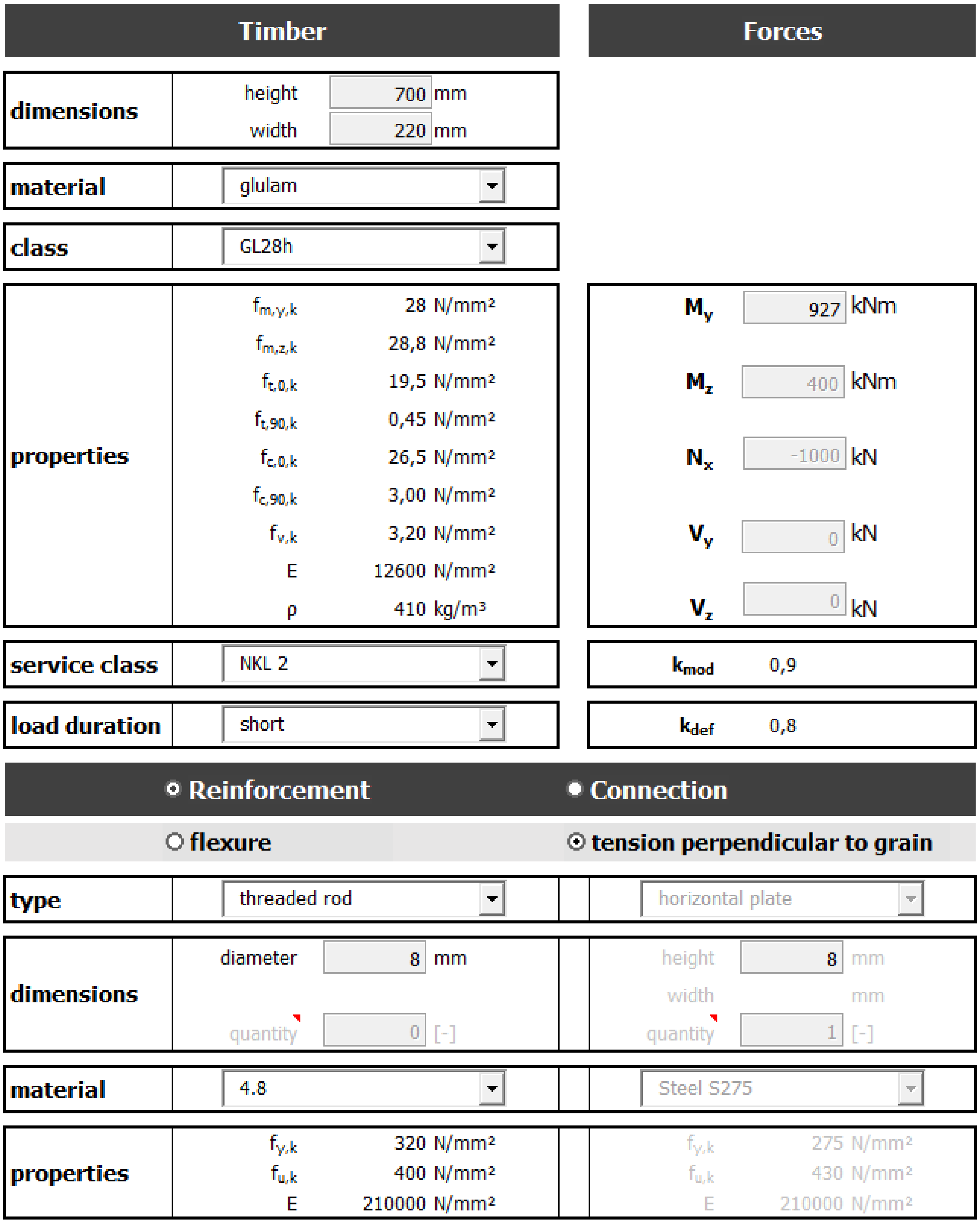


Figure 7-16 – Double Tapered Beam – input sheet

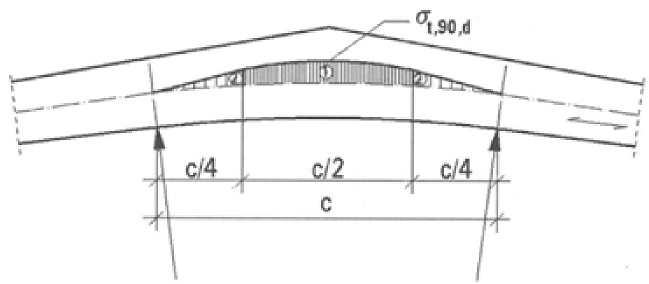
Reinforcement for Tension Perpendicular to the Grain

beam type	double tapered beam

position	○ **from inside**				⊙ **from above**			
dimensions	l	15	m		c	1.621	mm	
	r_{in}	-	m		r	-	mm	
	h_{ap}	1.621	mm		t	30	mm	
	h_c	1.521	mm		V_{beam}	0,56	m³	
angles	upper taper - α	7	°		lower taper - β	0	°	
check if reinforcement is needed								
load	k_5	-	[-]		k_6	-	[-]	
	k_7	-	[-]		k_p	0,02	[-]	
	$\sigma_{t,90,d}$	**0,24**	**N/mm²**					
resistance	**reinforcement needed?**				**nominal reinforcement enough?**			
	k_{dis}	1,40	[-]		k_{dis}	1,30	[-]	
	k_{vol}	0,45	[-]		k_{vol}	0,74	[-]	
	$f_{t,90,d}$	**0,19**	**N/mm²**		$f_{t,90,d}$	**0,30**	**N/mm²**	
verification	$\eta_{t,90,d}$	**1,21**	**[-]**		$\eta_{t,90,d}$	**0,79**	**[-]**	

Figure 7-17 – Double Tapered Beam – Reinforcement for Tension Perpendicular to the Grain Sheet 1

Nominal Reinforcement



dimensioning of reinforcement

number of rows	maximum		[-]	selected	1	[-]	
resistance of rod	fyd	264	N/mm²	$F_{t,90,fyd,d}$	12.721	N	
	fud	291	N/mm²	$F_{t,90,fud,d}$	13.993	N	
resistance of glue line	inner two quarter			outer quarter			
	$f_{k,1,d}$	2,77	N/mm²	$f_{k,1,d}$		N/mm²	
	l_{ad}	756	mm	l_{ad}		mm	
	$F_{t,90,fk1d,d}$	26.293	N	$F_{t,90,fk1d,d}$		N	
decisive value	$\mathbf{F_{t,90,d}}$	**12.721**	**N**	$F_{t,90,d}$		N	
spacing	$a_{1,in}$	712	mm	$a_{1,out}$		mm	
quantity of rods	$n_{1,in}$	4	[-]	$n_{1,out}$		[-]	

Figure 7-18 - Double Tapered Beam – Reinforcement for Tension Perpendicular to the Grain Sheet 2

7.2.2.2. Curved Beam

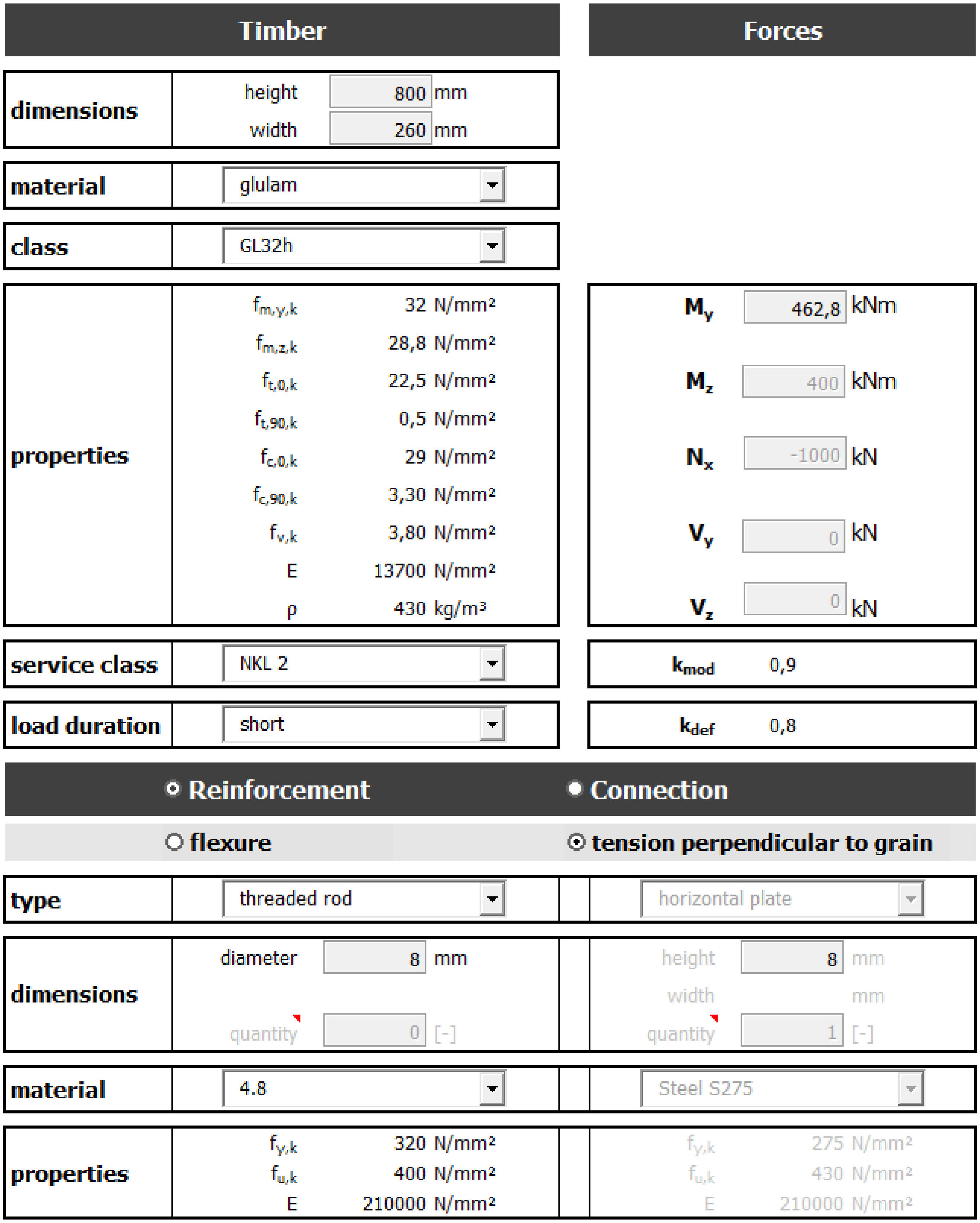


Figure 7-19 – Curved Beam – Input sheet

Reinforcement for Tension Perpendicular to the Grain

beam type	curved beam

position	○ **from inside**	⦿ **from above**

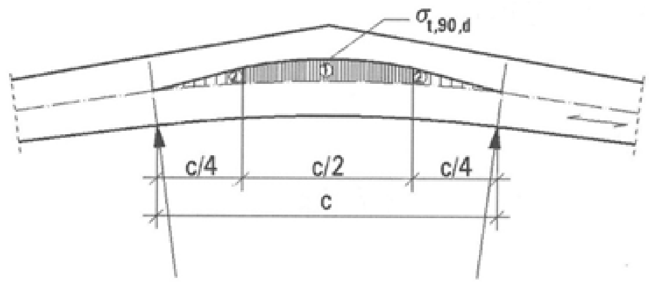
dimensions	l	22	m	c	5.253	mm
	r_{in}	8,5	m	r	8.900	mm
	h_{ap}	800	mm	t	30	mm
	h_c	761	mm	V_{beam}	1,16	m³
angles	upper taper - α	18	°	lower taper - β	18	°

check if reinforcement is needed

load	k_5	-	[-]	k_6	-	[-]
	k_7	-	[-]	k_p	0,02	[-]
	$\sigma_{t,90,d}$	**0,38**	**N/mm²**			
resistance	**reinforcement needed?**			**nominal reinforcement enough?**		
	$k_{dis,1}$	1,40	[-]	$k_{dis,2}$	1,15	[-]
	$k_{vol,1}$	0,39	[-]	$k_{vol,2}$	0,92	[-]
	$f_{t,90,d,1}$	**0,19**	**N/mm²**	$f_{t,90,d,2}$	**0,37**	**N/mm²**
verification	$\eta_{t,90,d,1}$	**2,00**	**[-]**	$\eta_{t,90,d,2}$	**1,03**	**[-]**

Figure 7-20 - Curved Beam – Reinforcement for Tension Perpendicular to the Grain Sheet 1

Reinforcement needed



dimensioning of reinforcement							
number of rows	maximum	8	[-]		selected	2	[-]
resistance of rod	fyd	264	N/mm²		$F_{t,90,fyd,d}$	12.721	N
	fud	291	N/mm²		$F_{t,90,fud,d}$	13.993	N
resistance of glue line	inner two quarter				outer quarter		
	$f_{k,1,d}$	2,77	N/mm²		$f_{k,1,d}$	2,77	N/mm²
	l_{ad}	350	mm		l_{ad}	350	mm
	$F_{t,90,fk1d,d}$	12.194	N		$F_{t,90,fk1d,d}$	12.194	N
decisive value	$\mathbf{F_{t,90,d}}$	**12.194**	**N**		$\mathbf{F_{t,90,d}}$	**12.194**	**N**
spacing	$a_{1,in}$	250	mm		$a_{1,out}$	375	mm
quantity of rods	$n_{1,in}$	12	[-]		$n_{1,out}$	5	[-]

Figure 7-21 - Curved Beam – Reinforcement for Tension Perpendicular to the Grain Sheet 2

7.2.2.3. Pitched Cambered Beam

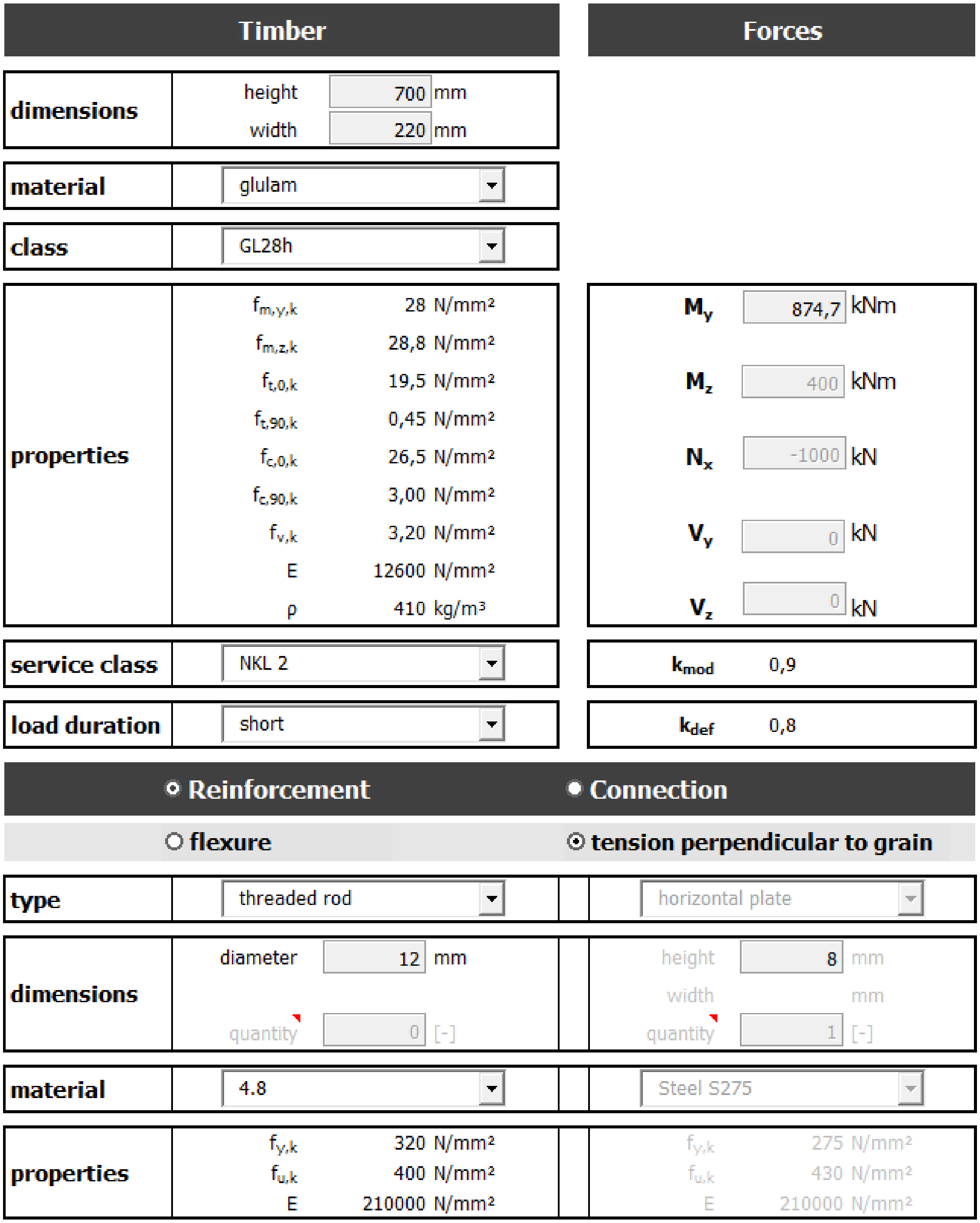


Figure 7-22 - Pitched Cambered Beam - Input Sheet

Reinforcement for Tension Perpendicular to the Grain

beam type	pitched cambered beam	

position	○ **from inside**	⦿ **from above**

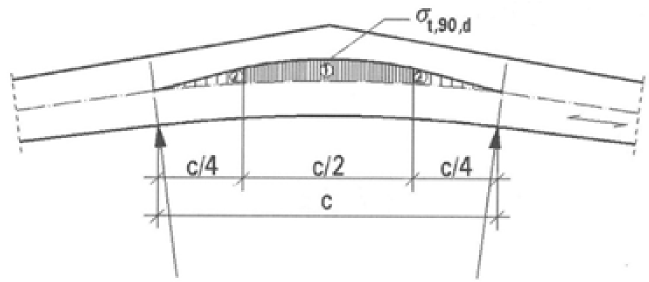
dimensions	l	15 m		c	6.251	mm
	r_{in}	18 m		r	18.974	mm
	h_{ap}	1.948 mm		t	30	mm
	h_c	1.211 mm		V_{beam}	2,21	m^3
angles	upper taper - α	17 °		lower taper - β	10	°

check if reinforcement is needed

load	k_5	0,06 [-]		k_6	0,03	[-]
	k_7	0,27 [-]		k_p	0,07	[-]
	$\sigma_{t,90,d}$	**0,42 N/mm²**				
resistance	**reinforcement needed?**			**nominal reinforcement enough?**		
	$k_{dis,1}$	1,70 [-]		$k_{dis,2}$	1,30	[-]
	$k_{vol,1}$	0,34 [-]		$k_{vol,2}$	0,70	[-]
	$f_{t,90,d,1}$	**0,18 N/mm²**		$f_{t,90,d,2}$	**0,28**	**N/mm²**
verification	$\eta_{t,90,d,1}$	**2,36 [-]**		$\eta_{t,90,d,2}$	**1,49**	**[-]**

Figure 7-23 - Pitched Cambered Beam - Reinforcement for Tension Perpendicular to the Grain Sheet 1

Reinforcement needed



dimensioning of reinforcement

number of rows	maximum	12 [-]		selected	2	[-]
resistance of rod	fyd	264 N/mm²		$F_{t,90,fyd,d}$	22.294	N
	fud	291 N/mm²		$F_{t,90,fud,d}$	24.524	N
resistance of glue line	inner two quarter			outer quarter		
	$f_{k,1,d}$	2,77 N/mm²		$f_{k,1,d}$	2,77	N/mm²
	l_{ad}	672 mm		l_{ad}	575	mm
	$F_{t,90,fk1d,d}$	35.081 N		$F_{t,90,fk1d,d}$	30.033	N
decisive value	$\mathbf{F_{t,90,d}}$	**22.294 N**		$\mathbf{F_{t,90,d}}$	**22.294**	**N**
spacing	$a_{1,in}$	470 mm		$a_{1,out}$	705	mm
quantity of rods	$n_{1,in}$	8 [-]		$n_{1,out}$	4	[-]

Figure 7-24 – Pitched Cambered Beam - Reinforcement for Tension Perpendicular to the Grain Sheet 2

7.2.3. Connection with Rods

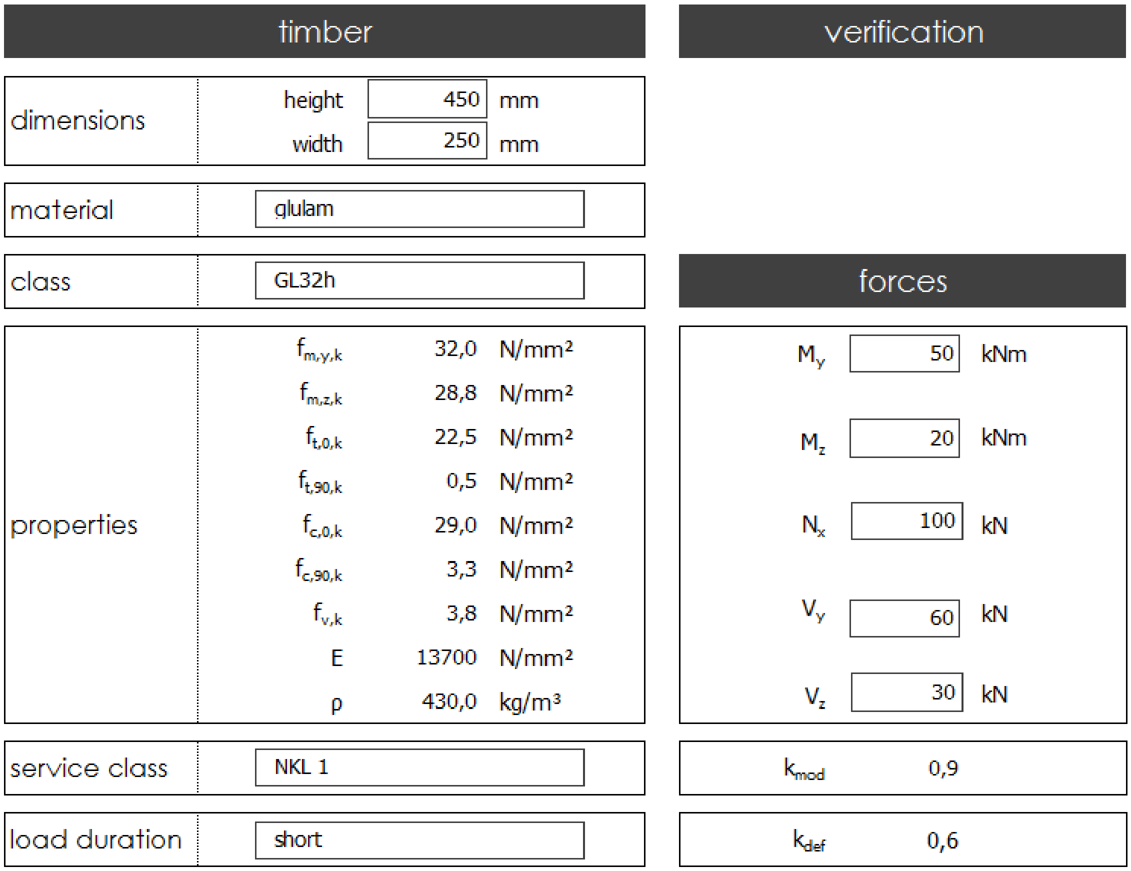


Figure 7-25 – Input sheet for connection with bars - part 1

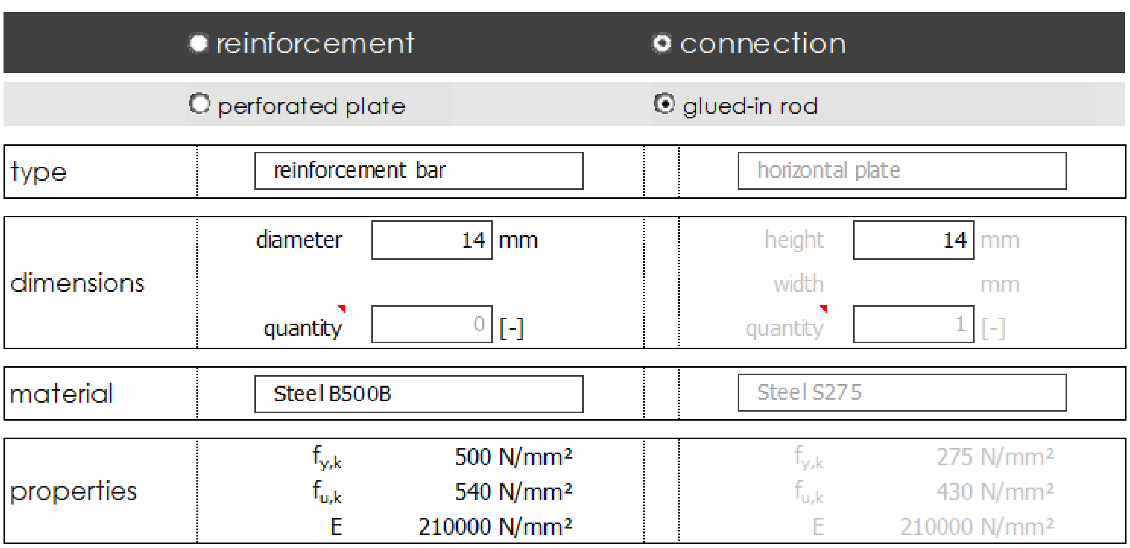
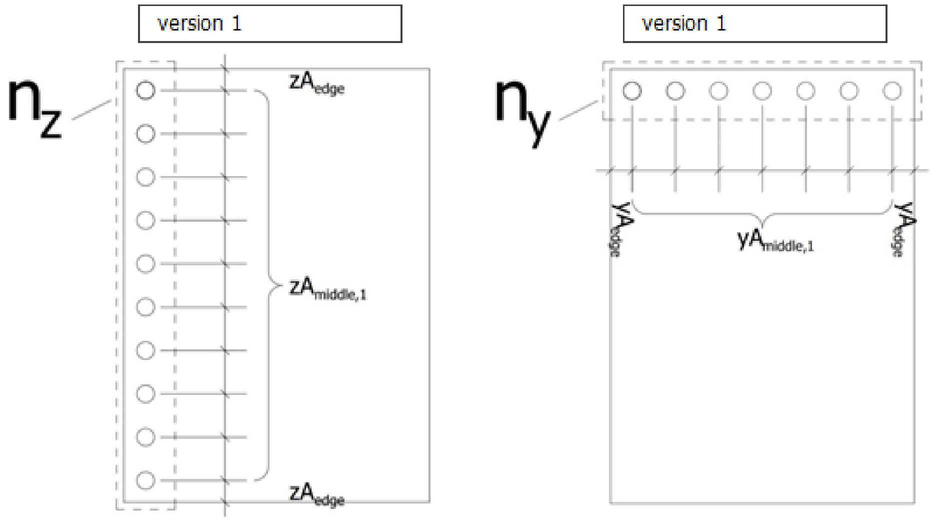


Figure 7-26 - – Input sheet for connection with bars - part 2

Connection with Glued-In Rods



reinforcement bar

	z-axis			y-axis		
quantity	$n_{z,1,max}$	6	[-]	$n_{y,1,max}$	3	[-]
	$n_{z,1}$	6	[-]	$n_{y,1}$	3	[-]
	factor for $n_{z,2}$	1,5	[-]	factor for $n_{y,2}$	1,25	[-]
	$n_{z,2}$	0	[-]	$n_{y,2}$	0	[-]
distance & spacing	zA_{edge}	35	mm	yA_{edge}	35	mm
	$zA_{middle,min}$	70,0	mm	$yA_{middle,min}$	70	mm
	$zA_{middle,1}$	76,0	mm	$yA_{middle,1}$	90,0	mm
	$zA_{middle,2}$	0,0	mm	$yA_{middle,2}$	0,0	mm

Figure 7-27 – Input sheet for connection with bars - part 2

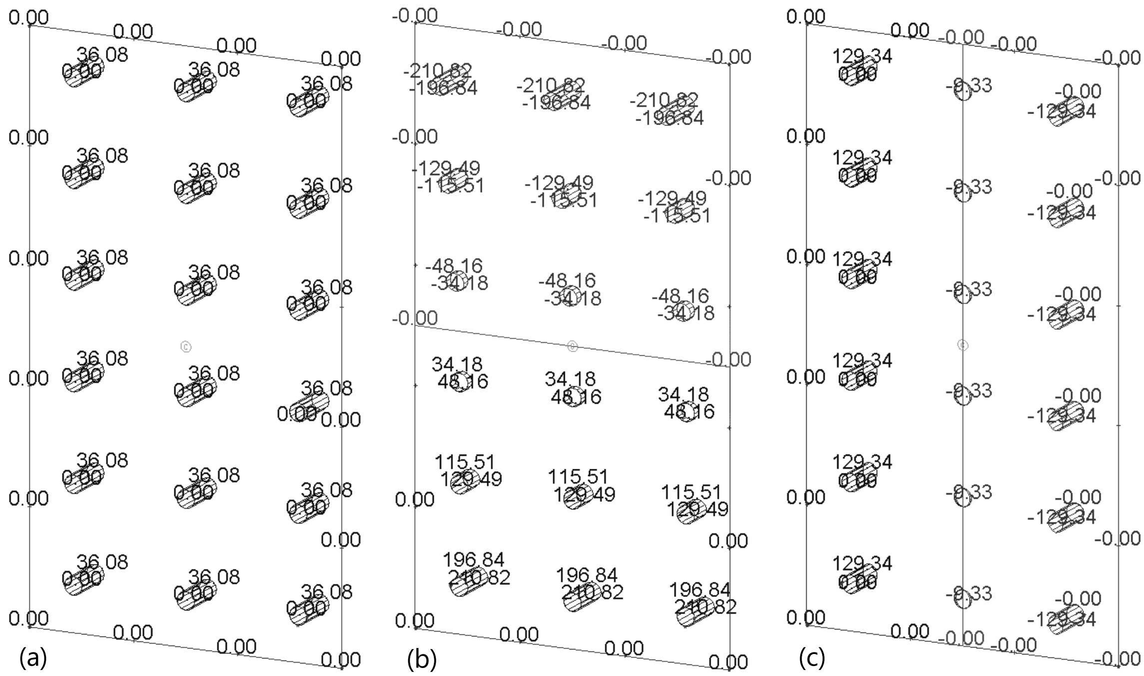


Figure 7-28 - Stress Diagram of Sofistik for (a) normal stresses, (b) bending stress around y-axis and (c) bending stress around z-axis

verification						
moment of inertia	$I_{y,conn}$	46.680.171	mm^4	$I_{z,conn}$	14.996.721	mm^4
	$l_{ad,min}$	140	mm	l_{ad}	1000	mm
	$f_{k,1,k}$	2,00	N/mm²	$f_{h,1,k}$	3,79	N/mm²
	$M_{y,Rk}$	154.685	kNm	$A_{net,t}$	112.248	mm²
axial load	$F_{ax,Rd,S}$	63.611	N	$F_{ax,Ed,N}$	5.556	N
	$F_{ax,Rd,S}$	60.456	N	$F_{ax,Ed,My}$	32.483	N
	$F_{ax,Rd,A}$	60.899	N	$F_{ax,Ed,Mz}$	19.914	N
	$F_{ax,Rd,T}$	97.138	N			
	$F_{ax,Rd}$	60.456	N	$F_{ax,Ed}$	57.952	N
	η_{ax}	0,96				
lateral load	$F_{v,Rd}$	3.358.045	N	$F_{v,Ed}$	0	N
	η_v	0,00				
interaktion	η_{ax+v}	0,92				

Figure 7-29 - Verification of connection with bars

7.2.4. Connection with Plates

timber			
dimensions	height	450	mm
	width	250	mm
material	glulam		
class	GL32h		
properties	$f_{m,y,k}$	32,0	N/mm²
	$f_{m,z,k}$	28,8	N/mm²
	$f_{t,0,k}$	22,5	N/mm²
	$f_{t,90,k}$	0,5	N/mm²
	$f_{c,0,k}$	29,0	N/mm²
	$f_{c,90,k}$	3,3	N/mm²
	$f_{v,k}$	3,8	N/mm²
	E	13700	N/mm²
	ρ	430,0	kg/m³
service class	NKL 1		
load duration	short		

verification

forces		
M_y	50	kNm
M_z	20	kNm
N_x	100	kN
V_y	60	kN
V_z	30	kN
k_{mod}	0,9	
k_{def}	0,6	

Figure 7-30 – General input sheet for connection with plates

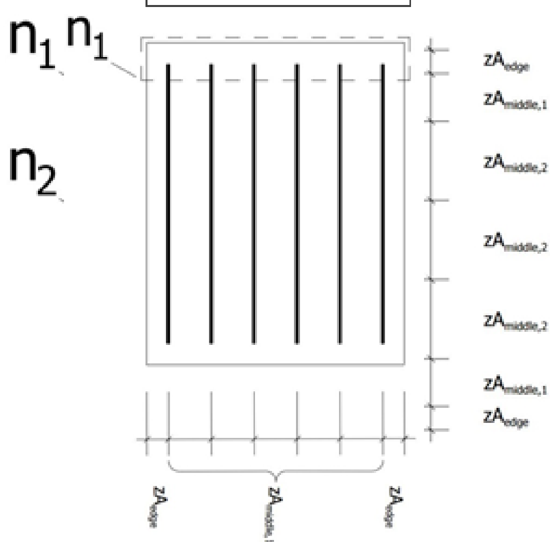
7.2.4.1.1. Connection with vertical plates

	reinforcement			connection		
	perforated plate			glued-in rod		
type	vertical plate			same as top reinforcement		
dimensions	height	20	mm	height	5	mm
	width	200	mm	width	200	mm
	quantity	0	[-]	quantity	1	[-]
material	Steel S235			please choose		
properties	$f_{y,k}$	235	N/mm²	$f_{y,k}$	235	N/mm²
	$f_{u,k}$	360	N/mm²	$f_{u,k}$	360	N/mm²
	E	210000	N/mm²	E	210000	N/mm²

Figure 7-31 - Input sheet for connection with vertical plates part 1

Connection with Perforated Plates

version 1



quantity	$n_{max,1}$	6	[-]	factor for n_2	1,25	[-]
	n_1	6	[-]	n_2	0	[-]
distance & spacing	$zA_{edge,min}$		mm	$zA_{middle,1}$		mm
	$zA_{middle,min}$		mm	$zA_{middle,2}$		mm
distance & spacing	$yA_{edge,min}$	20	mm	$yA_{middle,1}$	42,00	mm
	$yA_{middle,min}$	40	mm	$yA_{middle,2}$	0,00	mm
dimensions	max width	410	mm	max height	300	mm
	width	410	mm	height	300	mm
	d_{AD}	10	mm	thickness	2,5	mm
adhesive dowel	no. in width	28	[-]	no. in height	19	[-]
moment of inertia	$I_{y,conn}$	2.746.250	mm^4	$I_{z,conn}$	10.033.766	mm^4

Figure 7-32 - Input sheet for connection with vertical plates part 2

verification						
	$F_{AD,Rk}$	800	N	$f_{k,1,k}$	3,88	N/mm²
adhesive and timber	**adhesive**			**timber**		
	$F_{AD,Ed,N}$	57	N	$F_{t,Ed}$	482.259	N
	$F_{AD,Ed,V}$	0	N	$F_{t,Rd}$	1.432.392	N
	$F_{AD,Ed,M}$	0	N	η_w	0,34	
	$F_{AD,Ed}$	57	N	$F_{w,BS,Ed}$	16.667	N
	$F_{AD,Rd}$	554	N	$F_{w,bs,Rd}$	397.445	N
	η_{ax}	0,10		η_{ax}	0,04	
steel plate	$F_{SP,Ed,N}$	16.667	N	$F_{SP,Ed,Vy}$	0	N
	$F_{SP,Ed,My}$	384.615	N	$F_{SP,Ed,Vz}$	0	N
	$F_{SP,Ed,Mz}$	80.977	N	$F_{SP,Ed,V}$	0	N
	$F_{SP,Ed}$	482.259	N			
	$F_{SP,Rd}$	69.432	N	$F_{SP,Rd,V}$	105.828	N
	$\eta_{SP,NM}$	6,95		$\eta_{SP,V}$	0,00	
			η_{SP}	6,95		
failure			η	6,95		

Figure 7-33 - - Verification of connection with vertical plates

7.3. Appendix C: Source codes

7.3.1. General

```
Sub input_data()
Application.ScreenUpdating = False
Call service_class_ComboBox_Change

'timber dimensions
h_w = Tabelle1.wood_height_TextBox.Value
b_w = Tabelle1.wood_width_TextBox.Value

If reinf_OptionButton.Value = True Then
'reinforcement dimensions
    h_reinf_top = Tabelle1.height_reinf_top_TextBox.Value
    b_reinf_top = Tabelle1.width_reinf_top_TextBox.Value
    n_reinf_top = Tabelle1.quantity_reinf_top_TextBox.Value

    If Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Or Tabelle1.reinf_type_top_ComboBox
         = "threaded rod" Then
        dia_reinf_top = h_reinf_top
    End If

    h_reinf_bot = Tabelle1.height_reinf_bot_TextBox.Value
    b_reinf_bot = Tabelle1.width_reinf_bot_TextBox.Value
    n_reinf_bot = Tabelle1.quantity_reinf_bot_TextBox.Value

    If Tabelle1.reinf_type_bot_ComboBox = "reinforcement bar" Or Tabelle1.reinf_type_bot_ComboBox
         = "threaded rod" Then
        dia_reinf_bot = h_reinf_bot

    ElseIf Tabelle1.reinf_type_bot_ComboBox = "same as top reinforcement" Then
        If Tabelle1.reinf_type_bot_ComboBox = "reinforcement bar" Or
            Tabelle1.reinf_type_bot_ComboBox = "threaded rod" Then
            dia_reinf_bot = h_reinf_bot
        End If
    End If


ElseIf conn_OptionButton.Value = True Then

'connection dimensions

    If Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Or Tabelle1.reinf_type_top_ComboBox
         = "vertical plate" Or Tabelle1.reinf_type_top_ComboBox = "no top reinforcement" Then
        h_conn = Tabelle1.height_reinf_top_TextBox.Value
        b_conn = Tabelle1.width_reinf_top_TextBox.Value

    ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Or
         Tabelle1.reinf_type_top_ComboBox = "threaded rod" Then
        d_conn = Tabelle1.height_reinf_top_TextBox.Value

    End If

End If

'timber properties
f_w_myk = Tabelle1.Range("E13").Value
f_w_mzk = Tabelle1.Range("E14").Value
f_w_t0k = Tabelle1.Range("E15").Value
f_w_t90k = -Tabelle1.Range("E16").Value
f_w_c0k = Tabelle1.Range("E17").Value
f_w_c90k = -Tabelle1.Range("E18").Value
f_w_vk = Tabelle1.Range("E19").Value
E_w = Tabelle1.Range("E20").Value
rho_k = Tabelle1.Range("E21").Value
beta = 1
gamma_w = 1.3
f_w_myd = calc_f_d(f_w_myk, kmod, gamma_w)
f_w_mzd = calc_f_d(f_w_mzk, kmod, gamma_w)
```

```vba
f_w_t0d = calc_f_d(f_w_t0k, kmod, gamma_w)
f_w_t90d = calc_f_d(f_w_t90k, kmod, gamma_w)
f_w_c0d = calc_f_d(f_w_c0k, kmod, gamma_w)
f_w_c90d = calc_f_d(f_w_c90k, kmod, gamma_w)
f_w_vd = calc_f_d(f_w_vk, kmod, gamma_w)

'reinforcement properties

If Tabelle1.reinf_OptionButton.Value = True Then
    gamma_reinf = 1.1
    gamma_reinf_2 = 1.25

    f_reinf_top_yk = Tabelle1.Range("E73").Value
    f_reinf_top_uk = Tabelle1.Range("E74").Value
    E_reinf_top = Tabelle1.Range("E75").Value
    alpha_top = calc_alpha(E_reinf_top, E_w)

    f_reinf_bot_yk = Tabelle1.Range("I73").Value
    f_reinf_bot_uk = Tabelle1.Range("I74").Value
    E_reinf_bot = Tabelle1.Range("I75").Value
    alpha_bot = calc_alpha(E_reinf_bot, E_w)

    f_reinf_top_yd = calc_f_d(f_reinf_top_yk, 1, 1.1 * gamma_reinf)
    f_reinf_top_ud = calc_f_d(f_reinf_top_uk, 1, 1.1 * gamma_reinf_2)
    f_reinf_bot_yd = calc_f_d(f_reinf_bot_yk, 1, 1.1 * gamma_reinf)
    f_reinf_bot_ud = calc_f_d(f_reinf_bot_uk, 1, 1.1 * gamma_reinf_2)


ElseIf Tabelle1.conn_OptionButton.Value = True Then
    gamma_conn_1 = 1.1
    gamma_conn_2 = 1.25

    f_conn_yk = Tabelle1.Range("E73").Value
    f_conn_uk = Tabelle1.Range("E74").Value
    E_conn = Tabelle1.Range("E75").Value
    alpha = calc_alpha(E_conn, E_w)

    f_conn_yd = calc_f_d(f_conn_yk, 1, 1.1 * gamma_conn_1)
    f_conn_ud = calc_f_d(f_conn_uk, 1, 1.1 * gamma_conn_2)
End If

' external forces
M_y = Tabelle1.My_TextBox.Value
M_z = Tabelle1.Mz_TextBox.Value
N_x = Tabelle1.Nx_TextBox.Value
V_y = Tabelle1.Vy_TextBox.Value
V_z = Tabelle1.Vz_TextBox.Value

' areas
A_w = calc_A(1, h_w, b_w)

' moment of inertia
I_y_wood = calc_I_y_rec(1, 1, b_w, h_w)
I_z_wood = calc_I_z_rec(1, 1, b_w, h_w)

Application.ScreenUpdating = True

Tabelle1.Range("B90").Value = wood_type_ComboBox.Value
Tabelle1.Range("B91").Value = wood_class_ComboBox.Value
Tabelle1.Range("B92").Value = service_class_ComboBox.Value
Tabelle1.Range("B93").Value = loading_duration_ComboBox.Value
Tabelle1.Range("B94").Value = reinf_type_top_ComboBox.Value
Tabelle1.Range("B95").Value = reinf_mat_top_ComboBox.Value
Tabelle1.Range("B96").Value = reinf_type_bot_ComboBox.Value
Tabelle1.Range("B97").Value = reinf_mat_bot_ComboBox.Value
End Sub

' ######### COMBOBOXES ######################################################

' ###### WOOD ComboBoxes ######
```

```vba
Sub wood_comboboxes()
      Call fillwoodtype
End Sub
```

```vba
Private Sub fillwoodtype()
      Call fillwoodComboBox(Tabelle4, 1, Tabelle1.wood_type_ComboBox)
      If Tabelle1.wood_type_ComboBox.ListCount >= 1 Then Tabelle1.wood_type_ComboBox.ListIndex = 0
End Sub
```

```vba
Private Sub wood_type_ComboBox_Change()
      Tabelle1.wood_class_ComboBox.Clear
      If Tabelle1.wood_type_ComboBox.ListIndex = -1 Then Exit Sub
      Call fillwoodComboBox(Tabelle4, 2, Tabelle1.wood_class_ComboBox, 1,
            Tabelle1.wood_type_ComboBox.Text)
      If Tabelle1.wood_class_ComboBox.ListCount >= 1 Then Tabelle1.wood_class_ComboBox.ListIndex =
            0
If Tabelle1.wood_type_ComboBox.Value = "glulam" Then
    Range("E14").Value = Range("E13").Value * 1.2
Else
    Range("E14").Value = Range("E13").Value
End If
End Sub
```

```vba
Private Sub fillwoodComboBox(ByRef oSheet As Object, ByVal lColumn As Long, ByRef oComboBox As
  Object, Optional ByVal lColBedingung1 As Long = 0, Optional ByVal sBedingung1 As String = "")
    Dim z As Long
    Dim zMax As Long
    Dim bFlag As Boolean
      oComboBox.Clear
      zMax = oSheet.UsedRange.Row + oSheet.UsedRange.Rows.Count - 1
      For z = 2 To zMax
          If CStr(oSheet.Cells(z, lColumn).Value) <> "" Then
              bFlag = True
              If lColBedingung1 <> 0 Then
                  If CStr(oSheet.Cells(z, lColBedingung1)) <> sBedingung1 Then
                      bFlag = False
                  End If
              End If
              If bFlag = True Then
                  Call NoDuplicatesToWoodComboBox(oComboBox, oSheet.Cells(z, lColumn).Value)
              End If
          End If
      Next z
End Sub
```

```vba
Private Sub NoDuplicatesToWoodComboBox(ByRef oComboBox As Object, ByVal sAddText As String)
      Dim i As Long
      Dim bFlag As Boolean
          If oComboBox.ListCount = 0 Then
              oComboBox.AddItem sAddText
          Else
              bFlag = False
              For i = 0 To oComboBox.ListCount - 1
                  If CStr(oComboBox.List(i)) = CStr(sAddText) Then
                      bFlag = True
                      Exit For
                  End If
              Next i
              If bFlag = False Then
                  oComboBox.AddItem sAddText
              End If
          End If
End Sub
```

```vba
Sub wood_class_ComboBox_Change()
    Dim RowIndex As Integer
        RowIndex = 2
    Do Until RowIndex = 18
    If Tabelle4.Cells(RowIndex, 2).Value = Tabelle1.wood_class_ComboBox.Value Then
        Exit Do
            End If
```

```
        RowIndex = RowIndex + 1
    Loop
Tabelle1.Range("E13").Value = Tabelle4.Cells(RowIndex, 3).Value
Tabelle1.Range("E15").Value = Tabelle4.Cells(RowIndex, 4).Value
Tabelle1.Range("E16").Value = Tabelle4.Cells(RowIndex, 5).Value
Tabelle1.Range("E17").Value = Tabelle4.Cells(RowIndex, 6).Value
Tabelle1.Range("E18").Value = Tabelle4.Cells(RowIndex, 7).Value
Tabelle1.Range("E19").Value = Tabelle4.Cells(RowIndex, 8).Value
Tabelle1.Range("E20").Value = Tabelle4.Cells(RowIndex, 9).Value
Tabelle1.Range("E21").Value = Tabelle4.Cells(RowIndex, 10).Value
End Sub

' ###### STEEL ComboBoxes ######

' Filling ComboBoxes Top
```

```
Sub reinf_top_comboboxes()
     Call fillreinftoptype
End Sub
```

```
Private Sub fillreinftoptype()
     Call fillreinftopComboBox(Tabelle5, 1, Tabelle1.reinf_type_top_ComboBox)
     If          Tabelle1.reinf_type_top_ComboBox.ListCount          >=          1          Then
           Tabelle1.reinf_type_top_ComboBox.ListIndex = 0
End Sub
```

```
Private Sub reinf_type_top_ComboBox_Change()

     Tabelle1.reinf_mat_top_ComboBox.Clear
     If Tabelle1.reinf_type_top_ComboBox.ListIndex = -1 Then Exit Sub
     Call      fillreinftopComboBox(Tabelle5,      2,      Tabelle1.reinf_mat_top_ComboBox,      1,
           Tabelle1.reinf_type_top_ComboBox.Text)
     If          Tabelle1.reinf_mat_top_ComboBox.ListCount          >=          1          Then
           Tabelle1.reinf_mat_top_ComboBox.ListIndex = 0

' height and width or diameter
If  Tabelle1.reinf_type_top_ComboBox  =  "horizontal  plate"  Or  Tabelle1.reinf_type_top_ComboBox  =
  "vertical plate" Then
    Tabelle1.Range("D67:F75").Font.ColorIndex = 1
    Tabelle1.Range("D68:F68").Font.ColorIndex = 1

    Tabelle1.reinf_mat_top_ComboBox.Enabled = True
    Tabelle1.height_reinf_top_TextBox.Enabled = True
    Tabelle1.width_reinf_top_TextBox.Visible = True
    Tabelle1.width_reinf_top_TextBox.Enabled = True
    Tabelle1.quantity_reinf_top_TextBox.Enabled = True

    Tabelle1.Range("D67").Value = "height"
    Tabelle1.Range("D68").Value = "width"
    Tabelle1.Range("D69").Value = "quantity"

    If Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Then
        Tabelle1.quantity_reinf_top_TextBox.Value = 1
        Tabelle1.quantity_reinf_top_TextBox.Enabled = False
    End If

ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Or Tabelle1.reinf_type_top_ComboBox
  = "threaded rod" Then
    Tabelle1.Range("D67:F75").Font.ColorIndex = 1
    Tabelle1.Range("D68:F68").Font.ColorIndex = 2

    Tabelle1.reinf_mat_top_ComboBox.Enabled = True
    Tabelle1.height_reinf_top_TextBox.Enabled = True
    Tabelle1.width_reinf_top_TextBox.Visible = False
    Tabelle1.quantity_reinf_top_TextBox.Enabled = True

    Tabelle1.Range("D67").Value = "diameter"
    Tabelle1.Range("D69").Value = "quantity"
```

```
ElseIf Tabelle1.reinf_type_top_ComboBox = "please choose" Or Tabelle1.reinf_type_top_ComboBox =
  "no top reinforcement" Then
    Tabelle1.Range("D67:F75").Font.ColorIndex = 15

    Tabelle1.reinf_mat_top_ComboBox.Enabled = False
    Tabelle1.height_reinf_top_TextBox.Enabled = False
    Tabelle1.width_reinf_top_TextBox.Enabled = False
    Tabelle1.quantity_reinf_top_TextBox.Enabled = False
    Tabelle1.quantity_reinf_top_TextBox.Value = 0

    If Tabelle1.subtype2_OptionButton.Value = True Then
        Tabelle1.Range("D67").Value = "diameter"
        Tabelle1.Range("D69").Value = "quantity"
        Tabelle1.width_reinf_top_TextBox.Visible = False
    ElseIf Tabelle1.subtype1_OptionButton = True Then
        Tabelle1.Range("D67").Value = "height"
        Tabelle1.Range("D68").Value = "width"
        Tabelle1.Range("D69").Value = "quantity"
        Tabelle1.width_reinf_top_TextBox.Visible = True
    End If
End If

If Tabelle1.reinf_OptionButton.Value = True Then

    If Tabelle1.subtype1_OptionButton.Value = True Then
        Call reinf_type_bot_ComboBox_Change

    ElseIf Tabelle1.subtype2_OptionButton.Value = True Then
        Tabelle1.Range("D68:F68").Font.ColorIndex = 2
        Tabelle1.Range("D69:F69").Font.ColorIndex = 15
        Tabelle1.width_reinf_top_TextBox.Visible = False
        Tabelle1.quantity_reinf_top_TextBox.Enabled = False
    End If


ElseIf Tabelle1.conn_OptionButton.Value = True Then
    Tabelle1.quantity_reinf_top_TextBox.Enabled = False
    If Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Or Tabelle1.reinf_type_top_ComboBox
       = "vertical plate" Then
        Tabelle1.height_reinf_top_TextBox.Enabled = False
        Tabelle1.width_reinf_top_TextBox.Enabled = False
        Tabelle1.quantity_reinf_top_TextBox.Enabled = False
        MsgBox "Please enter the dimensions into the next sheet", , "DIMENSIONS OF PERFORATED
             PLATE"

    ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Or
       Tabelle1.reinf_type_top_ComboBox = "threaded rod" Then
        Tabelle1.Range("D68:F68").Font.ColorIndex = 2
        Tabelle1.width_reinf_top_TextBox.Visible = False
    End If
End If
End Sub
```

```
Private Sub fillreinftopComboBox(ByRef oSheet As Object, ByVal lColumn As Long, ByRef oComboBox
  As Object, Optional ByVal lColBedingung1 As Long = 0, Optional ByVal sBedingung1 As String =
  "")
    Dim z As Long
    Dim zMin As Long
    Dim zMax As Long
    Dim bFlag As Boolean
      oComboBox.Clear
    If reinf_OptionButton.Value = True Then
        If subtype1_OptionButton.Value = True Then
            zMin = 3
            zMax = 24
        ElseIf subtype2_OptionButton.Value = True Then
            zMin = 199
            zMax = 211
        End If
    ElseIf conn_OptionButton.Value = True Then
        If subtype1_OptionButton.Value = True Then
```

```
            zMin = 161
            zMax = 168
        ElseIf subtype2_OptionButton.Value = True Then
            zMin = 109
            zMax = 121
        End If
    End If
        For z = zMin To zMax
            If CStr(oSheet.Cells(z, lColumn).Value) <> "" Then
              bFlag = True
              If lColBedingung1 <> 0 Then
                  If CStr(oSheet.Cells(z, lColBedingung1)) <> sBedingung1 Then
                      bFlag = False
                  End If
              End If
              If bFlag = True Then
                  Call NoDuplicatesToReinfTopComboBox(oComboBox, oSheet.Cells(z, lColumn).Value)
              End If
          End If
      Next z
End Sub
```

```
Private Sub NoDuplicatesToReinfTopComboBox(ByRef oComboBox As Object, ByVal sAddText As String)
      Dim i As Long
      Dim bFlag As Boolean
          If oComboBox.ListCount = 0 Then
              oComboBox.AddItem sAddText
          Else
              bFlag = False
              For i = 0 To oComboBox.ListCount - 1
                  If CStr(oComboBox.List(i)) = CStr(sAddText) Then
                      bFlag = True
                      Exit For
                  End If
              Next i
              If bFlag = False Then
                  oComboBox.AddItem sAddText
              End If
          End If
End Sub

' Filling ComboBoxes Bottom
```

```
Sub reinf_bot_comboboxes()
      Call fillreinfbottype
End Sub
```

```
Private Sub fillreinfbottype()
      Call fillreinfbotComboBox(Tabelle5, 1, Tabelle1.reinf_type_bot_ComboBox)
      If          Tabelle1.reinf_type_bot_ComboBox.ListCount          >=          1          Then
            Tabelle1.reinf_type_bot_ComboBox.ListIndex = 0
End Sub
```

```
Private Sub reinf_type_bot_ComboBox_Change()
      Tabelle1.reinf_mat_bot_ComboBox.Clear
      If Tabelle1.reinf_type_bot_ComboBox.ListIndex = -1 Then Exit Sub
      Call      fillreinfbotComboBox(Tabelle5,      2,      Tabelle1.reinf_mat_bot_ComboBox,      1,
            Tabelle1.reinf_type_bot_ComboBox.Text)
      If          Tabelle1.reinf_mat_bot_ComboBox.ListCount          >=          1          Then
            Tabelle1.reinf_mat_bot_ComboBox.ListIndex = 0

' height and width or diameter

If  Tabelle1.reinf_type_bot_ComboBox  =  "horizontal  plate"  Or  Tabelle1.reinf_type_bot_ComboBox  =
  "vertical plate" Then
    Tabelle1.Range("H67:J75").Font.ColorIndex = 1
    Tabelle1.Range("H68:J68").Font.ColorIndex = 1

    Tabelle1.reinf_mat_bot_ComboBox.Enabled = True
    Tabelle1.height_reinf_bot_TextBox.Enabled = True
```

```
    Tabelle1.width_reinf_bot_TextBox.Enabled = True
    Tabelle1.width_reinf_bot_TextBox.Visible = True
    Tabelle1.quantity_reinf_bot_TextBox.Enabled = True

    Tabelle1.Range("H67").Value = "height"
    Tabelle1.Range("H68").Value = "width"
    Tabelle1.Range("H69").Value = "quantity"

    If Tabelle1.reinf_type_bot_ComboBox = "horizontal plate" Then
        Tabelle1.quantity_reinf_bot_TextBox.Value = 1
        Tabelle1.quantity_reinf_bot_TextBox.Enabled = False
    End If
ElseIf Tabelle1.reinf_type_bot_ComboBox = "reinforcement bar" Or Tabelle1.reinf_type_bot_ComboBox
  = "threaded rod" Then
    Tabelle1.Range("H67:J75").Font.ColorIndex = 1
    Tabelle1.Range("H68:J68").Font.ColorIndex = 2

    Tabelle1.reinf_mat_bot_ComboBox.Enabled = True
    Tabelle1.height_reinf_bot_TextBox.Enabled = True
    Tabelle1.width_reinf_bot_TextBox.Visible = False
    Tabelle1.quantity_reinf_bot_TextBox.Enabled = True

    Tabelle1.Range("H67").Value = "diameter"
    Tabelle1.Range("H69").Value = "quantity"

ElseIf Tabelle1.reinf_type_bot_ComboBox = "no bottom reinforcement" Then
    Tabelle1.Range("H67:J75").Font.ColorIndex = 15

    Tabelle1.reinf_mat_bot_ComboBox.Enabled = False
    Tabelle1.height_reinf_bot_TextBox.Enabled = False
    Tabelle1.width_reinf_bot_TextBox.Visible = True
    Tabelle1.quantity_reinf_bot_TextBox.Enabled = False
    Tabelle1.quantity_reinf_bot_TextBox.Value = 0

    Tabelle1.Range("H67").Value = "height"
    Tabelle1.Range("H68").Value = "width"
    Tabelle1.Range("H69").Value = "quantity"

ElseIf Tabelle1.reinf_type_bot_ComboBox = "same as top reinforcement" Then
    Tabelle1.height_reinf_bot_TextBox.Value = Tabelle1.height_reinf_top_TextBox.Value
    Tabelle1.width_reinf_bot_TextBox.Value = Tabelle1.width_reinf_top_TextBox.Value
    Tabelle1.quantity_reinf_bot_TextBox.Value = Tabelle1.quantity_reinf_top_TextBox.Value

    Tabelle1.reinf_mat_bot_ComboBox.Enabled = False
    Tabelle1.height_reinf_bot_TextBox.Enabled = False
    Tabelle1.width_reinf_bot_TextBox.Visible = True
    Tabelle1.width_reinf_bot_TextBox.Enabled = False
    Tabelle1.quantity_reinf_bot_TextBox.Enabled = False

    If Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Or Tabelle1.reinf_type_top_ComboBox
        = "vertical plate" Then
        Tabelle1.Range("H67:J75").Font.ColorIndex = 1
        Tabelle1.Range("H68:J68").Font.ColorIndex = 1

        Tabelle1.Range("H67").Value = "height"
        Tabelle1.Range("H68").Value = "width"
        Tabelle1.Range("H69").Value = "quantity"

        If Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Then
            Tabelle1.quantity_reinf_bot_TextBox.Value = 1
            Tabelle1.quantity_reinf_bot_TextBox.Enabled = False
        End If

    ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Or
        Tabelle1.reinf_type_top_ComboBox = "threaded rod" Then
        Tabelle1.Range("H67:J75").Font.ColorIndex = 1
        Tabelle1.Range("H68:J68").Font.ColorIndex = 2

        Tabelle1.width_reinf_bot_TextBox.Visible = False

        Tabelle1.Range("H67").Value = "diameter"
```

```
        Tabelle1.Range("H69").Value = "quantity"

    ElseIf Tabelle1.reinf_type_top_ComboBox = "no top reinforcement" Or
         Tabelle1.reinf_type_top_ComboBox = "please choose" Then
        Tabelle1.Range("H67:J75").Font.ColorIndex = 15

        Tabelle1.quantity_reinf_bot_TextBox.Value = 0

        Tabelle1.Range("H67").Value = "height"
        Tabelle1.Range("H68").Value = "width"
        Tabelle1.Range("H69").Value = "quantity"
    End If

End If

Call Tabelle2.num_top_layer
End Sub
```

```
Private Sub fillreinfbotComboBox(ByRef oSheet As Object, ByVal lColumn As Long, ByRef oComboBox
  As Object, Optional ByVal lColBedingung1 As Long = 0, Optional ByVal sBedingung1 As String =
  "")
    Dim z As Long
    Dim zMin As Long
    Dim zMax As Long
    Dim bFlag As Boolean
      oComboBox.Clear
    If reinf_OptionButton.Value = True Or conn_OptionButton.Value = True Then
        zMin = 55
        zMax = 74
    End If
        For z = zMin To zMax
          If CStr(oSheet.Cells(z, lColumn).Value) <> "" Then
              bFlag = True
              If lColBedingung1 <> 0 Then
                  If CStr(oSheet.Cells(z, lColBedingung1)) <> sBedingung1 Then
                      bFlag = False
                  End If
              End If
              If bFlag = True Then
                  Call NoDuplicatesToReinfBotComboBox(oComboBox, oSheet.Cells(z, lColumn).Value)
              End If
          End If
      Next z
End Sub
```

```
Private Sub NoDuplicatesToReinfBotComboBox(ByRef oComboBox As Object, ByVal sAddText As String)
      Dim i As Long
      Dim bFlag As Boolean
          If oComboBox.ListCount = 0 Then
              oComboBox.AddItem sAddText
          Else
              bFlag = False
              For i = 0 To oComboBox.ListCount - 1
                  If CStr(oComboBox.List(i)) = CStr(sAddText) Then
                      bFlag = True
                      Exit For
                  End If
              Next i
              If bFlag = False Then
                  oComboBox.AddItem sAddText
              End If
          End If
End Sub

' REINFORCEMENT Material ComboBoxes
```

```
Sub reinf_mat_top_ComboBox_Change()
    Dim RowIndex As Integer
        RowIndex = 3
    Do Until RowIndex = 23
```

```
    If Tabelle1.reinf_mat_top_ComboBox.Value = "please choose" Or
        Tabelle1.reinf_mat_top_ComboBox.Value = "user defined" Then
        Tabelle1.Range("E73").Value = ""
        Tabelle1.Range("E74").Value = ""
        Tabelle1.Range("E75").Value = ""
            Exit Do

    ElseIf Tabelle5.Cells(RowIndex, 2).Value = Tabelle1.reinf_mat_top_ComboBox.Value Then
        Tabelle1.Range("E73").Value = Tabelle5.Cells(RowIndex, 3).Value
        Tabelle1.Range("E74").Value = Tabelle5.Cells(RowIndex, 4).Value
        Tabelle1.Range("E75").Value = Tabelle5.Cells(RowIndex, 5).Value
            Exit Do
                End If
        RowIndex = RowIndex + 1
    Loop
Call reinf_mat_bot_ComboBox_Change
End Sub
```

```
Sub reinf_mat_bot_ComboBox_Change()
    Dim RowIndex As Integer
        RowIndex = 56
    Do Until RowIndex = 76

    If Tabelle1.reinf_type_bot_ComboBox.Value = "same as top reinforcement" Then
        Tabelle1.Range("I73").Value = Tabelle1.Range("E73").Value
        Tabelle1.Range("I74").Value = Tabelle1.Range("E74").Value
        Tabelle1.Range("I75").Value = Tabelle1.Range("E75").Value
            Exit Do
    ElseIf Tabelle1.reinf_type_bot_ComboBox.Value = "no bottom reinforcement" Then
        Tabelle1.Range("I73").Value = ""
        Tabelle1.Range("I74").Value = ""
        Tabelle1.Range("I75").Value = ""
            Exit Do

    ElseIf Tabelle5.Cells(RowIndex, 2).Value = Tabelle1.reinf_mat_bot_ComboBox.Value Then
        Tabelle1.Range("I73").Value = Tabelle5.Cells(RowIndex, 3).Value
        Tabelle1.Range("I74").Value = Tabelle5.Cells(RowIndex, 4).Value
        Tabelle1.Range("I75").Value = Tabelle5.Cells(RowIndex, 5).Value
            Exit Do
                End If
        RowIndex = RowIndex + 1
    Loop
End Sub
' ##### k_mod and k_def #####
```

```
Private Sub service_class_ComboBox_Change()
    Call loading_duration_ComboBox_Change
End Sub
```

```
Private Sub loading_duration_ComboBox_Change()
If Tabelle1.service_class_ComboBox.Value = "NKL 1" Then
    kdef = 0.6
    If Tabelle1.loading_duration_ComboBox.Value = "permanent" Then
        kmod = 0.6
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "long" Then
        kmod = 0.7
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "medium" Then
        kmod = 0.8
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "short" Then
        kmod = 0.9
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "very short" Then
        kmod = 1.1
    End If
ElseIf Tabelle1.service_class_ComboBox.Value = "NKL 2" Then
    kdef = 0.8
    If Tabelle1.loading_duration_ComboBox.Value = "permanent" Then
        kmod = 0.6
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "long" Then
        kmod = 0.7
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "medium" Then
```

```
        kmod = 0.8
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "short" Then
        kmod = 0.9
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "very short" Then
        kmod = 1.1
    End If

ElseIf Tabelle1.service_class_ComboBox.Value = "NKL 3" Then
    kdef = 2
    If Tabelle1.loading_duration_ComboBox.Value = "permanent" Then
        kmod = 0.5
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "long" Then
        kmod = 0.55
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "medium" Then
        kmod = 0.65
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "short" Then
        kmod = 0.7
    ElseIf Tabelle1.loading_duration_ComboBox.Value = "very short" Then
        kmod = 0.9
    End If
End If

Tabelle1.Range("I26").Value = kdef
Tabelle1.Range("I24").Value = kmod
End Sub

' ##### choose of calculation #####
```

```
Sub reinf_OptionButton_click()
If reinf_OptionButton.Value = True Then
    Tabelle3.Visible = xlSheetVeryHidden
    Tabelle7.Visible = xlSheetVeryHidden

    Tabelle1.Range("D67:J75").Font.ColorIndex = 15
    Tabelle1.Range("G71").Font.ColorIndex = 2

    reinf_mat_bot_ComboBox.Enabled = False

    Tabelle1.subtype1_OptionButton.Caption = "flexure"
    Tabelle1.subtype2_OptionButton.Caption = "tension perpendicular to grain"

    If subtype1_OptionButton.Value = True Then

        Call Tabelle1.reinf_bot_comboboxes

        Tabelle1.Rows("63:64").EntireRow.Hidden = False
        Tabelle1.Range("E63").Value = "Top"
        Tabelle1.Range("I63").Value = "Bottom"

        Tabelle1.reinf_type_bot_ComboBox.Enabled = True
        Tabelle1.width_reinf_top_TextBox.Visible = True
        Tabelle1.width_reinf_bot_TextBox.Visible = True

        Tabelle1.Mz_TextBox.Enabled = True
        Tabelle1.Nx_TextBox.Enabled = True
        Tabelle1.Vy_TextBox.Enabled = True
        Tabelle1.Vz_TextBox.Enabled = True
        Tabelle2.Visible = xlSheetVisible
        Tabelle6.Visible = xlSheetVeryHidden
    ElseIf subtype2_OptionButton.Value = True Then

        Tabelle1.Rows("63:64").EntireRow.Hidden = True

        Tabelle1.reinf_type_bot_ComboBox.Enabled = False

        Tabelle1.width_reinf_top_TextBox.Visible = False
        Tabelle1.width_reinf_bot_TextBox.Visible = False
        Tabelle1.Mz_TextBox.Enabled = False
        Tabelle1.Nx_TextBox.Enabled = False
        Tabelle1.Vy_TextBox.Enabled = False
        Tabelle1.Vz_TextBox.Enabled = False
```

```
        Tabelle2.Visible = xlSheetVeryHidden
        Tabelle6.Visible = xlSheetVisible

        MsgBox "'height' describes the height of the beam at the bearing", , "DEFINITION OF THE
              HEIGHT"
    End If
End If
End Sub
```

```
Sub conn_OptionButton_Click()
If conn_OptionButton.Value = True Then

    Tabelle2.Visible = xlSheetVeryHidden
    Tabelle6.Visible = xlSheetVeryHidden
    Tabelle1.Rows("63:64").EntireRow.Hidden = True

    Tabelle1.reinf_type_bot_ComboBox.Enabled = False
    Tabelle1.reinf_mat_bot_ComboBox.Enabled = False

    Tabelle1.Range("D67:J75").Font.ColorIndex = 15
    Tabelle1.Range("G71").Font.ColorIndex = 2

    Tabelle1.subtype1_OptionButton.Caption = "perforated plate"
    Tabelle1.subtype2_OptionButton.Caption = "glued-in rod"
    Tabelle4.Visible = xlSheetVeryHidden
    Tabelle5.Visible = xlSheetVeryHidden

    If subtype1_OptionButton.Value = True Then

        Tabelle1.width_reinf_top_TextBox.Visible = True
        Tabelle1.width_reinf_bot_TextBox.Visible = True

        Tabelle1.Mz_TextBox.Enabled = True
        Tabelle1.Nx_TextBox.Enabled = True
        Tabelle1.Vy_TextBox.Enabled = True
        Tabelle1.Vz_TextBox.Enabled = True
        Tabelle3.Visible = xlSheetVeryHidden
        Tabelle7.Visible = xlSheetVisible

    ElseIf subtype2_OptionButton.Value = True Then

        Tabelle1.width_reinf_top_TextBox.Visible = False
        Tabelle1.width_reinf_bot_TextBox.Visible = False

        Tabelle1.Mz_TextBox.Enabled = True
        Tabelle1.Nx_TextBox.Enabled = True
        Tabelle1.Vy_TextBox.Enabled = True
        Tabelle1.Vz_TextBox.Enabled = True

        Tabelle3.Visible = xlSheetVisible
        Tabelle7.Visible = xlSheetVeryHidden
    End If
End If
End Sub
```

```
Private Sub subtype1_OptionButton_Click()
If reinf_OptionButton.Value = True Then
    Call reinf_OptionButton_click

ElseIf conn_OptionButton.Value = True Then
    Call conn_OptionButton_Click
End If

Call reinf_top_comboboxes
End Sub
```

```
Private Sub subtype2_OptionButton_Click()

If reinf_OptionButton.Value = True Then
    Call reinf_OptionButton_click
```

```
ElseIf conn_OptionButton.Value = True Then
    Call conn_OptionButton_Click
End If

Call reinf_top_comboboxes
End Sub
```

```
Private Sub width_reinf_top_TextBox_lostfocus()
If reinf_OptionButton.Value = True And subtype1_OptionButton.Value = True Then
    Call height_reinf_top_TextBox_lostfocus
End If
End Sub
```

```
Private Sub quantity_reinf_top_TextBox_lostfocus()
If reinf_OptionButton.Value = True And subtype1_OptionButton.Value = True Then
    Call height_reinf_top_TextBox_lostfocus
End If
End Sub
```

```
Private Sub height_reinf_top_TextBox_lostfocus()
If    reinf_OptionButton.Value    =    True    And    subtype1_OptionButton.Value    =    True    And
  Tabelle1.reinf_type_bot_ComboBox.Value = "same as top reinforcement" Then
    'Call height_reinf_top_TextBox_lostfocus
    Tabelle1.height_reinf_bot_TextBox.Value = Tabelle1.height_reinf_top_TextBox.Value
    Tabelle1.width_reinf_bot_TextBox.Value = Tabelle1.width_reinf_top_TextBox.Value
    Tabelle1.quantity_reinf_bot_TextBox.Value = Tabelle1.quantity_reinf_top_TextBox.Value
End If
End Sub
' ########### basic formulae #######################
' ######### cross section ##########################
```

```
Public Function calc_h(h_w, h_reinf_top, h_reinf_bot)
    calc_h = h_w + h_reinf_top + h_reinf_bot
End Function
```

```
Public Function calc_alpha(E_reinf, E_w)
    calc_alpha = E_reinf / E_w
End Function
```

```
Public Function calc_A(n, h, b)
    calc_A = n * h * b
End Function
```

```
Public Function calc_A_circ(n, d)
    calc_A_circ = n * pi * (d ^ 2) / 4
End Function
```

```
Public Function calc_A_fakt(A, alpha)
    calc_A_fakt = A * alpha
End Function
```

```
Public Function calc_NA_z(A_w, h, A_reinf_fakt_top, z_reinf_top, A_reinf_fakt_bot, z_reinf_bot)
    calc_NA_z = (A_w * h / 2 + A_reinf_fakt_top * z_reinf_top + A_reinf_fakt_bot * z_reinf_bot) /
          (A_w + A_reinf_fakt_top + A_reinf_fakt_bot)
End Function
```

```
Public Function calc_NA_y(A_w, b, A_reinf_fakt_top, y_reinf_top, A_reinf_fakt_bot, y_reinf_bot)
    calc_NA_y = (A_w * b / 2 + A_reinf_fakt_top * y_reinf_top + A_reinf_fakt_bot * y_reinf_bot) /
          (A_w + A_reinf_fakt_top + A_reinf_fakt_bot)
End Function

' ######## Others #####################################
```

```
Public Function calc_f_d(f_k, kmod, gamma)
    calc_f_d = kmod * f_k / gamma
End Function
```

```
Public Function calc_z_reinf(h, zA)
    calc_z_reinf = h - zA
End Function
```

```
Public Function calc_yA_reinf_middle(b_w, yA_reinf_right, yA_reinf_left, n_reinf)
    calc_yA_reinf_middle = (b_w - yA_reinf_right - yA_reinf_left) / (n_reinf - 1)
End Function
```

7.3.2. Reinforcement for Flexure

```
Sub worksheet_activate()
    If Tabelle1.wood_type_ComboBox.Value = "please choose" Or Tabelle1.wood_class_ComboBox.Value
        = "please choose" Then
        MsgBox "Please choose the material for the cross-section"
        Tabelle1.Select
        Exit Sub

    ElseIf Tabelle1.service_class_ComboBox.Value = "please choose" Or
        Tabelle1.loading_duration_ComboBox.Value = "please choose" Then
        MsgBox "Please the service class and/or load duration"
        Tabelle1.Select
        Exit Sub

    ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "please choose" Then
        MsgBox "Please choose the top reinforcement"
        Tabelle1.Select
        Exit Sub
    ElseIf Tabelle1.reinf_type_bot_ComboBox.Value = "please choose" Then
        MsgBox "please choose the bottom reinforcement"
        Tabelle1.Select
        Exit Sub

    ElseIf Tabelle1.reinf_type_top_ComboBox.Value <> "no top reinforcement" And
        Tabelle1.Range("E73") = "" Then
        MsgBox "Please enter the properties of the rod"
        Tabelle1.Select
        Exit Sub
    ElseIf Tabelle1.reinf_type_top_ComboBox.Value <> "no top reinforcement" And
        Tabelle1.Range("E74") = "" Then
        MsgBox "Please enter the properties of the rod"
        Tabelle1.Select
        Exit Sub

    ElseIf Tabelle1.reinf_type_bot_ComboBox.Value <> "no bottom reinforcement" And
        Tabelle1.Range("I73") = "" Then
        MsgBox "Please enter the properties of the rod"
        Tabelle1.Select
        Exit Sub
    ElseIf Tabelle1.reinf_type_bot_ComboBox.Value <> "no bottom reinforcement" And
        Tabelle1.Range("I74") = "" Then
        MsgBox "Please enter the properties of the rod"
        Tabelle1.Select
        Exit Sub

    End If

    Tabelle2.Range("E6").Value = Tabelle1.reinf_type_top_ComboBox.Value

    If Tabelle1.reinf_type_bot_ComboBox.Value = "same as top reinforcement" Then
        Tabelle2.Range("I6").Value = Tabelle2.Range("E6").Value
    Else
        Tabelle2.Range("I6").Value = Tabelle1.reinf_type_bot_ComboBox.Value
    End If

    Tabelle2.Range("D7").Value = Tabelle1.Range("D67").Value
```

```
    Tabelle2.Range("D8").Value = Tabelle1.Range("D68").Value
    Tabelle2.Range("D9").Value = Tabelle1.Range("D69").Value
    Tabelle2.Range("E7").Value = Tabelle1.height_reinf_top_TextBox.Value
    Tabelle2.Range("E8").Value = Tabelle1.width_reinf_top_TextBox.Value
    Tabelle2.Range("E9").Value = Tabelle1.quantity_reinf_top_TextBox.Value

    Tabelle2.Range("H7").Value = Tabelle1.Range("H67").Value
    Tabelle2.Range("H8").Value = Tabelle1.Range("H68").Value
    Tabelle2.Range("H9").Value = Tabelle1.Range("H69").Value
    Tabelle2.Range("I7").Value = Tabelle1.height_reinf_bot_TextBox.Value
    Tabelle2.Range("I8").Value = Tabelle1.width_reinf_bot_TextBox.Value
    Tabelle2.Range("I9").Value = Tabelle1.quantity_reinf_bot_TextBox.Value

    If Tabelle1.reinf_type_top_ComboBox.Value = "no top reinforcement" Then
        Tabelle2.Range("D7:F9").Font.ColorIndex = 2
        Tabelle2.Range("D10:F13").Font.ColorIndex = 15
        Tabelle2.pos_top_in.Enabled = False
        Tabelle2.pos_top_out.Enabled = False
        Tabelle2.num_layer_top_ComboBox.Enabled = False
        Tabelle2.num_layer_top_ComboBox.Value = "please choose"
        Tabelle2.zA_dis_top_ComboBox.Enabled = False
    Else
        Tabelle2.Range("D7:F13").Font.ColorIndex = 1
        Tabelle2.pos_top_in.Enabled = True
        Tabelle2.pos_top_out.Enabled = True
        Tabelle2.num_layer_top_ComboBox.Enabled = True
        Tabelle2.zA_dis_top_ComboBox.Enabled = True
    End If

    If Tabelle1.reinf_type_bot_ComboBox.Value = "no bottom reinforcement" Then
        Tabelle2.Range("H7:J9").Font.ColorIndex = 2
        Tabelle2.Range("H10:J13").Font.ColorIndex = 15
        Tabelle2.pos_bot_in.Enabled = False
        Tabelle2.pos_bot_out.Enabled = False
        Tabelle2.num_layer_bot_ComboBox.Enabled = False
        Tabelle2.num_layer_bot_ComboBox.Value = "please choose"
        Tabelle2.zA_dis_top_ComboBox.Enabled = False
    Else
        Tabelle2.Range("H7:J13").Font.ColorIndex = 1
        Tabelle2.pos_bot_in.Enabled = True
        Tabelle2.pos_bot_out.Enabled = True
        Tabelle2.num_layer_bot_ComboBox.Enabled = True
        Tabelle2.zA_dis_top_ComboBox.Enabled = True
    End If

    If Tabelle1.reinf_type_top_ComboBox.Value = "reinforcement bar" Or
      Tabelle1.reinf_type_top_ComboBox.Value = "threaded rod" Then
        Tabelle2.Range("D8:F8").Font.ColorIndex = 2
    ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "horizontal plate" Or
      Tabelle1.reinf_type_top_ComboBox.Value = "vertical plate" Then
        Tabelle2.Range("D8:F8").Font.ColorIndex = 1
    End If

    If Tabelle1.reinf_type_bot_ComboBox.Value = "reinforcement bar" Or
      Tabelle1.reinf_type_bot_ComboBox.Value = "threaded rod" Then
        Tabelle2.Range("H8:J8").Font.ColorIndex = 2
    ElseIf Tabelle1.reinf_type_bot_ComboBox.Value = "horizontal plate" Or
      Tabelle1.reinf_type_bot_ComboBox.Value = "vertical plate" Then
        Tabelle2.Range("H8:J8").Font.ColorIndex = 1
    End If

    Call pos_top_in_Change
    Call Tabelle1.input_data
    Call version_grafics
    Call num_layer_top_ComboBox_Change
    Call zAdistopcomboBoxes
    Call zAdisbotcomboBoxes
End Sub
```

```
Sub reinforcement()
```

```
Call Tabelle1.input_data

' height differences with reinforcement
   If n_reinf_top > 0 And n_reinf_bot > 0 Then
      If pos_top_in = True And pos_bot_in = True Then
         h = h_w
            h_w_top = h
            h_w_bot = 0
      ElseIf pos_top_out = True And pos_bot_in = True Then
         h = h_w + h_reinf_top
            h_w_top = h_w
            h_w_bot = 0
      ElseIf pos_top_in = True And pos_bot_out = True Then
         h = h_w + h_reinf_bot
            h_w_top = h
            h_w_bot = h_reinf_bot
      ElseIf pos_top_out = True And pos_bot_out = True Then
         h = h_w + h_reinf_top + h_reinf_bot
            h_w_top = h_w + h_reinf_bot
            h_w_bot = h_reinf_bot
      End If

   ElseIf n_reinf_top = 0 And n_reinf_bot > 0 Then
      If pos_bot_in = True Then
         h = h_w
            h_w_top = h
            h_w_bot = 0
      ElseIf pos_bot_out = True Then
         h = h_w + h_reinf_bot
            h_w_top = h
            h_w_bot = h_reinf_bot
      End If

   ElseIf n_reinf_top > 0 And n_reinf_bot = 0 Then
      If pos_top_in = True Then
         h = h_w
            h_w_top = h
            h_w_bot = 0
      ElseIf pos_top_out = True Then
         h = h_w + h_reinf_top
            h_w_top = h_w
            h_w_bot = 0
      End If

   ElseIf n_reinf_top = 0 And n_reinf_bot = 0 Then
      h = h_w
            h_w_top = h
            h_w_bot = 0

   End If

' ### Spacing ###

   Call spacing_reinf


' ### Areas ###
   If n_reinf_top > 0 Then

      If     Tabelle1.reinf_type_top_ComboBox     =     "horizontal     plate"     Or
           Tabelle1.reinf_type_top_ComboBox = "vertical plate" Then
         A_reinf_top = calc_A(n_reinf_top, h_reinf_top, b_reinf_top)

      ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Then
         A_reinf_top = calc_A_circ(n_reinf_top, dia_reinf_top)

      ElseIf Tabelle1.reinf_type_top_ComboBox = "threaded rod" Then
         Call area_threaded_rod
         A_reinf_top = A_ef
```

```
        End If

    Else
    A_reinf_top = 0

    End If

    If n_reinf_bot > 0 Then

        If      Tabelle1.reinf_type_bot_ComboBox       =       "horizontal       plate"       Or
              Tabelle1.reinf_type_bot_ComboBox = "vertical plate" Then
            A_reinf_bot = calc_A(n_reinf_bot, h_reinf_bot, b_reinf_bot)

        ElseIf Tabelle1.reinf_type_bot_ComboBox = "reinforcement bar" Then
            A_reinf_bot = calc_A_circ(n_reinf_bot, dia_reinf_bot)

        ElseIf Tabelle1.reinf_type_bot_ComboBox = "threaded rod" Then
            Call area_threaded_rod
            A_reinf_bot = A_ef_bot

        ElseIf Tabelle1.reinf_type_bot_ComboBox = "same as top reinforcement" Then
            If n_reinf_top > 0 Then

                If      Tabelle1.reinf_type_top_ComboBox      =      "horizontal      plate"      Or
                      Tabelle1.reinf_type_top_ComboBox = "vertical plate" Then
                    A_reinf_bot = calc_A(n_reinf_bot, h_reinf_bot, b_reinf_bot)

                ElseIf Tabelle1.reinf_type_top_ComboBox = "threaded rod" Then
                    Call area_threaded_rod
                    A_reinf_bot = A_ef_bot

                ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Then
                    A_reinf_bot = calc_A_circ(n_reinf_bot, dia_reinf_bot)

                End If

            Else

            A_reinf_bot = 0
            End If

        End If

    Else

    A_reinf_bot = 0

    End If
    A_reinf_fakt_top = calc_A_fakt(A_reinf_top, alpha_top)
    A_reinf_fakt_bot = calc_A_fakt(A_reinf_bot, alpha_bot)


' ### Neutral Axis ###
    If n_reinf_bot > 0 Then

        If pos_bot_in = True Then
            h_w_NA = h_w / 2
            A_w = A_w - A_reinf_bot - A_reinf_top
        ElseIf pos_bot_out = True Then
            h_w_NA = h_w / 2 + h_reinf_bot
        End If

    ElseIf n_reinf_bot = 0 Then
        h_w_NA = h_w / 2

    End If


    NA_z_bot  =  calc_NA_z(A_w,  h_w_NA  *  2,  A_reinf_fakt_top,  z_reinf_top,  A_reinf_fakt_bot,
          z_reinf_bot)
```

```
    NA_z_top = h - NA_z_bot

    Tabelle2.Range("E150").Value = NA_z_bot

    NA_y_top = b_w / 2
    NA_y_bot = b_w - NA_y_top


' ### Moment of inertia ###

    Call moment_of_inertia_reinf


' ### Stresses and Strains of WOOD ###
    Call stress_strain_wood


' ### Stresses and Strains of REINFORCEMENT ###
    Call stress_strain_reinf

    Call grafic_reinf


' ### Resistance ###
    ' wood

    k_m = 0.7
    eta_w_myd_top = Abs(sigma_y_w_top) / f_w_myd
    eta_w_myd_bot = sigma_y_w_bot / f_w_myd

    eta_w_mzd_top = Abs(sigma_z_w_top) / f_w_mzd
    eta_w_mzd_bot = sigma_z_w_bot / f_w_mzd

    eta_w_Vy_top = tau_w_Vy_top / f_w_vd
    eta_w_Vy_bot = tau_w_Vy_bot / f_w_vd

    eta_w_Vz_top = tau_w_Vz_top / f_w_vd
    eta_w_Vz_bot = tau_w_Vz_top / f_w_vd


    If Tabelle1.Nx_TextBox.Value > 1 Then       ' tension
        eta_w_t0d_top = sigma_axial_w_top / f_w_t0d
        eta_w_c0d_top = 0

        eta_w_t0d_bot = sigma_axial_w_bot / f_w_t0d
        eta_w_c0d_bot = 0

        eta_w_top_1 = eta_w_t0d_top + eta_w_myd_top + k_m * eta_w_mzd_top
        eta_w_top_2 = eta_w_t0d_top + k_m * eta_w_myd_top + eta_w_mzd_top

        eta_w_top = WorksheetFunction.Max(eta_w_top_1, eta_w_top_2)

        eta_w_bot_1 = eta_w_t0d_bot + eta_w_myd_bot + k_m * eta_w_mzd_bot
        eta_w_bot_2 = eta_w_t0d_bot + k_m * eta_w_myd_bot + eta_w_mzd_bot

        eta_w_bot = WorksheetFunction.Max(eta_w_bot_1, eta_w_bot_2)

    ElseIf Tabelle1.Nx_TextBox.Value < 1 Then     ' compression
        eta_w_c0d_top = sigma_axial_w_top / f_w_c0d
        eta_w_t0d_top = 0

        eta_w_c0d_bot = sigma_axial_w_bot / f_w_c0d
        eta_w_t0d_bot = 0

        eta_w_top_1 = eta_w_c0d_top ^ 2 + eta_w_myd_top + k_m * eta_w_mzd_top
        eta_w_top_2 = eta_w_c0d_top ^ 2 + k_m * eta_w_myd_top + eta_w_mzd_top

        eta_w_top = WorksheetFunction.Max(eta_w_top_1, eta_w_top_2)

        eta_w_bot_1 = eta_w_c0d_bot ^ 2 + eta_w_myd_bot + k_m * eta_w_mzd_bot
```

```
    eta_w_bot_2 = eta_w_c0d_bot ^ 2 + k_m * eta_w_myd_bot + eta_w_mzd_bot

    eta_w_bot = WorksheetFunction.Max(eta_w_bot_1, eta_w_bot_2)

End If

eta_w_V_top = eta_w_Vy_top ^ 2 + eta_w_Vz_top ^ 2
eta_w_V_bot = eta_w_Vy_bot ^ 2 + eta_w_Vz_bot ^ 2

' steel

If n_reinf_top > 0 Then

    sigma_reinf_Rd_top = f_reinf_top_yk / gamma_reinf
    sigma_reinf_RdV_top = (f_reinf_top_yk / 3 ^ 0.5) / gamma_reinf
    eta_y_reinf_top = Abs(sigma_y_reinf_top_1_top) / sigma_reinf_Rd_top
    eta_z_reinf_top = Abs(sigma_z_reinf_top_right) / sigma_reinf_Rd_top
    eta_Vy_reinf_top = Abs(sigma_Vy_reinf_top) / sigma_reinf_RdV_top
    eta_Vz_reinf_top = Abs(sigma_Vz_reinf_top) / sigma_reinf_RdV_top
    eta_V_reinf_top = (eta_Vy_reinf_top ^ 2 + eta_Vz_reinf_top ^ 2) ^ 0.5

    If Tabelle1.Nx_TextBox.Value > 0 Then        ' tension

        eta_t_reinf_top = Abs(sigma_axial_reinf_top) / sigma_reinf_Rd_top
        eta_reinf_top = eta_t_reinf_top + eta_y_reinf_top + eta_z_reinf_top
    ElseIf Tabelle1.Nx_TextBox.Value < 0 Then          ' compression
        eta_c_reinf_top = Abs(sigma_axial_reinf_top) / sigma_reinf_Rd_top
        eta_reinf_top = eta_c_reinf_top + eta_y_reinf_top + eta_z_reinf_top
    End If

Else
    sigma_y_reinf_top_1_top = 0
    sigma_z_reinf_top_right = 0
    sigma_reinf_Rd_top = f_reinf_bot_yk / gamma_reinf
    eta_y_reinf_top = 0
    eta_z_reinf_top = 0
    eta_t_reinf_top = 0
    eta_c_reinf_top = 0
    eta_reinf_top = 0
    eta_Vy_reinf_top = 0
    eta_Vz_reinf_top = 0
    eta_V_reinf_top = 0
    sigma_axial_reinf_top = 0

End If

If n_reinf_bot > 0 Then

    sigma_reinf_Rd_bot = f_reinf_bot_yk / gamma_reinf
    sigma_reinf_RdV_bot = (f_reinf_bot_yk / 3 ^ 0.5) / gamma_reinf
    eta_y_reinf_bot = sigma_y_reinf_bot_1_bot / sigma_reinf_Rd_bot
    eta_z_reinf_bot = Abs(sigma_z_reinf_bot_right) / sigma_reinf_Rd_bot
    eta_Vy_reinf_bot = Abs(sigma_Vy_reinf_bot) / sigma_reinf_RdV_bot
    eta_Vz_reinf_bot = Abs(sigma_Vz_reinf_bot) / sigma_reinf_RdV_bot
    eta_V_reinf_bot = (eta_Vy_reinf_bot ^ 2 + eta_Vz_reinf_bot ^ 2) ^ 0.5


    If Tabelle1.Nx_TextBox.Value > 0 Then        ' tension

        eta_t_reinf_bot = Abs(sigma_axial_reinf_bot) / sigma_reinf_Rd_bot
        eta_reinf_bot = eta_t_reinf_bot + eta_y_reinf_bot + eta_z_reinf_bot
    ElseIf Tabelle1.Nx_TextBox.Value < 0 Then          ' compression
        eta_c_reinf_bot = Abs(sigma_axial_reinf_bot) / sigma_reinf_Rd_top
        eta_reinf_bot = eta_c_reinf_bot + eta_y_reinf_bot + eta_z_reinf_bot
    End If


Else
    sigma_y_reinf_bot_1_bot = 0
    sigma_z_reinf_bot_right = 0
```

```
        sigma_reinf_Rd_bot   =   WorksheetFunction.Min(0.9   *   f_reinf_top_uk   /   gamma_reinf_2,
              f_reinf_top_yk / gamma_reinf)
        eta_y_reinf_bot = 0
        eta_z_reinf_bot = 0
        eta_t_reinf_bot = 0
        eta_reinf_bot = 0
        eta_c_reinf_bot = 0
        eta_Vy_reinf_bot = 0
        eta_Vz_reinf_bot = 0
        eta_V_reinf_bot = 0
        sigma_axial_reinf_bot = 0
    End If


' ### filling the sheet ###
    ' # wood #
        Tabelle2.Range("E45").Value = sigma_axial_w_top
        Tabelle2.Range("I45").Value = sigma_axial_w_bot

        If Tabelle1.Nx_TextBox.Value > 1 Then        ' tension
            Tabelle2.Range("E46").Value = eta_w_t0d_top
            Tabelle2.Range("I46").Value = eta_w_t0d_bot

            Tabelle2.Rows("46").EntireRow.Hidden = False
            Tabelle2.Rows("47").EntireRow.Hidden = True


        ElseIf Tabelle1.Nx_TextBox.Value < 1 Then           ' compression
            Tabelle2.Range("E47").Value = eta_w_c0d_top
            Tabelle2.Range("I47").Value = eta_w_c0d_bot

            Tabelle2.Rows("46").EntireRow.Hidden = True
            Tabelle2.Rows("47").EntireRow.Hidden = False

        End If

        Tabelle2.Range("E49").Value = sigma_y_w_top
        Tabelle2.Range("E50").Value = eta_w_myd_top

        Tabelle2.Range("I49").Value = sigma_y_w_bot
        Tabelle2.Range("I50").Value = eta_w_myd_bot


        Tabelle2.Range("E52").Value = sigma_z_w_top
        Tabelle2.Range("E53").Value = eta_w_mzd_top

        Tabelle2.Range("I52").Value = sigma_z_w_bot
        Tabelle2.Range("I53").Value = eta_w_mzd_bot

        Tabelle2.Range("E56").Value = eta_w_top

        Tabelle2.Range("I56").Value = eta_w_bot


        Tabelle2.Range("E58").Value = tau_w_Vy_top
        Tabelle2.Range("E59").Value = eta_w_Vy_top

        Tabelle2.Range("I58").Value = tau_w_Vy_bot
        Tabelle2.Range("I59").Value = eta_w_Vy_bot


        Tabelle2.Range("E61").Value = tau_w_Vz_top
        Tabelle2.Range("E62").Value = eta_w_Vz_top

        Tabelle2.Range("I61").Value = tau_w_Vz_bot
        Tabelle2.Range("I62").Value = eta_w_Vz_bot

        Tabelle2.Range("E65").Value = eta_w_V_top

        Tabelle2.Range("I65").Value = eta_w_V_bot
    ' # steel #
```

```
        Tabelle2.Range("E75").Value = sigma_reinf_Rd_top
        Tabelle2.Range("I75").Value = sigma_reinf_Rd_bot

        Tabelle2.Range("E77").Value = sigma_axial_reinf_top
        Tabelle2.Range("I77").Value = sigma_axial_reinf_bot

        If Tabelle1.Nx_TextBox.Value > 1 Then        ' tension

            Tabelle2.Range("E78").Value = eta_t_reinf_top
            Tabelle2.Range("I78").Value = eta_t_reinf_bot

            Tabelle2.Rows("78").EntireRow.Hidden = False
            Tabelle2.Rows("79").EntireRow.Hidden = True


        ElseIf Tabelle1.Nx_TextBox.Value < 1 Then           ' compression
            Tabelle2.Range("E79").Value = eta_c_reinf_top
            Tabelle2.Range("I79").Value = eta_c_reinf_bot

            Tabelle2.Rows("78").EntireRow.Hidden = True
            Tabelle2.Rows("79").EntireRow.Hidden = False
        End If

        Tabelle2.Range("E81").Value = sigma_y_reinf_top_1_top
        Tabelle2.Range("E82").Value = eta_y_reinf_top

        Tabelle2.Range("I81").Value = sigma_y_reinf_bot_1_bot
        Tabelle2.Range("I82").Value = eta_y_reinf_bot

        Tabelle2.Range("E84").Value = sigma_z_reinf_top_right
        Tabelle2.Range("E85").Value = eta_z_reinf_top

        Tabelle2.Range("I84").Value = sigma_z_reinf_bot_right
        Tabelle2.Range("I85").Value = eta_z_reinf_bot

        Tabelle2.Range("E88").Value = eta_reinf_top
        Tabelle2.Range("I88").Value = eta_reinf_bot

        Tabelle2.Range("E90").Value = sigma_Vy_reinf_top
        Tabelle2.Range("E91").Value = eta_Vy_reinf_top
        Tabelle2.Range("E93").Value = sigma_Vz_reinf_top
        Tabelle2.Range("E94").Value = eta_Vz_reinf_top
        Tabelle2.Range("E97").Value = eta_V_reinf_top

        Tabelle2.Range("I90").Value = sigma_Vy_reinf_bot
        Tabelle2.Range("I91").Value = eta_Vy_reinf_bot
        Tabelle2.Range("I93").Value = sigma_Vz_reinf_bot
        Tabelle2.Range("I94").Value = eta_Vz_reinf_bot
        Tabelle2.Range("I97").Value = eta_V_reinf_bot


' check for failure
If eta_w_top > 1 Then
    MsgBox "compression failure in wood"
    End If

If eta_w_bot > 1 Then
    MsgBox "tension failure in wood"
    End If
If eta_w_V_top > 1 Or eta_w_V_bot > 1 Then
    MsgBox "shear failure in wood"
    End If

If eta_reinf_top > 1 Then
    MsgBox "compression failure in reinforcement"
    End If
If eta_reinf_bot > 1 Then
    MsgBox "tension failure in reinforcement"
    End If

End Sub
```

```
Private Sub stress_strain_wood()

' #### Stresses and Strains of WOOD ####

' ## Moment My ##
    If n_reinf_top > 0 And n_reinf_bot > 0 Then
        If pos_top_in = True And pos_bot_in = True Then
            sigma_y_w_top = calc_sigma(1, M_y, NA_z_top, I_y_t)
            sigma_y_w_bot = calc_sigma(1, M_y, -NA_z_bot, I_y_t)

        ElseIf pos_top_out = True And pos_bot_in = True Then
            sigma_y_w_top = calc_sigma(1, M_y, NA_z_top - h_reinf_top, I_y_t)
            sigma_y_w_bot = calc_sigma(1, M_y, -NA_z_bot, I_y_t)

        ElseIf pos_top_in = True And pos_bot_out = True Then
            sigma_y_w_top = calc_sigma(1, M_y, NA_z_top, I_y_t)
            sigma_y_w_bot = calc_sigma(1, M_y, h_reinf_bot - NA_z_bot, I_y_t)

        ElseIf pos_top_out = True And pos_bot_out = True Then
            sigma_y_w_top = calc_sigma(1, M_y, NA_z_top - h_reinf_top, I_y_t)
            sigma_y_w_bot = calc_sigma(1, M_y, h_reinf_bot - NA_z_bot, I_y_t)

        End If

    ElseIf n_reinf_top = 0 And n_reinf_bot > 0 Then
            sigma_y_w_top = calc_sigma(1, M_y, NA_z_top, I_y_t)

        If pos_bot_in = True Then
            sigma_y_w_bot = calc_sigma(1, M_y, -NA_z_bot, I_y_t)

        ElseIf pos_bot_out = True Then
            sigma_y_w_bot = calc_sigma(1, M_y, h_reinf_bot - NA_z_bot, I_y_t)

        End If

    ElseIf n_reinf_top > 0 And n_reinf_bot = 0 Then
            sigma_y_w_bot = calc_sigma(1, M_y, -NA_z_bot, I_y_t)

        If pos_top_in = True Then
            sigma_y_w_top = calc_sigma(1, M_y, NA_z_top, I_y_t)

        ElseIf pos_top_out = True Then
            sigma_y_w_top = calc_sigma(1, M_y, NA_z_top - h_reinf_top, I_y_t)

        End If

    ElseIf n_reinf_top = 0 And n_reinf_bot = 0 Then
            sigma_y_w_top = calc_sigma(1, M_y, NA_z_top, I_y_t)
            sigma_y_w_bot = calc_sigma(1, M_y, -NA_z_bot, I_y_t)

    End If

    eps_y_w_top = calc_eps(sigma_y_w_top, E_w)
    eps_y_w_bot = calc_eps(sigma_y_w_bot, E_w)

' ## Moment Mz ##
    sigma_z_w_top = calc_sigma(1, M_z, NA_y_top, I_z_t)
    sigma_z_w_bot = calc_sigma(1, M_z, -NA_y_bot, I_z_t)

    eps_z_w_top = calc_eps(sigma_z_w_top, E_w)
    eps_z_w_bot = calc_eps(sigma_z_w_bot, E_w)

' ## Compression or Tension ##
    sigma_axial_w_top = calc_sigma_axial(N_x, E_w)
    eps_axial_w_top = calc_eps(sigma_axial_w_top, E_w)

    sigma_axial_w_bot = calc_sigma_axial(N_x, E_w)
    eps_axial_w_bot = calc_eps(sigma_axial_w_bot, E_w)

' ## Shear ##
If Tabelle1.wood_type_ComboBox.Value = "softwood" Then
```

```
    k_cr = 2 / Abs(f_w_vk)
ElseIf Tabelle1.wood_type_ComboBox.Value = "hardwood" Then
    k_cr = 0.67
ElseIf Tabelle1.wood_type_ComboBox.Value = "glulam" Then
    k_cr = 2.5 / Abs(f_w_vk)
End If

tau_w_Vy_top = calc_sigma_axial(V_y * 1.5, E_w) / k_cr
tau_w_Vy_bot = tau_w_Vy_top
tau_w_Vz_top = calc_sigma_axial(V_z * 1.5, E_w) / k_cr
tau_w_Vz_bot = tau_w_Vz_top


End Sub
```

```
Private Sub stress_strain_reinf()

' #### Stresses and Strains of REINFORCEMENT ####
If n_reinf_top = 0 Then
    n_reinf_top_1 = 0
    n_reinf_top_2 = 0
    n_reinf_top_3 = 0
End If
If n_reinf_bot = 0 Then
    n_reinf_bot_1 = 0
    n_reinf_bot_2 = 0
    n_reinf_bot_3 = 0
End If

' ## Moment My ##
    If n_reinf_top_1 > 0 Then
        sigma_y_reinf_top_1_top = calc_sigma(alpha_top, M_y, NA_z_top - zA_reinf_top_1_top, I_y_t)
        sigma_y_reinf_top_1_bot = calc_sigma(alpha_top, M_y, NA_z_top - zA_reinf_top_1_bot, I_y_t)
        eps_y_reinf_top_1_top = calc_eps(sigma_y_reinf_top_1_top, E_reinf_top)
        eps_y_reinf_top_1_bot = calc_eps(sigma_y_reinf_top_1_bot, E_reinf_top)
    Else
        sigma_y_reinf_top_1_top = ""
        sigma_y_reinf_top_1_bot = ""
        eps_y_reinf_top_1_top = ""
        eps_y_reinf_top_1_bot = ""
    End If

    If n_reinf_top_2 > 0 Then
        sigma_y_reinf_top_2_top = calc_sigma(alpha_top, M_y, NA_z_top - zA_reinf_top_2_top, I_y_t)
        sigma_y_reinf_top_2_bot = calc_sigma(alpha_top, M_y, NA_z_top - zA_reinf_top_2_bot, I_y_t)
        eps_y_reinf_top_2_top = calc_eps(sigma_y_reinf_top_2_top, E_reinf_top)
        eps_y_reinf_top_2_bot = calc_eps(sigma_y_reinf_top_2_bot, E_reinf_top)
    Else
        sigma_y_reinf_top_2_top = ""
        sigma_y_reinf_top_2_bot = ""
        eps_y_reinf_top_2_top = ""
        eps_y_reinf_top_2_bot = ""
    End If

    If n_reinf_top_3 > 0 Then
        sigma_y_reinf_top_3_top = calc_sigma(alpha_top, M_y, NA_z_top - zA_reinf_top_3_top, I_y_t)
        sigma_y_reinf_top_3_bot = calc_sigma(alpha_top, M_y, NA_z_top - zA_reinf_top_3_bot, I_y_t)
        eps_y_reinf_top_3_top = calc_eps(sigma_y_reinf_top_3_top, E_reinf_top)
        eps_y_reinf_top_3_bot = calc_eps(sigma_y_reinf_top_3_bot, E_reinf_top)
    Else
        sigma_y_reinf_top_3_top = ""
        sigma_y_reinf_top_3_bot = ""
        eps_y_reinf_top_3_top = ""
        eps_y_reinf_top_3_bot = ""
    End If


    If n_reinf_bot_1 > 0 Then
        sigma_y_reinf_bot_1_top  =  calc_sigma(alpha_bot,  M_y,  -NA_z_bot  +  zA_reinf_bot_1_top,
              I_y_t)
```

```
        sigma_y_reinf_bot_1_bot  =  calc_sigma(alpha_bot,  M_y,  -NA_z_bot  +  zA_reinf_bot_1_bot,
              I_y_t)
        eps_y_reinf_bot_1_top = calc_eps(sigma_y_reinf_bot_1_top, E_reinf_bot)
        eps_y_reinf_bot_1_bot = calc_eps(sigma_y_reinf_bot_1_bot, E_reinf_bot)
    Else
        sigma_y_reinf_bot_1_top = ""
        sigma_y_reinf_bot_1_bot = ""
        eps_y_reinf_bot_1_top = ""
        eps_y_reinf_bot_1_bot = ""
    End If

    If n_reinf_bot_2 > 0 Then
        sigma_y_reinf_bot_2_top  =  calc_sigma(alpha_bot,  M_y,  -NA_z_bot  +  zA_reinf_bot_2_top,
              I_y_t)
        sigma_y_reinf_bot_2_bot  =  calc_sigma(alpha_bot,  M_y,  -NA_z_bot  +  zA_reinf_bot_2_bot,
              I_y_t)
        eps_y_reinf_bot_2_top = calc_eps(sigma_y_reinf_bot_2_top, E_reinf_bot)
        eps_y_reinf_bot_2_bot = calc_eps(sigma_y_reinf_bot_2_bot, E_reinf_bot)
    Else
        sigma_y_reinf_bot_2_top = ""
        sigma_y_reinf_bot_2_bot = ""
        eps_y_reinf_bot_2_top = ""
        eps_y_reinf_bot_2_bot = ""
    End If

    If n_reinf_bot_3 > 0 Then
        sigma_y_reinf_bot_3_top  =  calc_sigma(alpha_bot,  M_y,  -NA_z_bot  +  zA_reinf_bot_3_top,
              I_y_t)
        sigma_y_reinf_bot_3_bot  =  calc_sigma(alpha_bot,  M_y,  -NA_z_bot  +  zA_reinf_bot_3_bot,
              I_y_t)
        eps_y_reinf_bot_3_top = calc_eps(sigma_y_reinf_bot_3_top, E_reinf_bot)
        eps_y_reinf_bot_3_bot = calc_eps(sigma_y_reinf_bot_3_bot, E_reinf_bot)
    Else
        sigma_y_reinf_bot_3_top = ""
        sigma_y_reinf_bot_3_bot = ""
        eps_y_reinf_bot_3_top = ""
        eps_y_reinf_bot_3_bot = ""
    End If

' ## Moment Mz ##
    If n_reinf_top > 0 Then
        sigma_z_reinf_top_right = calc_sigma(alpha_top, M_z, NA_y_top - yA_reinf_top_right, I_z_t)
        sigma_z_reinf_top_left = calc_sigma(alpha_top, M_z, -NA_y_bot + yA_reinf_top_left, I_z_t)

        eps_z_reinf_top_right = calc_eps(sigma_z_reinf_top_right, E_reinf_top)
        eps_z_reinf_top_left = calc_eps(sigma_z_reinf_top_left, E_reinf_top)

    Else
        sigma_z_reinf_top_right = ""
        sigma_z_reinf_top_left = ""

        eps_z_reinf_top_right = ""
        eps_z_reinf_top_left = ""

    End If

    If n_reinf_bot > 0 Then
        sigma_z_reinf_bot_right = calc_sigma(alpha_bot, M_z, NA_y_top - yA_reinf_bot_right, I_z_t)
        sigma_z_reinf_bot_left = calc_sigma(alpha_bot, M_z, -NA_y_bot + yA_reinf_bot_left, I_z_t)

        eps_z_reinf_bot_right = calc_eps(sigma_z_reinf_bot_right, E_reinf_bot)
        eps_z_reinf_bot_left = calc_eps(sigma_z_reinf_bot_left, E_reinf_bot)

    Else
        sigma_z_reinf_bot_right = ""
        sigma_z_reinf_bot_left = ""

        eps_z_reinf_bot_right = ""
        eps_z_reinf_bot_left = ""

    End If
```

```vb
' ## Compression or Tension ##
    If n_reinf_top > 0 And n_reinf_bot = 0 Then
        sigma_axial_reinf_top = calc_sigma_axial(N_x, E_reinf_top)
        sigma_axial_reinf_bot = 0
        eps_axial_reinf_top = calc_eps(sigma_axial_reinf_top, E_reinf_top)
        eps_axial_reinf_bot = 0

    ElseIf n_reinf_top = 0 And n_reinf_bot > 0 Then
        sigma_axial_reinf_top = 0
        sigma_axial_reinf_bot = calc_sigma_axial(N_x, E_reinf_bot)
        eps_axial_reinf_top = 0
        eps_axial_reinf_bot = calc_eps(sigma_axial_reinf_bot, E_reinf_bot)

    ElseIf n_reinf_top > 0 And n_reinf_bot > 0 Then
        sigma_axial_reinf_top = calc_sigma_axial(N_x, E_reinf_top)
        sigma_axial_reinf_bot = calc_sigma_axial(N_x, E_reinf_bot)
        eps_axial_reinf_top = calc_eps(sigma_axial_reinf_top, E_reinf_top)
        eps_axial_reinf_bot = calc_eps(sigma_axial_reinf_bot, E_reinf_bot)

    ElseIf n_reinf_top = 0 And n_reinf_bot = 0 Then
        sigma_axial_reinf_top = 0
        sigma_axial_reinf_bot = 0
        eps_axial_reinf_top = 0
        eps_axial_reinf_bot = 0

    End If
' ## Shear ##
    If n_reinf_top > 0 And n_reinf_bot = 0 Then
        sigma_Vy_reinf_top = calc_sigma_axial(V_y, E_reinf_top)
        sigma_Vy_reinf_bot = 0
        eps_Vy_reinf_top = calc_eps(sigma_Vy_reinf_top, E_reinf_top)
        eps_Vy_reinf_bot = 0

        sigma_Vz_reinf_top = calc_sigma_axial(V_z, E_reinf_top)
        sigma_Vz_reinf_bot = 0
        eps_Vz_reinf_top = calc_eps(sigma_Vz_reinf_top, E_reinf_top)
        eps_Vz_reinf_bot = 0

    ElseIf n_reinf_top = 0 And n_reinf_bot > 0 Then
        sigma_Vy_reinf_top = 0
        sigma_Vy_reinf_bot = calc_sigma_axial(V_y, E_reinf_bot)
        eps_Vy_reinf_top = 0
        eps_Vy_reinf_bot = calc_eps(sigma_Vy_reinf_bot, E_reinf_bot)

        sigma_Vz_reinf_top = 0
        sigma_Vz_reinf_bot = calc_sigma_axial(V_z, E_reinf_bot)
        eps_Vz_reinf_top = 0
        eps_Vz_reinf_bot = calc_eps(sigma_Vz_reinf_bot, E_reinf_bot)

    ElseIf n_reinf_top > 0 And n_reinf_bot > 0 Then
        sigma_Vy_reinf_top = calc_sigma_axial(V_y, E_reinf_top)
        sigma_Vy_reinf_bot = calc_sigma_axial(V_y, E_reinf_bot)
        eps_Vy_reinf_top = calc_eps(sigma_Vy_reinf_top, E_reinf_top)
        eps_Vy_reinf_bot = calc_eps(sigma_Vy_reinf_bot, E_reinf_bot)

        sigma_Vz_reinf_top = calc_sigma_axial(V_z, E_reinf_top)
        sigma_Vz_reinf_bot = calc_sigma_axial(V_z, E_reinf_bot)
        eps_Vz_reinf_top = calc_eps(sigma_Vz_reinf_top, E_reinf_top)
        eps_Vz_reinf_bot = calc_eps(sigma_Vz_reinf_bot, E_reinf_bot)

    ElseIf n_reinf_top = 0 And n_reinf_bot = 0 Then
        sigma_Vy_reinf_top = 0
        sigma_Vy_reinf_bot = 0
        eps_Vy_reinf_top = 0
        eps_Vy_reinf_bot = 0

        sigma_Vz_reinf_top = 0
        sigma_Vz_reinf_bot = 0
        eps_Vz_reinf_top = 0
        eps_Vz_reinf_bot = 0
```

```
  End If

End Sub

' ######### COMBOBOXES ####################################################
' # number of top layers #
```

```
Sub num_top_layer()
    Dim num_layer_top As MSForms.ComboBox
    Set num_layer_top = Tabelle2.num_layer_top_ComboBox
If Tabelle1.reinf_type_top_ComboBox.Value = "vertical plate" Then
    With num_layer_top
        .Clear
        .Value = "one layer"
    End With
ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "horizontal plate" Or
  Tabelle1.reinf_type_top_ComboBox.Value = "reinforcement bar" Or
  Tabelle1.reinf_type_top_ComboBox.Value = "threaded rod" Then
    With num_layer_top
        .Clear
        .AddItem "one layer"
        .AddItem "two layers"
        .AddItem "three layers"
        .ListIndex = 0
    End With
End If
Call num_bot_layer

End Sub
' # number of bottom layers  #
```

```
Private Sub num_bot_layer()
    Dim num_layer_bot As MSForms.ComboBox
    Set num_layer_bot = Tabelle2.num_layer_bot_ComboBox
If Tabelle1.reinf_type_bot_ComboBox.Value = "vertical plate" Then
    With num_layer_bot
        .Clear
        .Value = "one layer"
    End With
ElseIf Tabelle1.reinf_type_bot_ComboBox.Value = "horizontal plate" Or
  Tabelle1.reinf_type_bot_ComboBox.Value = "reinforcement bar" Or
  Tabelle1.reinf_type_bot_ComboBox.Value = "threaded rod" Then
    With num_layer_bot
        .Clear
        .AddItem "one layer"
        .AddItem "two layers"
        .AddItem "three layers"
        .ListIndex = 0
    End With
End If

End Sub
```

```
Private Sub num_layer_top_ComboBox_Change()
If Tabelle1.reinf_type_bot_ComboBox.Value = "same as top reinforcement" Then
    Tabelle2.num_layer_bot_ComboBox.Value = Tabelle2.num_layer_top_ComboBox.Value
End If
Call num_layer_bot_ComboBox_Change
End Sub
```

```
Private Sub num_layer_bot_ComboBox_Change()
' top
Tabelle2.Range("D15:F19").Font.ColorIndex = 1
If Tabelle2.num_layer_top_ComboBox.Value = "please choose" Then
    Tabelle2.zA_dis_top_ComboBox.Enabled = False
    Tabelle2.Range("D15:F19").Font.ColorIndex = 15

ElseIf Tabelle2.num_layer_top_ComboBox.Value = "one layer" Then
    Tabelle2.zA_dis_top_ComboBox.Enabled = True
    Tabelle2.Range("D17:F19").Font.ColorIndex = 15
```

```
ElseIf Tabelle2.num_layer_top_ComboBox.Value = "two layers" Then
    Tabelle2.zA_dis_top_ComboBox.Enabled = True
    Tabelle2.Range("D18:F19").Font.ColorIndex = 15
ElseIf Tabelle2.num_layer_top_ComboBox.Value = "three layers" Then
    Tabelle2.zA_dis_top_ComboBox.Enabled = True
End If
' bottom
Tabelle2.Range("H15:J19").Font.ColorIndex = 1
If Tabelle2.num_layer_bot_ComboBox.Value = "please choose" Then
    Tabelle2.Range("H15:J19").Font.ColorIndex = 15
    Tabelle2.zA_dis_bot_ComboBox.Enabled = False

ElseIf Tabelle2.num_layer_bot_ComboBox.Value = "one layer" Then
    Tabelle2.Range("H17:J19").Font.ColorIndex = 15
    Tabelle2.zA_dis_bot_ComboBox.Enabled = True

ElseIf Tabelle2.num_layer_bot_ComboBox.Value = "two layers" Then
    Tabelle2.Range("H18:J19").Font.ColorIndex = 15
    Tabelle2.zA_dis_bot_ComboBox.Enabled = True

ElseIf Tabelle2.num_layer_bot_ComboBox.Value = "three layers" Then
    Tabelle2.zA_dis_bot_ComboBox.Enabled = True

End If

Call version_grafics
Call zA_dis_top_ComboBox_LostFocus
End Sub

' ##### Bottoms #####
```

```
Private Sub pos_top_in_Change()
Call pos_top_out_Click
Call pos_bot_in_Change
End Sub
```

```
Private Sub pos_top_out_Click()
End Sub
```

```
Private Sub pos_bot_in_Change()
Call pos_bot_out_Click
End Sub
```

```
Private Sub pos_bot_out_Click()
' Top reinforcement inside/outside
If  Tabelle1.reinf_type_top_ComboBox  =  "vertical  plate"  Or  Tabelle1.reinf_type_top_ComboBox  =
  "reinforcement bar" Or Tabelle1.reinf_type_top_ComboBox = "threaded rod" Then
    pos_top_in.Enabled = True
    pos_top_out.Enabled = False
ElseIf Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Then
    pos_top_out.Enabled = True
    pos_top_in.Enabled = True

End If
' Bottom reinforcement inside/outside
If Tabelle1.reinf_type_bot_ComboBox = "same as top reinforcement" Then
    pos_bot_out.Value = pos_top_out.Value
    pos_bot_in.Value = pos_top_in.Value
ElseIf Tabelle1.reinf_type_bot_ComboBox = "vertical plate" Or Tabelle1.reinf_type_bot_ComboBox =
  "reinforcement bar" Or Tabelle1.reinf_type_bot_ComboBox = "threaded rod" Then
    pos_bot_out.Enabled = False
    pos_bot_in.Enabled = True
ElseIf Tabelle1.reinf_type_bot_ComboBox = "horizontal plate" Then
    pos_bot_out.Enabled = True
    pos_bot_in.Enabled = True
End If
Call version_grafics

End Sub
```

```vb
' ### Distance zA ###
```

```vb
Private Sub zA_dis_top_ComboBox_LostFocus()
' # top #
h_reinf_top = Tabelle1.height_reinf_top_TextBox.Value
If Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Then
    zA_min_top = 16 * h_reinf_top
ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Or Tabelle1.reinf_type_top_ComboBox
  = "threaded bar" Then
    zA_min_top = 5 * h_reinf_top
End If

If n_reinf_top > 0 Then
    If Tabelle2.num_layer_top_ComboBox.Value = "one layer" Then
        zA_reinf_top_1 = zA_dis_top_ComboBox.Value + h_reinf_top / 2
        Tabelle2.Range("E17").Value = ""
        Tabelle2.Range("E19").Value = ""

    ElseIf Tabelle2.num_layer_top_ComboBox.Value = "two layers" Then
        zA_reinf_top_1 = zA_dis_top_ComboBox.Value + h_reinf_top / 2
        Tabelle2.Range("E17").Value = zA_reinf_top_1 + zA_min_top
        Tabelle2.Range("E19").Value = ""

    ElseIf Tabelle2.num_layer_top_ComboBox.Value = "three layers" Then
        zA_reinf_top_1 = zA_dis_top_ComboBox.Value + h_reinf_top / 2
        Tabelle2.Range("E17").Value = zA_reinf_top_1 + zA_min_top
        Tabelle2.Range("E19").Value = zA_reinf_top_1 + 2 * zA_min_top

    End If
Else
    zA_reinf_top_1 = 0
    Tabelle2.Range("E17").Value = ""
    Tabelle2.Range("E19").Value = ""
End If
If Tabelle2.Range("E19").Value > h_w / 2 Then
    MsgBox ("The top and bottom reinforcement may overlap")
End If
Call zA_dis_bot_ComboBox_LostFocus

End Sub
```

```vb
Private Sub zA_dis_bot_ComboBox_LostFocus()
' # bot #
h_reinf_bot = Tabelle1.height_reinf_bot_TextBox.Value
If Tabelle1.reinf_type_bot_ComboBox = "horizontal plate" Then
    zA_min_bot = 16 * h_reinf_bot
ElseIf Tabelle1.reinf_type_bot_ComboBox = "reinforcement bar" Or Tabelle1.reinf_type_bot_ComboBox
  = "threaded bar" Then
    zA_min_bot = 5 * h_reinf_bot
ElseIf Tabelle1.reinf_type_bot_ComboBox = "same as top reinforcement" Then
    zA_min_bot = zA_min_top
End If

If n_reinf_bot > 0 Then
    If Tabelle2.num_layer_bot_ComboBox.Value = "one layer" Then
        zA_reinf_bot_1 = zA_dis_bot_ComboBox.Value + h_reinf_bot / 2
        Tabelle2.Range("I17").Value = ""
        Tabelle2.Range("I19").Value = ""

    ElseIf Tabelle2.num_layer_bot_ComboBox.Value = "two layers" Then
        zA_reinf_bot_1 = zA_dis_bot_ComboBox.Value + h_reinf_bot / 2
        Tabelle2.Range("I17").Value = zA_reinf_bot_1 + zA_min_bot
        Tabelle2.Range("I19").Value = ""

    ElseIf Tabelle2.num_layer_bot_ComboBox.Value = "three layers" Then
        zA_reinf_bot_1 = zA_dis_bot_ComboBox.Value + h_reinf_bot / 2
        Tabelle2.Range("I17").Value = zA_reinf_bot_1 + zA_min_bot
        Tabelle2.Range("I19").Value = zA_reinf_bot_1 + 2 * zA_min_bot

    End If
```

```
Else
    zA_reinf_bot_1 = 0
    Tabelle2.Range("I17").Value = ""
    Tabelle2.Range("I19").Value = ""
End If
If Tabelle2.Range("I19").Value > h_w / 2 Then
    MsgBox ("The top and bottom reinforcement may overlap")
End If

End Sub
```

```
Private Sub spacing_reinf()
' ### Spacing calculations y ###

' # top reinforcement #
If n_reinf_top > 0 Then
    If Tabelle1.reinf_type_top_ComboBox = "vertical plate" Then
        n_reinf_top_max = WorksheetFunction.RoundDown(b_w / (16 * b_reinf_top), 0)
        If n_reinf_top > n_reinf_top_max Then
            MsgBox "The number of reinforcement plates is too high." & vbNewLine & "The maximum is
                  " & n_reinf_top_max & "." & vbNewLine & vbNewLine & vbNewLine & "Please enter
                  the same or a smaller value"
            Tabelle1.Select
            check = True
            Exit Sub
        End If
        yA_reinf_top_right = 8 * b_reinf_top
        yA_reinf_top_left = 8 * b_reinf_top
        If n_reinf_top = 1 Then
            yA_reinf_top_middle = b_w - yA_reinf_top_right - yA_reinf_top_left
        Else
            yA_reinf_top_middle = calc_yA_reinf_middle(b_w, yA_reinf_top_right, yA_reinf_top_left,
                  n_reinf_top)
        End If

    ElseIf Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Then
        If b_reinf_top > b_w Then
            MsgBox "The width of reinforcement plates is too high." & vbNewLine & "The maximum
                  width is " & b_w & "." & vbNewLine & vbNewLine & vbNewLine & "Please enter the
                  same or a smaller value"
            Tabelle1.Select
            check = True
            Exit Sub
        End If

        yA_reinf_top_right = (b_w - b_reinf_top) / 2
        yA_reinf_top_left = (b_w - b_reinf_top) / 2
        yA_reinf_top_middle = ""

    ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Or
          Tabelle1.reinf_type_top_ComboBox = "threaded rod" Then
        n_reinf_top_max = WorksheetFunction.RoundDown((b_w - 5 * h_reinf_top) / (5 * h_reinf_top)
              + 1, 0)
        If n_reinf_top > n_reinf_top_max Then
            MsgBox "The number of reinforcement rods is too high." & vbNewLine & "The maximum is "
                  & n_reinf_top_max & "." & vbNewLine & vbNewLine & vbNewLine & "Please enter the
                  same or a smaller value"
            Tabelle1.Select
            check = True
            Exit Sub
        End If
        yA_reinf_top_right = 2.5 * h_reinf_top
        yA_reinf_top_left = 2.5 * h_reinf_top
        If n_reinf_top = 1 Then
            yA_reinf_top_middle = b_w - yA_reinf_top_right - yA_reinf_top_left
        Else
            yA_reinf_top_middle = calc_yA_reinf_middle(b_w, yA_reinf_top_right, yA_reinf_top_left,
                  n_reinf_top)
        End If
```

```
    End If
Else
    yA_reinf_top_right = 0
    yA_reinf_top_left = 0
    yA_reinf_top_middle = 0
End If
' # bottom reinforcement #
If n_reinf_bot > 0 Then
    If Tabelle1.reinf_type_bot_ComboBox = "vertical plate" Then
        n_reinf_bot_max = WorksheetFunction.RoundDown(b_w / (16 * b_reinf_bot), 0)
        If n_reinf_bot > n_reinf_bot_max Then
            MsgBox "The number of reinforcement plates is too high." & vbNewLine & "The maximum is
                  " & n_reinf_bot_max & "." & vbNewLine & vbNewLine & vbNewLine & "Please enter
                  the same or a smaller value"
            Tabelle1.Select
            check = True
            Exit Sub
        End If
        yA_reinf_bot_right = 8 * b_reinf_bot
        yA_reinf_bot_left = 8 * b_reinf_bot
        If n_reinf_bot = 1 Then
            yA_reinf_bot_middle = b_w - yA_reinf_bot_right - yA_reinf_bot_left
        Else
            yA_reinf_bot_middle = calc_yA_reinf_middle(b_w, yA_reinf_bot_right, yA_reinf_bot_left,
                  n_reinf_bot)
        End If

    ElseIf Tabelle1.reinf_type_bot_ComboBox = "horizontal plate" Then
        If b_reinf_bot > b_w Then
            MsgBox "The width of reinforcement plates is too high." & vbNewLine & "The maximum
                  width is " & b_w & " mm." & vbNewLine & vbNewLine & vbNewLine & "Please enter
                  the same or a smaller value"
            Tabelle1.Select
            check = True
            Exit Sub
        End If

        yA_reinf_bot_right = (b_w - b_reinf_bot) / 2
        yA_reinf_bot_left = (b_w - b_reinf_bot) / 2
        yA_reinf_bot_middle = ""

    ElseIf      Tabelle1.reinf_type_bot_ComboBox      =      "reinforcement      bar"      Or
          Tabelle1.reinf_type_bot_ComboBox = "threaded rod" Then
        n_reinf_bot_max = WorksheetFunction.RoundDown((b_w - 5 * h_reinf_bot) / (5 * h_reinf_bot)
             + 1, 0)
        If n_reinf_bot > n_reinf_bot_max Then
            MsgBox "The number of reinforcement rods is too high." & vbNewLine & "The maximum is "
                  & n_reinf_bot_max & "." & vbNewLine & vbNewLine & vbNewLine & "Please enter the
                  same or a smaller value"
            Tabelle1.Select
            check = True
            Exit Sub
        End If
        yA_reinf_bot_right = 2.5 * h_reinf_bot
        yA_reinf_bot_left = 2.5 * h_reinf_bot
        If n_reinf_bot = 1 Then
            yA_reinf_bot_middle = b_w - yA_reinf_bot_right - yA_reinf_bot_left
        Else
            yA_reinf_bot_middle = calc_yA_reinf_middle(b_w, yA_reinf_bot_right, yA_reinf_bot_left,
                  n_reinf_bot)
        End If

    ElseIf Tabelle1.reinf_type_bot_ComboBox = "same as top reinforcement" Then
        If Tabelle1.reinf_type_top_ComboBox = "vertical plate" Then
            n_reinf_bot_max = WorksheetFunction.RoundDown(b_w / (16 * b_reinf_bot), 0)
            If n_reinf_bot > n_reinf_bot_max Then
                MsgBox "The number of reinforcement plates is too high." & vbNewLine & "The maximum
                      is " & n_reinf_bot_max & "." & vbNewLine & vbNewLine & vbNewLine & "Please
                      enter the same or a smaller value"
                Tabelle1.Select
                check = True
```

```
            Exit Sub
        End If
        yA_reinf_bot_right = 8 * b_reinf_bot
        yA_reinf_bot_left = 8 * b_reinf_bot
        If n_reinf_bot = 1 Then
            yA_reinf_bot_middle = b_w - yA_reinf_bot_right - yA_reinf_bot_left
        Else
            yA_reinf_bot_middle = calc_yA_reinf_middle(b_w, yA_reinf_bot_right,
                  yA_reinf_bot_left, n_reinf_bot)
        End If

    ElseIf Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Then
        n_reinf_bot_max = 1
        yA_reinf_bot_right = (b_w - b_reinf_bot) / 2
        yA_reinf_bot_left = (b_w - b_reinf_bot) / 2
        yA_reinf_bot_middle = ""

    ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Or
          Tabelle1.reinf_type_top_ComboBox = "threaded rod" Then
        n_reinf_bot_max = WorksheetFunction.RoundDown((b_w - 5 * h_reinf_bot) / (5 *
              h_reinf_bot) + 1, 0)
        If n_reinf_bot > n_reinf_bot_max Then
            MsgBox "The number of reinforcement rods is too high." & vbNewLine & "The maximum
                  is " & n_reinf_bot_max & "." & vbNewLine & vbNewLine & vbNewLine & "Please
                  enter the same or a smaller value"
            Tabelle1.Select
            check = True
            Exit Sub
        End If
        yA_reinf_bot_right = 2.5 * h_reinf_bot
        yA_reinf_bot_left = 2.5 * h_reinf_bot
        If n_reinf_bot = 1 Then
            yA_reinf_bot_middle = b_w - yA_reinf_bot_right - yA_reinf_bot_left
        Else
            yA_reinf_bot_middle = calc_yA_reinf_middle(b_w, yA_reinf_bot_right,
                  yA_reinf_bot_left, n_reinf_bot)
        End If
    End If
  End If
Else
    yA_reinf_bot_right = 0
    yA_reinf_bot_left = 0
    yA_reinf_bot_middle = 0

End If
y_reinf_top_right = yA_reinf_top_right
y_reinf_top_left = b_w - yA_reinf_top_left
y_reinf_bot_right = yA_reinf_bot_right
y_reinf_bot_left = b_w - yA_reinf_bot_left


' ### Spacing calculations zA ###

' # top reinforcement #
Call zA_dis_top_ComboBox_LostFocus
zA_reinf_top_2 = Tabelle2.Range("E17").Value
zA_reinf_top_3 = Tabelle2.Range("E19").Value
If n_reinf_top > 0 Then
    If Tabelle2.num_layer_top_ComboBox.Value = "one layer" Then
        zA_reinf_top = zA_reinf_top_1
        n_reinf_top_1 = n_reinf_top
        n_reinf_top_2 = 0
        n_reinf_top_3 = 0
        n_reinf_top = n_reinf_top * 1
        n_row_top = 1
    ElseIf Tabelle2.num_layer_top_ComboBox.Value = "two layers" Then
        zA_reinf_top = zA_reinf_top_1 + 0.5 * (zA_reinf_top_2 - zA_reinf_top_1)
        n_reinf_top_1 = n_reinf_top
        n_reinf_top_2 = n_reinf_top
        n_reinf_top_3 = 0
        n_reinf_top = n_reinf_top * 2
```

```
        n_row_top = 2
    ElseIf Tabelle2.num_layer_top_ComboBox.Value = "three layers" Then
        zA_reinf_top = zA_reinf_top_1 + 0.5 * (zA_reinf_top_3 - zA_reinf_top_1)
        n_reinf_top_1 = n_reinf_top
        n_reinf_top_2 = n_reinf_top
        n_reinf_top_3 = n_reinf_top
        n_reinf_top = n_reinf_top * 3
        n_row_top = 3
    End If

    z_reinf_top = h - zA_reinf_top

Else
z_reinf_top = 0

End If

' # bottom reinforcement #
zA_reinf_bot_2 = Tabelle2.Range("I17").Value
zA_reinf_bot_3 = Tabelle2.Range("I19").Value
If n_reinf_bot > 0 Then
    If Tabelle2.num_layer_bot_ComboBox.Value = "one layer" Then
        zA_reinf_bot = zA_reinf_bot_1
        n_reinf_bot_1 = n_reinf_bot
        n_reinf_bot_2 = 0
        n_reinf_bot_3 = 0
        n_reinf_bot = n_reinf_bot * 1
        n_row_bot = 1
    ElseIf Tabelle2.num_layer_bot_ComboBox.Value = "two layers" Then
        zA_reinf_bot = zA_reinf_bot_1 + 0.5 * (zA_reinf_bot_2 - zA_reinf_bot_1)
        n_reinf_bot_1 = n_reinf_bot
        n_reinf_bot_2 = n_reinf_bot
        n_reinf_bot_3 = 0
        n_reinf_bot = n_reinf_bot * 2
        n_row_bot = 2
    ElseIf Tabelle2.num_layer_bot_ComboBox.Value = "three layers" Then
        zA_reinf_bot = zA_reinf_bot_1 + 0.5 * (zA_reinf_bot_3 - zA_reinf_bot_1)
        n_reinf_bot_1 = n_reinf_bot
        n_reinf_bot_2 = n_reinf_bot
        n_reinf_bot_3 = n_reinf_bot
        n_reinf_bot = n_reinf_bot * 3
        n_row_bot = 3
    End If

    z_reinf_bot = zA_reinf_bot

Else
z_reinf_bot = 0
End If

End Sub
```

```
Private Sub moment_of_inertia_reinf()
' ### Moment of Inertia ###
Dim z_() As Variant
Dim y_() As Variant
If n_reinf_top > 0 Then
    If Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Then
        I_y_reinf_top_1 = calc_I_y_rec(alpha_top, n_reinf_top_1, b_reinf_top, h_reinf_top) +
              calc_I_y_rec_SA(alpha_top, n_reinf_top_1, b_reinf_top, h_reinf_top, NA_z_top,
              zA_reinf_top_1)
        I_y_reinf_top_2 = calc_I_y_rec(alpha_top, n_reinf_top_2, b_reinf_top, h_reinf_top) +
              calc_I_y_rec_SA(alpha_top, n_reinf_top_2, b_reinf_top, h_reinf_top, NA_z_top,
              zA_reinf_top_2)
        I_y_reinf_top_3 = calc_I_y_rec(alpha_top, n_reinf_top_3, b_reinf_top, h_reinf_top) +
              calc_I_y_rec_SA(alpha_top, n_reinf_top_3, b_reinf_top, h_reinf_top, NA_z_top,
              zA_reinf_top_3)
        I_y_reinf_top = I_y_reinf_top_1 + I_y_reinf_top_2 + I_y_reinf_top_3

        I_z_reinf_top = calc_I_z_rec(alpha_top, n_reinf_top, b_reinf_top, h_reinf_top)
```

```
ElseIf Tabelle1.reinf_type_top_ComboBox = "vertical plate" Then
    I_y_reinf_top_1 = calc_I_y_rec(alpha_top, n_reinf_top_1, b_reinf_top, h_reinf_top) +
        calc_I_y_rec_SA(alpha_top, n_reinf_top_1, b_reinf_top, h_reinf_top, NA_z_top,
        zA_reinf_top_1)
    I_y_reinf_top = I_y_reinf_top_1

    I_z_reinf_top = calc_I_z_rec(alpha_top, n_reinf_top, b_reinf_top, h_reinf_top)

        ' even numbers of plates
        If n_reinf_top Mod 2 = 0 Then
            nm_y = n_reinf_top / 2

            ReDim y_(nm_y)
            Dim k As Integer
            Ay_reinf_top = 0

            For k = 1 To nm_y
                y_(k) = ((k - 0.5) * yA_reinf_top_middle) ^ 2
                Ay_reinf_top = Ay_reinf_top + (A_reinf_top * y_(k))

            Next k

        ' uneven numbers of plates
        Else
            nm_y = (n_reinf_top - 1) / 2

            ReDim y_(nm_y)
            Dim l As Integer
            Ay_reinf_top = 0

            For l = 1 To nm_y
                y_(l) = (l * yA_reinf_top_middle) ^ 2
                Ay_reinf_top = Ay_reinf_top + (A_reinf_top * y_(l))
            Next l

        End If

        Ay_reinf_top = Ay_reinf_top * 2 * alpha_top
        I_z_reinf_top = Ay_reinf_top + I_z_reinf_top


ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Or
      Tabelle1.reinf_type_top_ComboBox = "threaded rod" Then
    I_y_reinf_top_1 = calc_I_cir(alpha_top, n_reinf_top_1, h_reinf_top) +
        calc_I_y_cir_SA(alpha_top, n_reinf_top_1, h_reinf_top, NA_z_top, zA_reinf_top_1)
    I_y_reinf_top_2 = calc_I_cir(alpha_top, n_reinf_top_2, h_reinf_top) +
        calc_I_y_cir_SA(alpha_top, n_reinf_top_2, h_reinf_top, NA_z_top, zA_reinf_top_2)
    I_y_reinf_top_3 = calc_I_cir(alpha_top, n_reinf_top_3, h_reinf_top) +
        calc_I_y_cir_SA(alpha_top, n_reinf_top_3, h_reinf_top, NA_z_top, zA_reinf_top_3)
    I_y_reinf_top = I_y_reinf_top_1 + I_y_reinf_top_2 + I_y_reinf_top_3

    I_z_reinf_top = calc_I_cir(alpha_top, n_reinf_top, h_reinf_top)

        ' even numbers of rods
        If n_reinf_top Mod 2 = 0 Then
            nm_y = n_reinf_top / 2

            ReDim y_(nm_y)
            Dim i As Integer
            Ay_reinf_top = 0

            For i = 1 To nm_y
                y_(i) = ((i - 0.5) * yA_reinf_top_middle) ^ 2
                Ay_reinf_top = Ay_reinf_top + (A_reinf_top * y_(i))

            Next i

        ' uneven numbers of rods
        Else
            nm_y = (n_reinf_top - 1) / 2
```

```
            ReDim y_(nm_y)
            Dim j As Integer
            Ay_reinf_top = 0

            For j = 1 To nm_y
                y_(j) = (j * yA_reinf_top_middle) ^ 2
                Ay_reinf_top = Ay_reinf_top + (A_reinf_top * y_(j))
            Next j


        End If

        Ay_reinf_top = Ay_reinf_top * n_row_top * alpha_top
        I_z_reinf_top = Ay_reinf_top + I_z_reinf_top
    End If
Else
    I_y_reinf_top = 0
    I_z_reinf_top = 0
End If

If n_reinf_bot > 0 Then

    If Tabelle1.reinf_type_bot_ComboBox = "horizontal plate" Then
        I_y_reinf_bot_1  =  calc_I_y_rec(alpha_bot,  n_reinf_bot_1,  b_reinf_bot,  h_reinf_bot)  +
              calc_I_y_rec_SA(alpha_bot,   n_reinf_bot_1,   b_reinf_bot,   h_reinf_bot,   NA_z_bot,
              zA_reinf_bot_1)
        I_y_reinf_bot_2  =  calc_I_y_rec(alpha_bot,  n_reinf_bot_2,  b_reinf_bot,  h_reinf_bot)  +
              calc_I_y_rec_SA(alpha_bot,   n_reinf_bot_2,   b_reinf_bot,   h_reinf_bot,   NA_z_bot,
              zA_reinf_bot_2)
        I_y_reinf_bot_3  =  calc_I_y_rec(alpha_bot,  n_reinf_bot_3,  b_reinf_bot,  h_reinf_bot)  +
              calc_I_y_rec_SA(alpha_bot,   n_reinf_bot_3,   b_reinf_bot,   h_reinf_bot,   NA_z_bot,
              zA_reinf_bot_3)
        I_y_reinf_bot = I_y_reinf_bot_1 + I_y_reinf_bot_2 + I_y_reinf_bot_3

        I_z_reinf_bot = calc_I_z_rec(alpha_bot, n_reinf_bot, b_reinf_bot, h_reinf_bot)

    ElseIf Tabelle1.reinf_type_bot_ComboBox = "vertical plate" Then
        I_y_reinf_bot_1  =  calc_I_y_rec(alpha_bot,  n_reinf_bot_1,  b_reinf_bot,  h_reinf_bot)  +
              calc_I_y_rec_SA(alpha_bot,   n_reinf_bot_1,   b_reinf_bot,   h_reinf_bot,   NA_z_bot,
              zA_reinf_bot_1)
        I_y_reinf_bot_2  =  calc_I_y_rec(alpha_bot,  n_reinf_bot_2,  b_reinf_bot,  h_reinf_bot)  +
              calc_I_y_rec_SA(alpha_bot,   n_reinf_bot_2,   b_reinf_bot,   h_reinf_bot,   NA_z_bot,
              zA_reinf_bot_2)
        I_y_reinf_bot_3  =  calc_I_y_rec(alpha_bot,  n_reinf_bot_3,  b_reinf_bot,  h_reinf_bot)  +
              calc_I_y_rec_SA(alpha_bot,   n_reinf_bot_3,   b_reinf_bot,   h_reinf_bot,   NA_z_bot,
              zA_reinf_bot_3)
        I_y_reinf_bot = I_y_reinf_bot_1 + I_y_reinf_bot_2 + I_y_reinf_bot_3

        I_z_reinf_bot = calc_I_z_rec(alpha_bot, n_reinf_bot, b_reinf_bot, h_reinf_bot)

            ' even numbers of plates
            If n_reinf_bot Mod 2 = 0 Then
                nm_y = n_reinf_bot / 2

                ReDim y_(nm_y)
                Dim k_bot As Integer
                Ay_reinf_bot = 0

                For k_bot = 1 To nm_y
                    y_(k_bot) = ((k_bot - 0.5) * yA_reinf_bot_middle) ^ 2
                    Ay_reinf_bot = Ay_reinf_bot + (A_reinf_bot * y_(k_bot))

                Next k_bot

            ' uneven numbers of plates
            Else
                nm_y = (n_reinf_bot - 1) / 2

                ReDim y_(nm_y)
                Dim l_bot As Integer
```

```
            Ay_reinf_bot = 0

            For l_bot = 1 To nm_y
                y_(l_bot) = (l_bot * yA_reinf_bot_middle) ^ 2
                Ay_reinf_bot = Ay_reinf_bot + (A_reinf_bot * y_(l_bot))
            Next l_bot

        End If

        Ay_reinf_bot = Ay_reinf_bot * 2 * alpha_bot
        I_z_reinf_bot = Ay_reinf_bot + I_z_reinf_bot


ElseIf Tabelle1.reinf_type_bot_ComboBox = "reinforcement bar" Or
      Tabelle1.reinf_type_bot_ComboBox = "threaded rod" Then
    I_y_reinf_bot_1 = calc_I_cir(alpha_bot, n_reinf_bot_1, h_reinf_bot) +
          calc_I_y_cir_SA(alpha_bot, n_reinf_bot_1, h_reinf_bot, NA_z_bot, zA_reinf_bot_1)
    I_y_reinf_bot_2 = calc_I_cir(alpha_bot, n_reinf_bot_2, h_reinf_bot) +
          calc_I_y_cir_SA(alpha_bot, n_reinf_bot_2, h_reinf_bot, NA_z_bot, zA_reinf_bot_2)
    I_y_reinf_bot_3 = calc_I_cir(alpha_bot, n_reinf_bot_3, h_reinf_bot) +
          calc_I_y_cir_SA(alpha_bot, n_reinf_bot_3, h_reinf_bot, NA_z_bot, zA_reinf_bot_3)
    I_y_reinf_bot = I_y_reinf_bot_1 + I_y_reinf_bot_2 + I_y_reinf_bot_3

    I_z_reinf_bot = calc_I_cir(alpha_bot, n_reinf_bot, h_reinf_bot)

        ' even numbers of rods
        If n_reinf_bot Mod 2 = 0 Then
            nm_y = n_reinf_bot / 2

            ReDim y_(nm_y)
            Dim i_bot As Integer
            Ay_reinf_bot = 0

            For i_bot = 1 To nm_y
                y_(i_bot) = ((i_bot - 0.5) * yA_reinf_bot_middle) ^ 2
                Ay_reinf_bot = Ay_reinf_bot + (A_reinf_bot * y_(i_bot))

            Next i_bot

        ' uneven numbers of rods
        Else
            nm_y = (n_reinf_bot - 1) / 2

            ReDim y_(nm_y)
            Dim j_bot As Integer
            Ay_reinf_bot = 0

            For j_bot = 1 To nm_y
                y_(j_bot) = (j_bot * yA_reinf_bot_middle) ^ 2
                Ay_reinf_bot = Ay_reinf_bot + (A_reinf_bot * y_(j_bot))
            Next j_bot


        End If

        Ay_reinf_bot = Ay_reinf_bot * n_row_bot * alpha_bot
        I_z_reinf_bot = Ay_reinf_bot + I_z_reinf_bot

ElseIf Tabelle1.reinf_type_bot_ComboBox = "same as top reinforcement" Then
    If n_reinf_top > 0 Then
        If Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Or
              Tabelle1.reinf_type_top_ComboBox = "vertical plate" Then
            I_y_reinf_bot_1 = calc_I_y_rec(alpha_bot, n_reinf_bot_1, b_reinf_bot, h_reinf_bot)
                  + calc_I_y_rec_SA(alpha_bot, n_reinf_bot_1, b_reinf_bot, h_reinf_bot,
                  NA_z_bot, zA_reinf_bot_1)
            I_y_reinf_bot_2 = calc_I_y_rec(alpha_bot, n_reinf_bot_2, b_reinf_bot, h_reinf_bot)
                  + calc_I_y_rec_SA(alpha_bot, n_reinf_bot_2, b_reinf_bot, h_reinf_bot,
                  NA_z_bot, zA_reinf_bot_2)
            I_y_reinf_bot_3 = calc_I_y_rec(alpha_bot, n_reinf_bot_3, b_reinf_bot, h_reinf_bot)
                  + calc_I_y_rec_SA(alpha_bot, n_reinf_bot_3, b_reinf_bot, h_reinf_bot,
                  NA_z_bot, zA_reinf_bot_3)
```

```
            I_y_reinf_bot = I_y_reinf_bot_1 + I_y_reinf_bot_2 + I_y_reinf_bot_3

            I_z_reinf_bot = calc_I_z_rec(1, n_reinf_bot, b_reinf_bot, h_reinf_bot) +
                  calc_I_z_rec_SA(1, n_reinf_bot, b_reinf_bot, h_reinf_bot, NA_y_bot)

        ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Or
              Tabelle1.reinf_type_top_ComboBox = "threaded rod" Then
            I_y_reinf_bot_1 = calc_I_cir(1, n_reinf_bot_1, h_reinf_bot) + calc_I_y_cir_SA(1,
                  n_reinf_bot_1, h_reinf_bot, NA_z_bot, zA_reinf_bot_1)
            I_y_reinf_bot_2 = calc_I_cir(1, n_reinf_bot_2, h_reinf_bot) + calc_I_y_cir_SA(1,
                  n_reinf_bot_2, h_reinf_bot, NA_z_bot, zA_reinf_bot_2)
            I_y_reinf_bot_3 = calc_I_cir(1, n_reinf_bot_3, h_reinf_bot) + calc_I_y_cir_SA(1,
                  n_reinf_bot_3, h_reinf_bot, NA_z_bot, zA_reinf_bot_3)
            I_y_reinf_bot = I_y_reinf_bot_1 + I_y_reinf_bot_2 + I_y_reinf_bot_3

            I_z_reinf_bot = calc_I_cir(1, n_reinf_bot, h_reinf_bot) + calc_I_z_cir_SA(1,
                  n_reinf_bot, h_reinf_bot, NA_y_bot)

        End If
    Else
        I_y_reinf_bot = 0
        I_z_reinf_bot = 0
    End If

End If

Else
    I_y_reinf_bot = 0
    I_z_reinf_bot = 0
End If
If NA_z_bot > h_w / 2 Then
    I_y_wood = (1 / 12) * A_w * (h_w ^ 2) + A_w * (NA_z_bot - (h_w / 2)) ^ 2
ElseIf NA_z_bot < h_w / 2 Then
    I_y_wood = (1 / 12) * A_w * (h_w ^ 2) + A_w * (NA_z_top - (h_w / 2)) ^ 2
End If
I_z_wood = (1 / 12) * A_w * (b_w ^ 2)

I_y_t = I_y_wood + I_y_reinf_top + I_y_reinf_bot
    Tabelle2.Range("E21").Value = I_y_t

I_z_t = I_z_wood + I_z_reinf_top + I_z_reinf_bot
    Tabelle2.Range("I21").Value = I_z_t

End Sub
```

```
Private Sub zAdistopcomboBoxes()
h_reinf_top = Tabelle1.height_reinf_top_TextBox.Value
If Tabelle1.reinf_type_top_ComboBox = "horizontal plate" Then
    zA_edge_min_top = 8 * h_reinf_top
ElseIf Tabelle1.reinf_type_top_ComboBox = "reinforcement bar" Or Tabelle1.reinf_type_top_ComboBox
  = "threaded bar" Then
    zA_edge_min_top = 2.5 * h_reinf_top
End If

    Dim zA_dis_top As MSForms.ComboBox
    Set zA_dis_top = Tabelle2.zA_dis_top_ComboBox
If Tabelle1.reinf_type_top_ComboBox.Value = "vertical plate" Then
    With zA_dis_top
        .Clear
        .Value = "0"
    End With
ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "horizontal plate" Or
  Tabelle1.reinf_type_top_ComboBox.Value = "reinforcement bar" Or
  Tabelle1.reinf_type_top_ComboBox.Value = "threaded rod" Then
    With zA_dis_top
        .Clear
        .AddItem "0"
        .AddItem CStr(zA_edge_min_top)
        .ListIndex = 0
    End With
End If
```

```
Call zAdisbotcomboBoxes
End Sub
```

```
Private Sub zAdisbotcomboBoxes()
    h_reinf_bot = Tabelle1.height_reinf_bot_TextBox.Value

    Dim zA_dis_bot As MSForms.ComboBox
    Set zA_dis_bot = Tabelle2.zA_dis_bot_ComboBox

    If Tabelle1.reinf_type_bot_ComboBox.Value = "vertical plate" Then
        With zA_dis_bot
            .Clear
            .Value = "0"
        End With

    ElseIf Tabelle1.reinf_type_bot_ComboBox.Value = "horizontal plate" Or
          Tabelle1.reinf_type_bot_ComboBox.Value = "reinforcement bar" Or
          Tabelle1.reinf_type_bot_ComboBox.Value = "threaded rod" Then
        If Tabelle1.reinf_type_bot_ComboBox = "horizontal plate" Then
            zA_edge_min_bot = 8 * h_reinf_bot
        ElseIf Tabelle1.reinf_type_bot_ComboBox = "reinforcement bar" Or
              Tabelle1.reinf_type_bot_ComboBox = "threaded bar" Then
            zA_edge_min_bot = 2.5 * h_reinf_bot
        End If

        With zA_dis_bot
            .Clear
            .AddItem "0"
            .AddItem CStr(zA_edge_min_bot)
            .ListIndex = 0
        End With

    ElseIf Tabelle1.reinf_type_bot_ComboBox.Value = "same as top reinforcement" Then

        If Tabelle1.reinf_type_top_ComboBox.Value = "vertical plate" Then
        With zA_dis_bot
            .Clear
            .Value = "0"
        End With
        ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "horizontal plate" Or
              Tabelle1.reinf_type_top_ComboBox.Value = "reinforcement bar" Or
              Tabelle1.reinf_type_top_ComboBox.Value = "threaded rod" Then
        zA_edge_min_bot = zA_edge_min_top

            With zA_dis_bot
            .Clear
            .AddItem "0"
            .AddItem CStr(zA_edge_min_bot)
            .ListIndex = 0
        End With
        End If
    End If

End Sub
Option Explicit
' ############# moment of inertia ######################################
' rectangular
```

```
Public Function calc_I_y_rec(alpha, n, b, h)
    calc_I_y_rec = (1 / 12) * alpha * n * b * (h ^ 3)
End Function
```

```
Public Function calc_I_y_rec_SA(alpha, n, b, h, NA_z, zA)
    calc_I_y_rec_SA = alpha * n * b * h * (NA_z - zA) ^ 2
End Function
```

```
Public Function calc_I_z_rec(alpha, n, b, h)
    calc_I_z_rec = (1 / 12) * alpha * n * (b ^ 3) * h
End Function
```

```
Public Function calc_I_z_rec_SA(alpha, n, b, h, NA_y)
    calc_I_z_rec_SA = alpha * n * b * h * (NA_y / 2) ^ 2
End Function

Public Function calc_w_y_rec(alpha, n, b, h)
    calc_w_y_rec = (1 / 6) * alpha * n * b * (h ^ 2)
End Function

Public Function calc_w_z_rec(alpha, n, b, h)
    calc_w_z_rec = (1 / 6) * alpha * n * (b ^ 2) * h
End Function

' circular

Public Function calc_I_cir(alpha, n, d)
    calc_I_cir = alpha * n * (d / 2) ^ 4 * pi / 4
End Function

Public Function calc_I_y_cir_SA(alpha, n, d, NA_z, zA)
    calc_I_y_cir_SA = alpha * n * (d / 2) ^ 2 * pi * (NA_z - zA) ^ 2
End Function

Public Function calc_I_z_cir_SA(alpha, n, h, NA_y)
    calc_I_z_cir_SA = alpha * n * (h / 2) ^ 2 * pi * (NA_y / 2) ^ 2
End Function

' ############# stresses ######################################
' ####### flexural #######

Public Function calc_sigma(alpha, M, h, I_t)
    calc_sigma = -alpha * ((M * 10 ^ 6) * h) / I_t
End Function
' ####### normal stresses #######

Public Function calc_sigma_axial(P, E)
    calc_sigma_axial = (P * E) / (((A_reinf_fakt_top + A_reinf_fakt_bot + A_w) / 1000) * E_w)
End Function

' ############# strains ######################################

Public Function calc_eps(sigma, E)
    calc_eps = sigma / E
End Function
```

7.3.3. Reinforcement for Tension Perpendicular to the Grain

```
Sub worksheet_activate()

    If Tabelle1.wood_type_ComboBox.Value = "please choose" Or Tabelle1.wood_class_ComboBox.Value
        = "please choose" Then
        MsgBox "Please choose the material for the cross-section"
        Tabelle1.Select
        Exit Sub

    ElseIf Tabelle1.service_class_ComboBox.Value = "please choose" Or
        Tabelle1.loading_duration_ComboBox.Value = "please choose" Then
        MsgBox "Please the service class and/or load duration"
        Tabelle1.Select
        Exit Sub

    ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "please choose" Then
        MsgBox "Please the type of reinforcement"
        Tabelle1.Select
        Exit Sub

    ElseIf Tabelle1.Range("E73") = "" Or Tabelle1.Range("E74") = "" Or Tabelle1.Range("E75") = ""
        Then
```

```
        MsgBox "Please enter the properties of the rod"
        Tabelle1.Select
        Exit Sub
    End If
    Dim reinf_tpg_type As MSForms.ComboBox
    Set reinf_tpg_type = Tabelle6.reinf_tpg_type_ComboBox
    With reinf_tpg_type
        .Clear
        .AddItem "double tapered beam"
        .AddItem "curved beam"
        .AddItem "pitched cambered beam"
    End With
    reinf_tpg_type_ComboBox.Value = Range("A7").Value

    d_tpg = Tabelle1.height_reinf_top_TextBox.Value
    m_tpg_max = WorksheetFunction.RoundDown(((h - 2 * 2.5 * d_tpg) / (4 * d_tpg)) + 1, 0)

End Sub
```

```
Sub worksheet_deactivate()
Range("A7").Value = reinf_tpg_type_ComboBox.Value
End Sub
```

```
Sub reinf_tpg()
Call Tabelle1.input_data
Call basic_calc_conn
l_beam_tpg = Tabelle6.length_tpg_TextBox.Value * 1000
alpha_ap = Tabelle6.alpha_tpg_TextBox.Value
beta_tpg = Tabelle6.beta_tpg_TextBox.Value
m_tpg = Tabelle6.m_tbg_TextBox.Value
t_tpg = Tabelle6.t_tpg_TextBox.Value

If Tabelle6.pos_in_tbg_OptionButton.Value = True Then
    b_tpg = b_w - m_tpg * dia_reinf_top
Else
    b_tpg = b_w
End If

h_s = h_w
M_ap_d = Tabelle1.My_TextBox.Value
f_k_1_k = 4
f_k_1_d = kmod * f_k_1_k / gamma_w

If Tabelle1.reinf_type_top_ComboBox.Value = "threaded rod" Then
    Call area_threaded_rod
    If A_ef = "" Then
        MsgBox "Please choose only threaded rods with the following diameter" & vbNewLine &
              vbNewLine & "d = 6 mm" & vbNewLine & "d = 8 mm" & vbNewLine & "d = 10 mm" &
              vbNewLine & "d = 12 mm" & vbNewLine & "d = 16 mm" & vbNewLine & "d = 20 mm" &
              vbNewLine & "d = 24 mm" & vbNewLine & "d = 30 mm"
        Exit Sub
    Else
        A_tpg = A_ef
    End If
ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "reinforcement bar" Then
    A_tpg = calc_A_circ(1, dia_reinf_top)
End If


If Tabelle6.reinf_tpg_type_ComboBox.Value = "double tapered beam" Then

    r_in = 1.79769313486231E+308
    beta_tpg = 0

    h_ap = h_s + Tan(alpha_ap * pi / 180) * l_beam_tpg / 2
    c = h_ap

    h_c1 = h_s + Tan(alpha_ap * pi / 180) * (l_beam_tpg / 2 - c / 4)
    h_c2 = h_s + Tan(alpha_ap * pi / 180) * (l_beam_tpg / 2 - c / 2)
```

```
    r = r_in + 0.5 * h_ap
        Tabelle6.Range("I25").Value = "-"

    V_beam = ((1 - 0.25 * Tan(alpha_ap * pi / 180)) * b_tpg * h_ap ^ 2) / 1000 ^ 3

    k_dis_1 = 1.4
    k_dis_2 = 1.3

    k_p = 0.2 * Tan(alpha_ap * pi / 180)

ElseIf Tabelle6.reinf_tpg_type_ComboBox.Value = "curved beam" Then

    If Tabelle6.r_in_tpg_TextBox.Value = "-" Or Tabelle6.beta_tpg_TextBox.Value = "0" Then
    Exit Sub
    End If
    r_in = Tabelle6.r_in_tpg_TextBox.Value * 1000
    c = 2 * r_in * Sin(beta_tpg * pi / 180)
    If alpha_ap = beta_tpg Then

        h_ap = h_s

        h_c1 = Cos(alpha_ap * pi / 180) * h_s
        h_c2 = h_c1

        r = r_in + 0.5 * h_ap
            Tabelle6.Range("I25").Value = r

        V_beam = (((2 * beta_tpg * pi) / 360) * ((r + (h_ap / 2)) ^ 2 - (r - (h_ap / 2)) ^ 2) *
              b_tpg) / 1000 ^ 3


    Else

        h_ap = h_s + (l_beam_tpg / 2) * (Tan(alpha_ap * pi / 180) - Tan(beta_tpg * pi / 180)) +
              r_in * (Sin(beta_tpg * pi / 180) - Tan(beta_tpg * pi / 180) + Cos(beta_tpg * pi /
              180) - 1)

        h_c1 = Cos(alpha_ap * pi / 180) * (h_s + ((l_beam_tpg - (c / 2)) / 2) * (Tan(alpha_ap * pi
              / 180) - Tan(beta_tpg * pi / 180)))
        h_c2 = Cos(alpha_ap * pi / 180) * (h_s + ((l_beam_tpg - c) / 2) * (Tan(alpha_ap * pi /
              180) - Tan(beta_tpg * pi / 180)))


        r = r_in + 0.5 * h_ap
            Tabelle6.Range("I25").Value = r

        V_beam = (((2 * beta_tpg * pi) / 360) * ((r + (h_ap / 2)) ^ 2 - (r - (h_ap / 2)) ^ 2) *
              b_tpg) / 1000 ^ 3


    End If

    k_dis_1 = 1.4
    k_dis_2 = 1.15

    k_p = 0.25 * (h_ap / r)


ElseIf Tabelle6.reinf_tpg_type_ComboBox.Value = "pitched cambered beam" Then

    If Tabelle6.r_in_tpg_TextBox.Value = "-" Or Tabelle6.beta_tpg_TextBox.Value = "0" Then
        Exit Sub
    End If

    r_in = Tabelle6.r_in_tpg_TextBox.Value * 1000
    c = 2 * r_in * Sin(beta_tpg * pi / 180)
    If alpha_ap = beta_tpg Then

        h_ap = (c / 2) * Tan(alpha_ap * pi / 180) + (h_s / Cos(alpha_ap * pi / 180)) - r_in * (1 -
              Cos(alpha_ap * pi / 180))
```

```
        h_c1 = Cos(alpha_ap * pi / 180) * h_s
        h_c2 = h_c1

        r = r_in + 0.5 * h_ap
            Tabelle6.Range("I25").Value = r

    Else

        h_ap = h_s + (l_beam_tpg / 2) * (Tan(alpha_ap * pi / 180) - Tan(beta_tpg * pi / 180))
        h_ap = h_ap + (c / 2) * Tan(beta_tpg * pi / 180) - r_in * (1 - Cos(beta_tpg * pi / 180))

        h_c1 = Cos(alpha_ap * pi / 180) * (h_s + ((l_beam_tpg - (c / 2)) / 2) * (Tan(alpha_ap * pi
              / 180) - Tan(beta_tpg * pi / 180)))
        h_c2 = Cos(alpha_ap * pi / 180) * (h_s + ((l_beam_tpg - c) / 2) * (Tan(alpha_ap * pi /
              180) - Tan(beta_tpg * pi / 180)))

        r = r_in + 0.5 * h_ap
            Tabelle6.Range("I25").Value = r

    End If

    V_beam = (2 * (0.5 * (r_in + h_ap) ^ 2 * (Sin(beta_tpg * pi / 180) / (Sin((90 + (alpha_ap -
          beta_tpg)) * pi / 180))) * Sin((90 - alpha_ap) * pi / 180) - (beta_tpg / 360) * pi *
          r_in ^ 2) * b_tpg) / 1000 ^ 3
    k_dis_1 = 1.7
    k_dis_2 = 1.3

    k_5 = 0.2 * Tan(alpha_ap * pi / 180)
    k_6 = 0.25 - 1.5 * Tan(alpha_ap * pi / 180) + 2.6 * (Tan(alpha_ap * pi / 180)) ^ 2
    k_7 = 2.1 * Tan(alpha_ap * pi / 180) - 4 * (Tan(alpha_ap * pi / 180)) ^ 2

    k_p = k_5 + k_6 * (h_ap / r) + k_7 * (h_ap / r) ^ 2

End If
sigma_t_90_d = k_p * ((6 * M_ap_d * 10 ^ 6) / (b_tpg * h_ap ^ 2))

Tabelle6.Range("E26").Value = h_ap
' ### check if strengthening is needed ###
l_ad_tpg_1 = h_c1 / 2 - t_tpg
l_ad_tpg_2 = h_c2 / 2 - t_tpg
F_t_90_tpg_Rd_1 = calc_conn_pullout_1(f_reinf_top_yd, A_tpg)
F_t_90_tpg_Rd_2 = calc_conn_pullout_1(f_reinf_top_ud, A_tpg)
F_t_90_tpg_Rd_3_in = 0.5 * calc_conn_pullout_2(dia_reinf_top, l_ad_tpg_1, f_k_1_d)
F_t_90_tpg_Rd_3_out = 0.5 * calc_conn_pullout_2(dia_reinf_top, l_ad_tpg_2, f_k_1_d)
F_t_90_tpg_Rd_in = WorksheetFunction.Min(F_t_90_tpg_Rd_1, F_t_90_tpg_Rd_2, F_t_90_tpg_Rd_3_in)
F_t_90_tpg_Rd_out = WorksheetFunction.Min(F_t_90_tpg_Rd_1, F_t_90_tpg_Rd_2, F_t_90_tpg_Rd_3_out)

If   Tabelle1.wood_type_ComboBox.Value   =   "hardwood"   Or   Tabelle1.wood_type_ComboBox.Value   =
  "softwood" Then
    k_vol_1 = 1
ElseIf Tabelle1.wood_type_ComboBox.Value = "glulam" Then
    k_vol_1 = (0.01 / V_beam) ^ 0.2
End If

f_w_tpg_t90d_1 = k_vol_1 * k_dis_1 * Abs(f_w_t90d)
eta_tpg_t90d_1 = sigma_t_90_d / f_w_tpg_t90d_1
' check if reinforcement is needed
If eta_tpg_t90d_1 > 1 Then
    'yes

    k_vol_2 = (600 / h_ap) ^ 0.3
    f_w_tpg_t90d_2 = k_vol_2 * k_dis_2 * Abs(f_w_t90d)
    eta_tpg_t90d_2 = sigma_t_90_d / f_w_tpg_t90d_2

    ' check if constructive reinforcement is enough
    If eta_tpg_t90d_2 > 1 Then

        'no - reinforcement needed!

        Tabelle6.Range("F56").Value = "reinforcement needed"
        Tabelle6.Range("B69:J95").Font.ColorIndex = 1
```

```
        Tabelle6.m_tbg_TextBox.Enabled = True


        a_1_in = WorksheetFunction.RoundDown(F_t_90_tpg_Rd_in * m_tpg / (sigma_t_90_d * b_tpg), -
              1)

        If a_1_in < 250 Then
            Tabelle6.Range("E93").Font.ColorIndex = 3
        ElseIf a_1_in > 0.75 * h_ap Then
            a_1_in = 0.75 * h_ap
        End If

        n_tpg_in = WorksheetFunction.RoundUp(((c / 2) / a_1_in) + 1, 0)

        a_1_out = 3 / 2 * a_1_in

        If a_1_out > 0.75 * h_ap Then
            a_1_out = 0.75 * h_ap
        End If

        n_tpg_out = WorksheetFunction.RoundUp(c / (4 * a_1_out) + 1, 0)



    ElseIf eta_tpg_t90d_2 <= 1 Then
        Tabelle6.Range("F56").Value = "nominal reinforcement"
        Tabelle6.Range("B69:J95").Font.ColorIndex = 1
        Tabelle6.m_tbg_TextBox.Enabled = True
        Tabelle6.Range("H82:J95").Font.ColorIndex = 15


        'yes - how many rods are needed?
        a_1_in = F_t_90_tpg_Rd_in * ((m_tpg * 640) / (sigma_t_90_d * b_tpg ^ 2))
        If a_1_in < 250 Then
            Tabelle6.Range("I93").Font.ColorIndex = 3
        ElseIf a_1_in > 0.75 * h_ap Then
            a_1_in = 0.75 * h_ap
        End If
        n_tpg_in = WorksheetFunction.RoundUp((c / a_1_in) + 1, 0)

    End If

ElseIf eta_tpg_t90d_1 <= 1 Then
    'no
    MsgBox "no reinforcement needed"
    Tabelle6.Range("F56").Value = "no reinforcement needed"
    Tabelle6.Range("B69:J95").Font.ColorIndex = 15
    Tabelle6.m_tbg_TextBox.Enabled = False

End If


' VOLUMEN eintragen
Tabelle6.Range("I24").Value = c
Tabelle6.Range("I26").Value = b_tpg_net
If h_c2 = "" Then
    Tabelle6.Range("E27").Value = h_c1
Else
    Tabelle6.Range("E27").Value = h_c2
End If
Tabelle6.Range("I27").Value = V_beam

Tabelle6.Range("E71").Value = m_tpg_max

If k_5 = "" Then
    Tabelle6.Range("E45").Value = "-"
Else
    Tabelle6.Range("E45").Value = k_5
End If
If k_6 = "" Then
```

```
    Tabelle6.Range("I45").Value = "-"
Else
    Tabelle6.Range("I45").Value = k_6
End If
If k_7 = "" Then
    Tabelle6.Range("E46").Value = "-"
Else
    Tabelle6.Range("E46").Value = k_7
End If
If k_p = "" Then
    Tabelle6.Range("I46").Value = "-"
Else
    Tabelle6.Range("I46").Value = k_p
End If
Tabelle6.Range("E47").Value = sigma_t_90_d
Tabelle6.Range("I47").Value = sigma_t_90_red_d
Tabelle6.Range("E50").Value = k_dis_1
Tabelle6.Range("I50").Value = k_dis_2
Tabelle6.Range("E51").Value = k_vol_1
Tabelle6.Range("I51").Value = k_vol_2
Tabelle6.Range("E52").Value = f_w_tpg_t90d_1
Tabelle6.Range("I52").Value = f_w_tpg_t90d_2
Tabelle6.Range("E54").Value = eta_tpg_t90d_1
    If eta_tpg_t90d_1 > 1 Then
        Tabelle6.Range("E54").Font.ColorIndex = 3
    Else
        Tabelle6.Range("E54").Font.ColorIndex = 1
    End If

Tabelle6.Range("I54").Value = eta_tpg_t90d_2
    If eta_tpg_t90d_2 > 1 Then
        Tabelle6.Range("I54").Font.ColorIndex = 3
    Else
        Tabelle6.Range("I54").Font.ColorIndex = 1
    End If
Tabelle6.Range("E71").Value = d_tpg
Tabelle6.Range("E75").Value = f_reinf_top_yd
Tabelle6.Range("I75").Value = F_t_90_tpg_Rd_1
Tabelle6.Range("E76").Value = f_reinf_top_ud
Tabelle6.Range("I76").Value = F_t_90_tpg_Rd_2
Tabelle6.Range("E83").Value = f_k_1_d
Tabelle6.Range("E84").Value = l_ad_tpg_1
Tabelle6.Range("E85").Value = F_t_90_tpg_Rd_3_in
Tabelle6.Range("E91").Value = F_t_90_tpg_Rd_in
Tabelle6.Range("E93").Value = a_1_in
Tabelle6.Range("E95").Value = n_tpg_in
Tabelle6.Range("E99").Value = tau_ef_d_in
Tabelle6.Range("E10").Value = eta_tpg_in

If eta_tpg_t90d_2 > 1 Then
    Tabelle6.Range("I83").Value = f_k_1_d
    Tabelle6.Range("I84").Value = l_ad_tpg_2
    Tabelle6.Range("I85").Value = F_t_90_tpg_Rd_3_out
    Tabelle6.Range("I91").Value = F_t_90_tpg_Rd_out
    Tabelle6.Range("I93").Value = a_1_out
    Tabelle6.Range("I95").Value = n_tpg_out
    Tabelle6.Range("I99").Value = tau_ef_d_out
    Tabelle6.Range("I101").Value = eta_tpg_out
ElseIf eta_tpg_t90d_2 <= 1 Then
    Tabelle6.Range("I83").Value = ""
    Tabelle6.Range("I84").Value = ""
    Tabelle6.Range("I85").Value = ""
    Tabelle6.Range("I91").Value = ""
    Tabelle6.Range("I93").Value = ""
    Tabelle6.Range("I95").Value = ""
    Tabelle6.Range("I99").Value = ""
    Tabelle6.Range("I101").Value = ""
End If
```

```
End Sub
' ### COMBOBOXES ###
```

```
Private Sub reinf_tpg_type_ComboBox_Change()

If Tabelle6.reinf_tpg_type_ComboBox.Value = "double tapered beam" Then
    Tabelle6.Shapes("doubletaper_image").Visible = True
    Tabelle6.Shapes("curved_image").Visible = False
    Tabelle6.Shapes("pitchedcambered_image").Visible = False

    Tabelle6.r_in_tpg_TextBox.Enabled = False
        Tabelle6.r_in_tpg_TextBox.Value = "-"
    Tabelle6.beta_tpg_TextBox.Enabled = False
        Tabelle6.beta_tpg_TextBox.Value = 0

ElseIf Tabelle6.reinf_tpg_type_ComboBox.Value = "curved beam" Then
    Tabelle6.Shapes("doubletaper_image").Visible = False
    Tabelle6.Shapes("curved_image").Visible = True
    Tabelle6.Shapes("pitchedcambered_image").Visible = False

    Tabelle6.r_in_tpg_TextBox.Enabled = True
    Tabelle6.beta_tpg_TextBox.Enabled = True

ElseIf Tabelle6.reinf_tpg_type_ComboBox.Value = "pitched cambered beam" Then
    Tabelle6.Shapes("doubletaper_image").Visible = False
    Tabelle6.Shapes("curved_image").Visible = False
    Tabelle6.Shapes("pitchedcambered_image").Visible = True

    Tabelle6.r_in_tpg_TextBox.Enabled = True
    Tabelle6.beta_tpg_TextBox.Enabled = True

End If

'Call reinf_tpg
End Sub
```

```
Private Sub alpha_tpg_TextBox_LostFocus()
    Call reinf_tpg
End Sub
```

```
Private Sub beta_tpg_TextBox_LostFocus()
    Call reinf_tpg
End Sub
```

```
Private Sub h_s_tpg_TextBox_LostFocus()
    Call reinf_tpg
End Sub
```

```
Private Sub length_tpg_TextBox_LostFocus()
    Call reinf_tpg
End Sub
```

```
Private Sub m_tbg_TextBox_LostFocus()
    Call reinf_tpg
End Sub
```

```
Private Sub r_in_tpg_TextBox_LostFocus()
    Call reinf_tpg
End Sub
```

```
Private Sub t_tpg_TextBox_LostFocus()
    Call reinf_tpg
End Sub
```

7.3.4. Connections

7.3.4.1. Glued-in Rods

```
Sub worksheet_activate()
If Tabelle1.wood_type_ComboBox.Value = "please choose" Or Tabelle1.wood_class_ComboBox.Value =
  "please choose" Then
    MsgBox "Please choose the material for the cross-section"
    Tabelle1.Select
    Exit Sub

ElseIf Tabelle1.service_class_ComboBox.Value = "please choose" Or
  Tabelle1.loading_duration_ComboBox.Value = "please choose" Then
    MsgBox "Please the service class and/or load duration"
    Tabelle1.Select
    Exit Sub

ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "please choose" Or
  Tabelle1.reinf_type_top_ComboBox.Value = "vertical plate" Or
  Tabelle1.reinf_type_top_ComboBox.Value = "horizontal plate" Then
    MsgBox "Please choose a connection type"
    Tabelle1.Select
    Exit Sub

ElseIf Tabelle1.Range("E73") = "" Or Tabelle1.Range("E74") = "" Or Tabelle1.Range("E75") = ""
  Then
    MsgBox "Please enter the properties of the rod"
    Tabelle1.Select
    Exit Sub
End If
Call conn_bar
If Tabelle1.reinf_type_top_ComboBox.Value = "reinforcement bar" Then
    Tabelle3.Range("F23").Value = "reinforcement bar"
ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "threaded rod" Then
    Tabelle3.Range("F23").Value = "threaded rod"
End If

End Sub
```

```
Sub connection_moment_inertia()
Call Tabelle1.input_data
' ###### basics for calculations ############################
    ' penetration length

    l_ad_min_1 = 0.5 * d_conn ^ 2
    l_ad_min_2 = 10 * d_conn
    l_ad_min = WorksheetFunction.Max(l_ad_min_1, l_ad_min_2)
        Tabelle3.Range("E44").Value = l_ad_min
    l_ad = Tabelle3.l_ad_conn_TextBox.Value

    ' strength of the glue-line

    If l_ad <= 250 Then
        f_k_1_k = 4
    ElseIf l_ad > 250 And l_ad <= 500 Then
        f_k_1_k = 5.25 - 0.005 * l_ad
    ElseIf l_ad > 500 And l_ad <= 1000 Then
        f_k_1_k = 3.5 - 0.0015 * l_ad
    End If
    rho_k_1 = rho_k

    ' strength of the wood

    f_h_1_k = 0.125 * 0.082 * (1 - 0.01 * d_conn) * rho_k_1
    f_k_1_d = calc_f_d(f_k_1_k, kmod, gamma_w)
        Tabelle3.Range("E45").Value = f_k_1_k

    f_h_1_d = calc_f_d(f_h_1_k, kmod, gamma_w)
        Tabelle3.Range("I45").Value = f_h_1_k
```

```
' ####### glued-in rods and bars #######

If Tabelle1.reinf_type_top_ComboBox.Value = "threaded rod" Then
        Call area_threaded_rod
        A_conn = A_ef
    If A_ef = "" Then
        MsgBox "Please choose only threaded rods with the following diameter" & vbNewLine &
              vbNewLine & "d = 6 mm" & vbNewLine & "d = 8 mm" & vbNewLine & "d = 10 mm" &
              vbNewLine & "d = 12 mm" & vbNewLine & "d = 16 mm" & vbNewLine & "d = 20 mm" &
              vbNewLine & "d = 24 mm" & vbNewLine & "d = 30 mm"
        Exit Sub
    End If
ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "reinforcement bar" Then
    A_conn = calc_A_circ(1, d_conn)
End If
I_y_conn = calc_I_cir(1, 1, d_conn)
I_z_conn = calc_I_cir(1, 1, d_conn)
Call moment_inertia_conn_cir

' ##### CALCULATION ######################################

    ' ### axial load ###

    A_w_net = WorksheetFunction.Min(A_w - n_z * n_y * d_conn, n_z * n_y * 36 * d_conn ^ 2)

    F_ax_Rd_1 = calc_conn_pullout_1(f_conn_yd, A_conn)
    F_ax_Rd_2 = calc_conn_pullout_1(f_conn_ud, A_conn)
    F_ax_Rd_3 = calc_conn_pullout_2(d_conn, l_ad, f_k_1_d)
    F_w_Rd = A_w_net * f_w_t0d / (n_y * n_z)

    If F_ax_Rd_3 < F_ax_Rd_1 And F_ax_Rd_3 < F_ax_Rd_2 And F_ax_Rd_3 < F_w_Rd Then
        MsgBox "Please be reminded that the connection fails due to adhesive failure," & vbNewLine
              & "this is considered as a brittle failure." & vbNewLine & vbNewLine & "Please
              choose a smaller diameter to achieve ductile steel failure!"
    End If

    If F_w_Rd < F_ax_Rd_1 And F_w_Rd < F_ax_Rd_2 And F_w_Rd < F_ax_Rd_3 Then
        MsgBox "Please be reminded that the connection fails due to timber failure," & vbNewLine &
              "this is considered as a brittle failure." & vbNewLine & vbNewLine & "Please choose
              a smaller diameter to achieve ductile steel failure!"
    End If

    F_ax_Rd = WorksheetFunction.Min(F_ax_Rd_1, F_ax_Rd_2, F_ax_Rd_3, F_w_Rd)

    F_ax_Ed_N = (N_x * 1000) / (n_z * n_y)
    F_ax_Ed_My = (((M_y * 1000000) / I_y_conn) * ((h_w - 2 * zA_edge) / 2 + d_conn / 2)) * A_conn
    F_ax_Ed_Mz = (((Abs(M_z) * 1000000) / I_z_conn) * ((b_w - 2 * yA_edge) / 2 + d_conn / 2)) *
          A_conn
    F_ax_Ed = F_ax_Ed_N + F_ax_Ed_My + F_ax_Ed_Mz

    eta_conn_ax = F_ax_Ed / F_ax_Rd

    ' #### lateral load ###

    M_y_Rk = 0.3 * f_conn_uk * d_conn ^ 2.6
        Tabelle3.Range("E47").Value = M_y_Rk
    F_v_Rk = calc_conn_shear(beta, M_y_Rk, f_k_1_k, d_conn)
    F_v_Rd = kmod * F_v_Rk / gamma_conn_1

    F_v_Ed_Vy = (V_y * 1000) / (n_z * n_y)
    F_v_Ed_Vz = (V_z * 1000) / (n_z * n_y)
    F_v_Ed = ((F_v_Ed_Vy) ^ 2 + (F_v_Ed_Vz) ^ 2) ^ 0.5

    eta_conn_v = F_v_Ed / F_v_Rd


    ' ### combined ###

    Tabelle3.Range("I47").Value = A_w_net

    eta_conn_com = eta_conn_ax ^ 2 + eta_conn_v ^ 2
```

```
    Tabelle3.Range("E49").Value = F_ax_Rd_1
    Tabelle3.Range("E50").Value = F_ax_Rd_2
    Tabelle3.Range("E51").Value = F_ax_Rd_3
    Tabelle3.Range("E52").Value = F_w_Rd
    Tabelle3.Range("E53").Value = F_ax_Rd
    Tabelle3.Range("I49").Value = F_ax_Ed_N
    Tabelle3.Range("I50").Value = F_ax_Ed_My
    Tabelle3.Range("I51").Value = F_ax_Ed_Mz
    Tabelle3.Range("I53").Value = F_ax_Ed
    Tabelle3.Range("H54").Value = eta_conn_ax

    Tabelle3.Range("E58").Value = F_v_Rd
    Tabelle3.Range("I58").Value = F_v_Ed
    Tabelle3.Range("H59").Value = eta_conn_v
    Tabelle3.Range("H61").Value = eta_conn_com
End Sub
```

```
Sub conn_bar()
If Tabelle3.n_z_1_TextBox.Value = "1" And Tabelle3.conn_choice_z_ComboBox.Value = "version 1"
  Then
    Tabelle3.n_z_1_TextBox.Value = 2
    MsgBox "The minimum number of rods was change to 2"

ElseIf Tabelle3.n_y_1_TextBox.Value = "1" And Tabelle3.conn_choice_y_ComboBox.Value = "version 1"
  Then
    Tabelle3.n_y_1_TextBox.Value = 2
    MsgBox "The minimum number of rods was change to 2"

End If


' ####### z-axis ########
d_conn = Tabelle1.height_reinf_top_TextBox.Value
h = Tabelle1.wood_height_TextBox.Value
zA_edge_min = 2.5 * d_conn
zA_edge = zA_edge_min
zA_middle_min = 5 * d_conn
n_z_max = WorksheetFunction.RoundDown(((h - 2 * zA_edge) / zA_middle_min) + 1, 0)
If n_z_max < 2 Then
    MsgBox "Please choose a smaller rod diameter"
    Exit Sub
End If
n_z_1 = n_z_1_TextBox.Value

If conn_choice_z_ComboBox = "version 1" Then
    Tabelle3.Range("D29:F39").Font.ColorIndex = 1
    Tabelle3.Range("D31:F32").Font.ColorIndex = 15
    Tabelle3.Range("D39:F39").Font.ColorIndex = 15
    n_z_1_TextBox.Enabled = True
    fact_n_z_2_TextBox.Enabled = False

    zA_middle_1 = (h - 2 * zA_edge) / (n_z_1 - 1)
    zA_middle_2 = 0

    n_z_2 = 0

    n_z = n_z_1


ElseIf conn_choice_z_ComboBox = "version 2" Then
    If n_z_1_TextBox.Value = 1 Then
        MsgBox "Please choose either two rods or select 'version 1'"
        Exit Sub
    End If

    Tabelle3.Range("D29:F41").Font.ColorIndex = 1
    n_z_1_TextBox.Enabled = True
    fact_n_z_2_TextBox.Enabled = True
    zA_middle_1 = zA_middle_min
```

```
    zA_middle_2 = fact_n_z_2_TextBox.Value * zA_middle_1                                     '  factor
          for spacing zA_middle_2

    n_z_2  =  WorksheetFunction.RoundDown(((h  -  2  *  (zA_edge  +  (n_z_1  -  1)  *  zA_middle_1))  /
          zA_middle_2) - 1, 0)
    If n_z_2 < 0 Then
       n_z_2 = 0
       zA_middle_2 = 0
    Else
       zA_middle_2 = ((h - 2 * (zA_edge + (n_z_1 - 1) * zA_middle_1)) / (n_z_2 + 1))
    End If
    n_z = n_z_1 * 2 + n_z_2
    n_z_max = WorksheetFunction.RoundDown((h - 2 * zA_middle_2 - 2 * zA_edge) / (2 * zA_middle_1)
          + 1, 0)

ElseIf conn_choice_z_ComboBox = "version 3" Then
    Tabelle3.Range("D29:F41").Font.ColorIndex = 1
    Tabelle3.Range("D31:F32").Font.ColorIndex = 15
    n_z_1_TextBox.Enabled = True
    fact_n_z_2_TextBox.Enabled = False
    zA_middle_1 = zA_middle_min

    If zA_middle_2 < 0 Then
    zA_middle_2 = 0
    Else
    zA_middle_2 = (h - 2 * (zA_edge + (n_z_1 - 1) * zA_middle_1))
    End If

    n_z_2 = 0

    n_z = n_z_1 * 2


    n_z_max = WorksheetFunction.RoundDown(n_z_max / 2, 0)

ElseIf conn_choice_z_ComboBox = "please choose" Then
    Tabelle3.Range("D29:F41").Font.ColorIndex = 15
    n_z_1_TextBox.Enabled = False
    fact_n_z_2_TextBox.Enabled = False

End If

' ####### y-axis ########
d_conn = Tabelle1.height_reinf_top_TextBox.Value
b_w = Tabelle1.wood_width_TextBox.Value
yA_edge_min = 2.5 * d_conn
yA_edge = yA_edge_min
yA_middle_min = 5 * d_conn
n_y_max = WorksheetFunction.RoundDown(((b_w - 2 * yA_edge_min) / yA_middle_min) + 1, 0)
If n_y_max < 2 Then
    MsgBox "Please choose a smaller rod diameter"
    Exit Sub
End If

n_y_1 = n_y_1_TextBox.Value
If conn_choice_y_ComboBox = "version 1" Then
    Tabelle3.Range("H29:J41").Font.ColorIndex = 1
    Tabelle3.Range("H31:J33").Font.ColorIndex = 15
    Tabelle3.Range("H39:J40").Font.ColorIndex = 15
    n_y_1_TextBox.Enabled = True
    fact_n_y_2_TextBox.Enabled = False

    yA_middle_1 = (b_w - 2 * yA_edge) / (n_y_1 - 1)
    n_y_2 = 0
    yA_middle_2 = 0

    n_y = n_y_1 + n_y_2

ElseIf conn_choice_y_ComboBox = "version 2" Then
    If n_y_1_TextBox.Value = 1 Then
       MsgBox "Please choose either two rods or select 'version 1'"
```

```
        Exit Sub
    End If
    Tabelle3.Range("H29:J39").Font.ColorIndex = 1
    n_y_1_TextBox.Enabled = True
    fact_n_y_2_TextBox.Enabled = True
    yA_middle_1 = yA_middle_min
    yA_middle_2 = fact_n_y_2_TextBox.Value * yA_middle_1                          ' factor
          for spacing zA_middle_2

    n_y_2 = WorksheetFunction.RoundDown(((b_w - 2 * (yA_edge + (n_y_1 - 1) * yA_middle_1)) /
          yA_middle_2) - 1, 0)
    If n_y_2 < 0 Then
        n_y_2 = 0
    Else
        yA_middle_2 = ((b_w - 2 * (yA_edge + (n_y_1 - 1) * yA_middle_1)) / (n_y_2 + 1))
    End If
    n_y = n_y_1 * 2 + n_y_2

    n_y_max = WorksheetFunction.RoundDown((b_w - 2 * yA_middle_2 - 2 * yA_edge) / (2 *
          yA_middle_1) + 1, 0)

ElseIf conn_choice_y_ComboBox = "version 3" Then
    Tabelle3.Range("H29:J39").Font.ColorIndex = 1
    Tabelle3.Range("H31:J32").Font.ColorIndex = 15
    n_y_1_TextBox.Enabled = True
    fact_n_y_2_TextBox.Enabled = False

    yA_middle_1 = yA_middle_min
    yA_middle_2 = (b_w - 2 * (yA_edge + (n_y_1 - 1) * yA_middle_1))
    n_y_2 = 0
    n_y = n_y_1 * 2

    n_y_max = WorksheetFunction.RoundDown(n_y_max / 2, 0)

ElseIf conn_choice_y_ComboBox = "please choose" Then
    Tabelle3.Range("H29:J41").Font.ColorIndex = 15
    n_y_1_TextBox.Enabled = False
    fact_n_y_2_TextBox.Enabled = False
End If
Tabelle3.Range("E29").Value = n_z_max
Tabelle3.Range("E32").Value = n_z_2
Tabelle3.Range("I29").Value = n_y_max
Tabelle3.Range("I32").Value = n_y_2
Tabelle3.Range("E34").Value = zA_edge_min
Tabelle3.Range("E35").Value = zA_middle_min
Tabelle3.Range("E36").Value = zA_middle_1
Tabelle3.Range("E37").Value = zA_middle_2
Tabelle3.Range("I34").Value = yA_edge_min
Tabelle3.Range("I35").Value = yA_middle_min
Tabelle3.Range("I36").Value = yA_middle_1
Tabelle3.Range("I37").Value = yA_middle_2

If n_z_max < n_z_1 Then
    Tabelle3.Range("E29").Font.ColorIndex = 3
    Exit Sub
End If
If n_y_max < n_y_1 Then
    Tabelle3.Range("I29").Font.ColorIndex = 3
    Exit Sub
End If
Tabelle3.Range("F39").Font.ColorIndex = 2
Call connection_moment_inertia

End Sub

' ######## ComboBoxes ####################################
' ### z-axis ###
```

```
Private Sub conn_choice_z_ComboBox_change()
If ActiveSheet.Name = "input" Then
    Exit Sub
```

```
End If

If conn_choice_z_ComboBox.Value = "version 1" Then
    Tabelle3.Shapes("z_version1_grafik").Visible = True
    Tabelle3.Shapes("z_version2_grafik").Visible = False
    Tabelle3.Shapes("z_version3_grafik").Visible = False

ElseIf conn_choice_z_ComboBox.Value = "version 2" Then
    Tabelle3.Shapes("z_version1_grafik").Visible = False
    Tabelle3.Shapes("z_version2_grafik").Visible = True
    Tabelle3.Shapes("z_version3_grafik").Visible = False

ElseIf conn_choice_z_ComboBox.Value = "version 3" Then
    Tabelle3.Shapes("z_version1_grafik").Visible = False
    Tabelle3.Shapes("z_version2_grafik").Visible = False
    Tabelle3.Shapes("z_version3_grafik").Visible = True

ElseIf conn_choice_z_ComboBox.Value = "please choose" Then
    Tabelle3.Shapes("z_version1_grafik").Visible = False
    Tabelle3.Shapes("z_version2_grafik").Visible = False
    Tabelle3.Shapes("z_version3_grafik").Visible = False

End If

Call conn_bar
End Sub
' ### y-axis ###
```

```
Private Sub conn_choice_y_ComboBox_change()
If ActiveSheet.Name = "input" Then
    Exit Sub
End If

If conn_choice_y_ComboBox.Value = "version 1" Then
    Tabelle3.Shapes("y_version1_grafik").Visible = True
    Tabelle3.Shapes("y_version2_grafik").Visible = False
    Tabelle3.Shapes("y_version3_grafik").Visible = False

ElseIf conn_choice_y_ComboBox.Value = "version 2" Then
    Tabelle3.Shapes("y_version1_grafik").Visible = False
    Tabelle3.Shapes("y_version2_grafik").Visible = True
    Tabelle3.Shapes("y_version3_grafik").Visible = False

ElseIf conn_choice_y_ComboBox.Value = "version 3" Then
    Tabelle3.Shapes("y_version1_grafik").Visible = False
    Tabelle3.Shapes("y_version2_grafik").Visible = False
    Tabelle3.Shapes("y_version3_grafik").Visible = True

ElseIf conn_choice_y_ComboBox.Value = "please choose" Then
    Tabelle3.Shapes("y_version1_grafik").Visible = False
    Tabelle3.Shapes("y_version2_grafik").Visible = False
    Tabelle3.Shapes("y_version3_grafik").Visible = False

End If
Call conn_bar
End Sub
' #### TextBoxes ####
```

```
Private Sub l_ad_conn_TextBox_LostFocus()
  Call conn_choice_z_ComboBox_change
End Sub

' ### z-axis ###
```

```
Private Sub fact_n_z_2_TextBox_LostFocus()
  Call conn_choice_z_ComboBox_change
End Sub
```

```
Private Sub n_z_1_TextBox_LostFocus()
  Call conn_choice_z_ComboBox_change
End Sub
```

```
Private Sub zA_edge_TextBox_LostFocus()
  Call conn_choice_z_ComboBox_change
End Sub

' ### y-axis ###
```

```
Private Sub fact_n_y_2_TextBox_LostFocus()
  Call conn_choice_y_ComboBox_change
End Sub
```

```
Private Sub n_y_1_TextBox_LostFocus()
  Call conn_choice_y_ComboBox_change
End Sub
```

```
Private Sub yA_edge_TextBox_LostFocus()
  Call conn_choice_y_ComboBox_change
End Sub
```

7.3.4.2. Perforated Plates

```
Sub worksheet_activate()

    If Tabelle1.wood_type_ComboBox.Value = "please choose" Or Tabelle1.wood_class_ComboBox.Value
          = "please choose" Then
        MsgBox "Please choose the material for the cross-section"
        Tabelle1.Select
        Exit Sub

    ElseIf Tabelle1.service_class_ComboBox.Value = "please choose" Or
          Tabelle1.loading_duration_ComboBox.Value = "please choose" Then
        MsgBox "Please the service class and/or load duration"
        Tabelle1.Select
        Exit Sub

    ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "please choose" Or
          Tabelle1.reinf_type_top_ComboBox.ListIndex = "reinforcement bar" Or
          Tabelle1.reinf_type_top_ComboBox.Value = "threaded rod" Then
        MsgBox "Please choose a connection type"
        Tabelle1.Select
        Exit Sub

    ElseIf Tabelle1.Range("E73") = "" Or Tabelle1.Range("E74") = "" Or Tabelle1.Range("E75") = ""
          Then
        MsgBox "Please enter the properties of the plate"
        Tabelle1.Select
        Exit Sub
    End If
    Call Tabelle1.input_data
    If Tabelle1.reinf_type_top_ComboBox.Value = "vertical plate" Then
        Tabelle7.Rows("17:20").Font.ColorIndex = 15
        Tabelle7.Rows("24:27").Font.ColorIndex = 1
        Tabelle7.Range("F9").Value = "vertical plate"

        max_b_perp = WorksheetFunction.Min(h_w - 2 * 20, 1260)

    ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "horizontal plate" Then
        Tabelle7.Rows("17:20").Font.ColorIndex = 1
        Tabelle7.Rows("24:27").Font.ColorIndex = 15
        Tabelle7.Range("F9").Value = "horizontal plate"

        max_b_perp = WorksheetFunction.Min(b_w - 2 * 20, 1260)
    End If

    Tabelle7.Range("E32").Value = max_b_perp
```

```
    max_h_perp = 300
       Tabelle7.Range("I32").Value = max_h_perp
    d_perp = 10
       Tabelle7.Range("E34").Value = d_perp
    t_perp = 2.5
       Tabelle7.Range("I34").Value = t_perp

    Tabelle7.n_1_perp_TextBox.Value = n_max

    Tabelle7.width_perp_TextBox.Value = max_b_perp
    Tabelle7.height_perp_TextBox.Value = max_h_perp
    Call conn_choice_perp_ComboBox_change
    conn_choice_perp_ComboBox.Value = Range("A4").Value



End Sub
```

```
Sub worksheet_deactivate()
Range("A4").Value = conn_choice_perp_ComboBox.Value
End Sub
```

```
Sub connection_moment_inertia()
Call Tabelle1.input_data
b_perp = width_perp_TextBox.Value
l_ad = height_perp_TextBox.Value
d_perp = Tabelle7.Range("E34").Value
t_perp = Tabelle7.Range("I34").Value
'Call width_perp_TextBox_LostFocus
' ###### basics for calculations ############################


    ' strength of the glue-line

    If l_ad <= 250 Then
       f_k_1_k = 4
    ElseIf l_ad > 250 And l_ad <= 500 Then
       f_k_1_k = 5.25 - 0.005 * l_ad
    ElseIf l_ad > 500 And l_ad <= 1000 Then
       f_k_1_k = 3.5 - 0.0015 * l_ad
    End If
    f_k_1_d = calc_f_d(f_k_1_k, kmod, gamma_w)
       Tabelle3.Range("E45").Value = f_k_1_k


    ' strength of the wood

    f_h_1_k = 0.125 * 0.082 * (1 - 0.01 * d_perp) * rho_k_1
    f_h_1_d = calc_f_d(f_h_1_k, kmod, gamma_w)
       Tabelle3.Range("I45").Value = f_h_1_k



    F_AD_Rk = Tabelle7.Range("E49").Value

    m_perp_AD = Tabelle7.Range("E36").Value
    n_perp_AD = Tabelle7.Range("I36").Value

    If Tabelle7.n_1_perp_TextBox.Value = 0 Then
       Exit Sub
    End If

    A_perp = calc_A(1, t_perp, b_perp - m_perp_AD * d_perp)
    n_AD = n_perp_AD * m_perp_AD

    I_p_AD = (n_AD / 12) * ((n_perp_AD ^ 2 - 1) * 15 ^ 2 + (m_perp_AD ^ 2 - 1) * 15 ^ 2)

' ####### vertical plate #######
If Tabelle1.reinf_type_top_ComboBox.Value = "vertical plate" Then
```

```
    I_y_perp = calc_I_y_rec(1, 1, t_perp, b_perp - m_perp_AD * d_perp)
    w_y_perp = calc_w_y_rec(1, 1, t_perp, b_perp - m_perp_AD * d_perp)
    I_z_perp = calc_I_z_rec(1, 1, t_perp, b_perp - m_perp_AD * d_perp)
    w_z_perp = calc_w_z_rec(1, 1, t_perp, b_perp - m_perp_AD * d_perp)

    Call moment_inertia_conn_vertical

    ' ##### CALCULATION #######################################

    ' ### steel plate ###

        F_SP_Ed_N = (N_x * 1000) / n_perp
        F_SP_Ed_My = ((M_y * 1000000) / (n_perp * w_y_perp)) * A_perp
        F_SP_Ed_Mz = ((M_z * 1000000) / I_z_perp) * (b_w - 2 * yA_edge) / 2 * A_perp

        F_SP_Ed_Vy = (V_y * 1000) / n_perp
        F_SP_Ed_Vz = (V_z * 1000) / n_perp


    ' ### adhesive dowels ###

        F_AD_Ed_N = ((N_x * 1000) + F_SP_Ed_Mz) / (n_perp * n_AD)
        F_AD_Ed_V = (V_z * 1000) / (n_perp * n_AD)
        F_AD_Ed_M = ((M_y * 1000000) / (n_perp * I_p_AD)) * d_mn_perp



' ####### horizontal plate #######
ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "horizontal plate" Then
    I_y_perp = calc_I_y_rec(1, 1, b_perp - m_perp_AD * d_perp, t_perp)
    w_y_perp = calc_w_y_rec(1, 1, b_perp - m_perp_AD * d_perp, t_perp)
    I_z_perp = calc_I_z_rec(1, 1, b_perp - m_perp_AD * d_perp, t_perp)
    w_z_perp = calc_w_z_rec(1, 1, b_perp - m_perp_AD * d_perp, t_perp)

    Call moment_inertia_conn_horizontal

    ' ##### CALCULATION #######################################

    ' ### steel plate ###

        F_SP_Ed_N = (N_x * 1000) / n_perp
        F_SP_Ed_Mz = ((M_z * 1000000) / (n_perp * w_z_perp)) * A_perp
        F_SP_Ed_My = ((M_y * 1000000) / I_y_perp) * (h_w - 2 * zA_edge) / 2 * A_perp

        F_SP_Ed_Vy = (V_y * 1000) / n_perp
        F_SP_Ed_Vz = (V_z * 1000) / n_perp


    ' ### adhesive dowels ###

        F_AD_Ed_N = ((N_x * 1000) + F_SP_Ed_My) / (n_perp * n_AD)
        F_AD_Ed_V = (V_z * 1000) / (n_perp * n_AD)
        F_AD_Ed_M = ((M_z * 1000000) / (n_perp * I_p_AD)) * d_mn_perp

End If
' ## steel plate ##
F_SP_Ed = F_SP_Ed_N + F_SP_Ed_My + F_SP_Ed_Mz
F_SP_Ed_V = F_SP_Ed_Vy + F_SP_Ed_Vz
F_SP_Rd = WorksheetFunction.Min(0.9 * A_perp * f_conn_uk / (gamma_conn_2), A_perp * f_conn_yk /
  (gamma_conn_1))
F_SP_Rd_V = f_conn_yk * A_perp / (3 ^ -0.5 * gamma_conn_2)

eta_SP_NM = F_SP_Ed / F_SP_Rd
eta_SP_V = F_SP_Ed_V / F_SP_Rd_V
eta_SP = eta_SP_NM + eta_SP_V

' ## adhesive dowel ##
F_AD_Ed = (F_AD_Ed_N ^ 2 + F_AD_Ed_V ^ 2) ^ 0.5 + F_AD_Ed_M
F_AD_Rd = calc_f_d(F_AD_Rk, kmod, gamma_w)
eta_AD = F_AD_Ed / F_AD_Rd
```

```
' ## timber ##
A_w_net = A_w - (t_perp - b_perp) * n_perp
F_w_Rd = A_w_net * 0.8 * f_w_t0d
eta_w = F_SP_Ed / F_w_Rd
    ' # block shear #


    If Tabelle1.reinf_type_top_ComboBox.Value = "vertical plate" Then
        t_1 = yA_middle_1
        t_2 = yA_middle_2
    ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "horizontal plate" Then
        t_1 = zA_middle_1
        t_2 = zA_middle_2
    End If

    A_net_t_a = (b_perp - 2 * 2.5) * t_1
    A_net_v_a = 2 * (h_perp - 2.5) * ((b_perp - 2 * 2.5) + t_1)
    A_net_t_b = (b_perp + 2 * 10) * t_1
    A_net_v_b = 2 * (h_perp - 2.5) * (b_perp + 2 * 10)


    F_bs_Rd_a = WorksheetFunction.Max(1.5 * A_net_t_a * f_w_t0d, A_net_v_a * f_w_vd)
    F_bs_Rd_b = WorksheetFunction.Max(1.5 * A_net_t_b * f_w_t0d, A_net_v_b * f_w_vd)

    F_bs_Rd = WorksheetFunction.Min(F_bs_Rd_a, F_bs_Rd_b)

    If F_SP_Ed_N > 0 Then
        eta_bs = F_SP_Ed_N / F_bs_Rd
    Else
        eta_bs = ""
    End If



eta_conn_plate = WorksheetFunction.Max(eta_AD, eta_GL, eta_SP)

' ###### FILLING THE SHEET ##################
Tabelle7.Range("E52").Value = F_AD_Ed_N
Tabelle7.Range("E53").Value = F_AD_Ed_V
Tabelle7.Range("E54").Value = F_AD_Ed_M
Tabelle7.Range("E55").Value = F_AD_Ed
Tabelle7.Range("E56").Value = F_AD_Rd
Tabelle7.Range("E58").Value = eta_AD

Tabelle7.Range("I52").Value = F_SP_Ed
Tabelle7.Range("I53").Value = F_w_Rd
Tabelle7.Range("I54").Value = eta_w
Tabelle7.Range("I55").Value = F_SP_Ed_N
Tabelle7.Range("I56").Value = F_bs_Rd
Tabelle7.Range("I58").Value = eta_bs

Tabelle7.Range("E63").Value = F_SP_Ed_N
Tabelle7.Range("E64").Value = F_SP_Ed_My
Tabelle7.Range("E65").Value = F_SP_Ed_Mz
Tabelle7.Range("E66").Value = F_SP_Ed
Tabelle7.Range("E67").Value = F_SP_Rd
Tabelle7.Range("E69").Value = eta_SP_NM
Tabelle7.Range("I63").Value = F_SP_Ed_Vy
Tabelle7.Range("I64").Value = F_SP_Ed_Vz
Tabelle7.Range("I65").Value = F_SP_Ed_V
Tabelle7.Range("I67").Value = F_SP_Rd_V
Tabelle7.Range("I69").Value = eta_SP_V
Tabelle7.Range("H71").Value = eta_SP
Tabelle7.Range("H78").Value = eta_conn_plate
End Sub

' ######## ComboBoxes ###################################

' ### z-axis ###
```

```
Private Sub conn_choice_perp_ComboBox_change()
```

```
If ActiveSheet.Name = "input" Then
    Exit Sub
End If

' plates
If Tabelle1.reinf_type_top_ComboBox.Value = "vertical plate" Then
    Tabelle7.Shapes("horizontal_Version1_Grafik").Visible = False
    Tabelle7.Shapes("horizontal_Version2_Grafik").Visible = False
    Tabelle7.Shapes("horizontal_Version3_Grafik").Visible = False

    Tabelle7.Range("B13:J78").Font.ColorIndex = 15

    b_w = Tabelle1.wood_width_TextBox.Value

    yA_edge_min = 20
    yA_middle_min = 40

    yA_edge = yA_edge_min

    n_max = WorksheetFunction.RoundDown(((b_w - 2 * yA_edge_min) / yA_middle_min) + 1, 0)
    n_1 = n_1_perp_TextBox.Value

    If n_max < 2 Then
    MsgBox "This cross-section is too small for efficient connection"
    Exit Sub
    End If

    If conn_choice_perp_ComboBox = "version 1" Then

        Tabelle7.Shapes("vertical_Version1_Grafik").Visible = True
        Tabelle7.Shapes("vertical_Version2_Grafik").Visible = False
        Tabelle7.Shapes("vertical_Version3_Grafik").Visible = False
        Tabelle7.Range("B13:J78").Font.ColorIndex = 1
        Tabelle7.Range("B18:J19").Font.ColorIndex = 15
        Tabelle7.Range("H13:J14").Font.ColorIndex = 15
        Tabelle7.Range("H26:J26").Font.ColorIndex = 15

        n_1_perp_TextBox.Enabled = True
        fact_n_2_perp_TextBox.Enabled = False
        width_perp_TextBox.Enabled = True
        height_perp_TextBox.Enabled = True

        yA_middle_1 = (b_w - 2 * yA_edge) / (n_1 - 1)

        n_2 = 0
        yA_middle_2 = 0

        n_perp = n_1


  ElseIf conn_choice_perp_ComboBox = "version 2" Then

        Tabelle7.Shapes("vertical_Version1_Grafik").Visible = False
        Tabelle7.Shapes("vertical_Version2_Grafik").Visible = True
        Tabelle7.Shapes("vertical_Version3_Grafik").Visible = False
        Tabelle7.Range("B13:J78").Font.ColorIndex = 1
        Tabelle7.Range("B18:J19").Font.ColorIndex = 15

        n_1_perp_TextBox.Enabled = True
        fact_n_2_perp_TextBox.Enabled = True
        width_perp_TextBox.Enabled = True
        height_perp_TextBox.Enabled = True

        yA_middle_1 = yA_middle_min
        yA_middle_2 = fact_n_2_perp_TextBox.Value * yA_middle_1                                 '
              factor for spacing yA_middle_2

        n_2 = WorksheetFunction.RoundDown(((b_w - (2 * yA_edge + 2 * (n_1 - 1) * yA_middle_1)) /
              yA_middle_2) - 1, 0)
        If n_2 < 0 Then
            n_2 = 0
```

```
        Else
        yA_middle_2 = ((b_w - 2 * (yA_edge + (n_1 - 1) * yA_middle_1)) / (n_2 + 1))
        End If

        n_max  =  WorksheetFunction.RoundDown((b_w  -  2  *  yA_middle_2  -  2  *  yA_edge)  /  (2  *
              yA_middle_1) + 1, 0)

        n_perp = n_1 * 2 + n_2
    ElseIf conn_choice_perp_ComboBox = "version 3" Then

        Tabelle7.Shapes("vertical_Version1_Grafik").Visible = False
        Tabelle7.Shapes("vertical_Version2_Grafik").Visible = False
        Tabelle7.Shapes("vertical_Version3_Grafik").Visible = True
        Tabelle7.Range("B13:J78").Font.ColorIndex = 1
        Tabelle7.Range("B18:J19").Font.ColorIndex = 15
        Tabelle7.Range("H13:J14").Font.ColorIndex = 15

        n_1_perp_TextBox.Enabled = True
        fact_n_2_perp_TextBox.Enabled = False
        width_perp_TextBox.Enabled = True
        height_perp_TextBox.Enabled = True

        n_2 = 0
        yA_middle_1 = yA_middle_min
        yA_middle_2 = (b_w - 2 * (yA_edge + (n_1 - 1) * yA_middle_1))

        n_perp = n_z_1 * 2

        n_max = WorksheetFunction.RoundDown(n_max / 2, 0)

    ElseIf conn_choice_perp_ComboBox = "please choose" Then

        Tabelle7.Shapes("vertical_Version1_Grafik").Visible = False
        Tabelle7.Shapes("vertical_Version2_Grafik").Visible = False
        Tabelle7.Shapes("vertical_Version3_Grafik").Visible = False
        n_1_perp_TextBox.Enabled = False
        fact_n_2_perp_TextBox.Enabled = False
        width_perp_TextBox.Enabled = False
        height_perp_TextBox.Enabled = False
    End If

'horizontal plates
ElseIf Tabelle1.reinf_type_top_ComboBox.Value = "horizontal plate" Then
    Tabelle7.Shapes("vertical_Version1_Grafik").Visible = False
    Tabelle7.Shapes("vertical_Version2_Grafik").Visible = False
    Tabelle7.Shapes("vertical_Version3_Grafik").Visible = False

    Tabelle7.Range("B13:J78").Font.ColorIndex = 15
    h = Tabelle1.wood_height_TextBox.Value

    zA_edge_min = 20
    zA_middle_min = 40

    zA_edge = zA_edge_min

    n_max = WorksheetFunction.RoundDown(((h - 2 * zA_edge_min) / zA_middle_min) + 1, 0)

    n_1 = n_1_perp_TextBox.Value

    If conn_choice_perp_ComboBox = "version 1" Then

        Tabelle7.Shapes("horizontal_Version1_Grafik").Visible = True
        Tabelle7.Shapes("horizontal_Version2_Grafik").Visible = False
        Tabelle7.Shapes("horizontal_Version3_Grafik").Visible = False
        Tabelle7.Range("B13:J78").Font.ColorIndex = 1
        Tabelle7.Range("B25:J26").Font.ColorIndex = 15
        Tabelle7.Range("H13:J14").Font.ColorIndex = 15
        Tabelle7.Range("H19:J19").Font.ColorIndex = 15

        n_1_perp_TextBox.Enabled = True
        fact_n_2_perp_TextBox.Enabled = False
```

```
    width_perp_TextBox.Enabled = True
    height_perp_TextBox.Enabled = True

    zA_middle_1 = (h - 2 * zA_edge) / (n_1 - 1)

    n_2 = 0
    zA_middle_2 = 0

    n_perp = n_1

  ElseIf conn_choice_perp_ComboBox = "version 2" Then

    Tabelle7.Shapes("horizontal_Version1_Grafik").Visible = False
    Tabelle7.Shapes("horizontal_Version2_Grafik").Visible = True
    Tabelle7.Shapes("horizontal_Version3_Grafik").Visible = False
    Tabelle7.Range("B13:J78").Font.ColorIndex = 1
    Tabelle7.Range("B25:J26").Font.ColorIndex = 15

    n_1_perp_TextBox.Enabled = True
    fact_n_2_perp_TextBox.Enabled = True
    width_perp_TextBox.Enabled = True
    height_perp_TextBox.Enabled = True

    zA_middle_1 = zA_middle_min
    zA_middle_2 = fact_n_2_perp_TextBox.Value * zA_middle_1                          '
        factor for spacing yA_middle_2

    n_2  =  WorksheetFunction.RoundDown(((h  -  2  *  (zA_edge  +  (n_1  -  1)  *  zA_middle_1))  /
        zA_middle_2) - 1, 0)
    If n_2 < 0 Then
       n_2 = 0
    End If
    zA_middle_2 = ((h - 2 * (zA_edge + (n_1 - 1) * zA_middle_1)) / (n_2 + 1))

    n_perp = n_1 * 2 + n_2

    n_max  =  WorksheetFunction.RoundDown((h  -  2  *  zA_middle_2  -  2  *  zA_edge)  /  (2  *
        zA_middle_1) + 1, 0)


 ElseIf conn_choice_perp_ComboBox = "version 3" Then

    Tabelle7.Shapes("horizontal_Version1_Grafik").Visible = False
    Tabelle7.Shapes("horizontal_Version2_Grafik").Visible = False
    Tabelle7.Shapes("horizontal_Version3_Grafik").Visible = True
    Tabelle7.Range("B13:J78").Font.ColorIndex = 1
    Tabelle7.Range("B25:J26").Font.ColorIndex = 15
    Tabelle7.Range("H13:J14").Font.ColorIndex = 15

    n_1_perp_TextBox.Enabled = True
    fact_n_2_perp_TextBox.Enabled = False
    width_perp_TextBox.Enabled = True
    height_perp_TextBox.Enabled = True

    n_2 = 0
    zA_middle_1 = zA_middle_min
    zA_middle_2 = (h - 2 * (zA_edge + (n_1 - 1) * zA_middle_1))

    n_perp = n_1 * 2

    n_max = WorksheetFunction.RoundDown(n_max / 2, 0)
  ElseIf conn_choice_perp_ComboBox = "please choose" Then

    Tabelle7.Shapes("horizontal_Version1_Grafik").Visible = False
    Tabelle7.Shapes("horizontal_Version2_Grafik").Visible = False
    Tabelle7.Shapes("horizontal_Version3_Grafik").Visible = False
    Tabelle7.Range("B13:J79").Font.ColorIndex = 15
    n_1_perp_TextBox.Enabled = False
    fact_n_2_perp_TextBox.Enabled = False
    width_perp_TextBox.Enabled = False
    height_perp_TextBox.Enabled = False
```

```
    End If

End If

    Tabelle7.Range("E13").Value = n_max
    Tabelle7.Range("I14").Value = n_2
    Tabelle7.Range("E18").Value = zA_edge_min
    Tabelle7.Range("E19").Value = zA_middle_min
    Tabelle7.Range("E25").Value = yA_edge_min
    Tabelle7.Range("E26").Value = yA_middle_min

    Tabelle7.Range("I18").Value = zA_middle_1
    Tabelle7.Range("I19").Value = zA_middle_2

    Tabelle7.Range("I25").Value = yA_middle_1
    Tabelle7.Range("I26").Value = yA_middle_2


If n_max < n_1 Then
    Tabelle7.Range("E13").Font.ColorIndex = 3
    Exit Sub
End If
Tabelle7.Range("F47").Font.ColorIndex = 2

Call connection_moment_inertia
End Sub

' #### TextBoxes ####
' ### perforated plates ###
```

```
Private Sub n_1_perp_TextBox_lostfocus()
  Call conn_choice_perp_ComboBox_change
End Sub
```

```
Private Sub fact_n_2_perp_TextBox_LostFocus()
  Call conn_choice_perp_ComboBox_change
End Sub
```

```
Private Sub yA_edge_perp_TextBox_LostFocus()
  Call conn_choice_perp_ComboBox_change
End Sub
```

```
Private Sub zA_edge_perp_TextBox_LostFocus()
  Call conn_choice_perp_ComboBox_change
End Sub
```

```
Private Sub width_perp_TextBox_LostFocus()
    max_b_perp = Tabelle7.Range("E32").Value
    b_perp = width_perp_TextBox.Value

    If CStr(b_perp) > max_b_perp Then
        MsgBox ("the width of the plate is too high")
    End If

    m_perp_AD = WorksheetFunction.RoundDown((b_perp - 15) / 15 + 1, 0)
        Tabelle7.Range("E36").Value = m_perp_AD

    d_m = b_perp / 2 - 5

    If m_perp_AD < 1 Then
        MsgBox ("the width of the plate is too small")
    End If

    Call height_perp_TextBox_LostFocus


End Sub
```

```
Private Sub height_perp_TextBox_LostFocus()
```

```
    max_h_perp = Tabelle7.Range("I32").Value
    h_perp = height_perp_TextBox.Value

    If CStr(h_perp) > max_h_perp Then
        MsgBox ("the height of the plate is too high")
    End If

    n_perp_AD = WorksheetFunction.RoundDown(((h_perp - 27.5) / 15) + 1, 0)
        Tabelle7.Range("I36").Value = n_perp_AD

    d_n = h_perp / 2 - 5

    d_mn_perp = (d_m ^ 2 + d_n ^ 2) ^ 0.5

    If n_perp_AD < 3 Then
        MsgBox ("the width of the plate is too small")
    End If

    Call conn_choice_perp_ComboBox_change

End Sub
```

7.3.4.3. General

```
Option Explicit
' ############## Connections #############################
```

```
Public Function calc_conn_pullout_1(f_y_k, A)
    calc_conn_pullout_1 = f_y_k * A
End Function
```

```
Public Function calc_conn_pullout_2(d, l_ad, f_k_1_k)
    calc_conn_pullout_2 = pi * d * l_ad * f_k_1_k
End Function
```

```
Public Function calc_conn_pullout_rec(b, h, l_ad, f_k_1_k)
    calc_conn_pullout_rec = b * h * l_ad * f_k_1_k
End Function
```

```
Public Function calc_conn_shear(beta, M_y_Rk, f_k_1_k, d)
    calc_conn_shear = ((2 * beta) / (1 + beta)) ^ 1 / 2 * (2 * M_y_Rk * f_h_1_k * d) ^ 1 / 2
End Function
```

```
Sub area_threaded_rod()
    If Tabelle1.height_reinf_top_TextBox.Enabled = True Then

        If Tabelle1.height_reinf_top_TextBox.Value = 6 Then
            A_ef = 20.1
        ElseIf Tabelle1.height_reinf_top_TextBox.Value = 8 Then
            A_ef = 48.1
        ElseIf Tabelle1.height_reinf_top_TextBox.Value = 10 Then
            A_ef = 58
        ElseIf Tabelle1.height_reinf_top_TextBox.Value = 12 Then
            A_ef = 84.3
        ElseIf Tabelle1.height_reinf_top_TextBox.Value = 16 Then
            A_ef = 157
        ElseIf Tabelle1.height_reinf_top_TextBox.Value = 20 Then
            A_ef = 245
        ElseIf Tabelle1.height_reinf_top_TextBox.Value = 24 Then
            A_ef = 353
        ElseIf Tabelle1.height_reinf_top_TextBox.Value = 30 Then
            A_ef = 561
        End If

    ElseIf Tabelle1.height_reinf_bot_TextBox.Enabled = True Then
```

```
        If Tabelle1.height_reinf_bot_TextBox.Value = 6 Then
            A_ef_bot = 20.1
        ElseIf Tabelle1.height_reinf_bot_TextBox.Value = 8 Then
            A_ef_bot = 48.1
        ElseIf Tabelle1.height_reinf_bot_TextBox.Value = 10 Then
            A_ef_bot = 58
        ElseIf Tabelle1.height_reinf_bot_TextBox.Value = 12 Then
            A_ef_bot = 84.3
        ElseIf Tabelle1.height_reinf_bot_TextBox.Value = 16 Then
            A_ef_bot = 157
        ElseIf Tabelle1.height_reinf_bot_TextBox.Value = 20 Then
            A_ef_bot = 245
        ElseIf Tabelle1.height_reinf_bot_TextBox.Value = 24 Then
            A_ef_bot = 353
        ElseIf Tabelle1.height_reinf_bot_TextBox.Value = 30 Then
            A_ef_bot = 561
        End If

    End If

End Sub
```

```
Sub basic_calc_conn()



End Sub
```

```
Sub moment_inertia_conn_cir()
' ##### rods and bars ########################
n_z_1 = Tabelle3.n_z_1_TextBox.Value
n_z_2 = Tabelle3.Range("E32").Value
zA_middle_1 = Tabelle3.Range("E36").Value
zA_middle_2 = Tabelle3.Range("E37").Value
n_y_1 = Tabelle3.n_y_1_TextBox.Value
n_y_2 = Tabelle3.Range("I32").Value
yA_middle_1 = Tabelle3.Range("I36").Value
yA_middle_2 = Tabelle3.Range("I37").Value
n_z = n_z_1 + n_z_2
n_y = n_y_1 + n_y_2
Az_conn = 0
I_y_conn = 0
Dim z_() As Variant
Dim y_() As Variant
' ### moment of inertia y ###
' ## VERSION 1 ##
If Tabelle3.conn_choice_z_ComboBox.Value = "version 1" Then
    ' even numbers of rows
    If n_z Mod 2 = 0 Then
        nm_z = n_z / 2

        ReDim z_(nm_z)
        Dim i As Integer
        Az_conn = 0

            For i = 1 To nm_z
            z_(i) = ((i - 0.5) * zA_middle_1) ^ 2
            Az_conn = Az_conn + (A_conn * z_(i))
        Next i

    ' uneven numbers of rows
    Else
        nm_z = (n_z - 1) / 2

        ReDim z_(nm_z)
        Dim j As Integer
        Az_conn = 0

        For j = 1 To nm_z
            z_(j) = (j * zA_middle_1) ^ 2
```

```
            Az_conn = Az_conn + (A_conn * z_(j))
        Next j

    End If


' ## VERSION 2 ##
ElseIf Tabelle3.conn_choice_z_ComboBox.Value = "version 2" Then

    ' even numbers of rows
    If n_z Mod 2 = 0 Then
        nm_z1 = n_z_1 - 1
        nm_z2 = n_z_2 / 2

        ReDim z_(nm_z2)
        Dim i1 As Integer, i2 As Integer
        Az_conn = 0

        For i2 = 0 To nm_z2
            z_(i2) = ((i2 + 0.5) * zA_middle_2) ^ 2
            Az_conn = Az_conn + (A_conn * z_(i2))
        Next i2

        ReDim z_(nm_z1)
        For i1 = 1 To nm_z1
            z_(i1) = (((nm_z2 + 0.5) * zA_middle_2) + i1 * zA_middle_1) ^ 2
            Az_conn = Az_conn + (A_conn * z_(i1))
        Next i1

    ' uneven numbers of rows
    Else
        nm_z1 = n_z_1 - 1
        nm_z2 = n_z_2 / 2 + 0.5

        ReDim z_(nm_z2)
        Dim j1 As Integer, j2 As Integer
        Az_conn = 0

        For j2 = 1 To nm_z2
            z_(j2) = (j2 * zA_middle_2) ^ 2
            Az_conn = Az_conn + (A_conn * z_(j2))
        Next j2

        ReDim z_(nm_z1)
        For j1 = 1 To nm_z1
            z_(j1) = ((nm_z2 * zA_middle_2) + j1 * zA_middle_1) ^ 2
            Az_conn = Az_conn + (A_conn * z_(j1))
        Next j1

    End If

' ## VERSION 3 ##

ElseIf Tabelle3.conn_choice_z_ComboBox.Value = "version 3" Then
    nm_z1 = n_z_1 - 1

    ReDim z_(nm_z1)
    Dim ii As Integer
    Az_conn = 0

    For ii = 1 To nm_z1
        z_(ii) = ((0.5 * zA_middle_2) + ii * zA_middle_1) ^ 2
        Az_conn = Az_conn + (A_conn * z_(ii))
    Next ii

End If

Az_conn = Az_conn * 2 * n_y
I_y_conn = n_z * n_y * I_y_conn
I_y_conn = Az_conn + I_y_conn
Tabelle3.Range("E42").Value = I_y_conn
```

```
' ### moment of inertia z ###

' ## VERSION 1 ##
If Tabelle3.conn_choice_y_ComboBox.Value = "version 1" Then

    ' even numbers of rows
    If n_y Mod 2 = 0 Then
        nm_y = n_y / 2

        ReDim y_(nm_y)
        Dim k As Integer
        Ay_conn = 0

        For k = 1 To nm_y
            y_(k) = ((k - 0.5) * yA_middle_1) ^ 2
            Ay_conn = Ay_conn + (A_conn * y_(k))
        Next k

    ' uneven numbers of rows
    Else
        nm_y = (n_y - 1) / 2

        ReDim y_(nm_y)
        Dim l As Integer
        Ay_conn = 0

        For l = 1 To nm_y
            y_(l) = (l * yA_middle_1) ^ 2
            Ay_conn = Ay_conn + (A_conn * y_(l))
        Next l

    End If
' ## VERSION 2 ##
ElseIf Tabelle3.conn_choice_y_ComboBox.Value = "version 2" Then

    ' even numbers of rows
    If n_y Mod 2 = 0 Then
        nm_y1 = n_y_1 - 1
        nm_y2 = n_y_2 / 2

        ReDim y_(nm_y2)
        Dim k1 As Integer, k2 As Integer
        Ay_conn = 0

        For k2 = 0 To nm_y2
            y_(k2) = ((k2 + 0.5) * yA_middle_2) ^ 2
            Ay_conn = Ay_conn + (A_conn * y_(k2))
        Next k2

        ReDim y_(nm_y1)
        For k1 = 1 To nm_y1
            y_(k1) = (((nm_y2 + 0.5) * yA_middle_2) + k1 * yA_middle_1) ^ 2
            Ay_conn = Ay_conn + (A_conn * y_(k1))
        Next k1

    ' uneven numbers of rows
    Else
        nm_y1 = n_y_1 - 1
        nm_y2 = n_y_2 / 2 + 0.5

        ReDim y_(nm_y2)
        Dim l1 As Integer, l2 As Integer
        Ay_conn = 0

        For l2 = 1 To nm_y2
            y_(l2) = (l2 * yA_middle_2) ^ 2
            Ay_conn = Ay_conn + (A_conn * y_(l2))
        Next l2

        ReDim y_(nm_y1)
```

```
        For l1 = 1 To nm_y1
            y_(l1) = ((nm_y2 * yA_middle_2) + l1 * yA_middle_1) ^ 2
            Ay_conn = Ay_conn + (A_conn * y_(l1))
        Next l1

    End If
' ## VERSION 3 ##
ElseIf Tabelle3.conn_choice_y_ComboBox.Value = "version 3" Then

    nm_y1 = n_y_1 - 1

    ReDim y_(nm_y1)
    Dim kk As Integer
    Ay_conn = 0
    For kk = 1 To nm_y1
        y_(kk) = ((0.5 * yA_middle_2) + kk * yA_middle_1) ^ 2
        Ay_conn = Ay_conn + (A_conn * y_(kk))
    Next kk
End If
Ay_conn = Ay_conn * 2 * n_z
I_z_conn = n_z * n_y * I_z_conn
I_z_conn = Ay_conn + I_z_conn
Tabelle3.Range("I42").Value = I_z_conn
End Sub
' ####### horizontal plate ###################################
```

```
Sub moment_inertia_conn_horizontal()
n_1 = Tabelle7.n_1_perp_TextBox.Value
n_2 = Tabelle7.Range("I14").Value
zA_middle_1 = Tabelle7.Range("I18").Value
zA_middle_2 = Tabelle7.Range("I19").Value
n_perp = n_1 + n_2

Dim z_() As Variant
Dim y_() As Variant
Az_perp = 0
' #### VERSION 1 ####
If Tabelle7.conn_choice_perp_ComboBox.Value = "version 1" Then
' ### moment of inertia y ###
    ' even numbers
    If n_perp Mod 2 = 0 Then
        nm_z = n_1 / 2

        ReDim z_(nm_z)
        Dim i As Integer
            For i = 1 To nm_z
            z_(i) = ((i - 0.5) * zA_middle_1) ^ 2
            Az_perp = Az_perp + (A_perp * z_(i))
        Next i

    ' uneven numbers
    Else
        nm_z = (n_1 - 1) / 2

        ReDim z_(nm_z)
        Dim j As Integer
        For j = 1 To nm_z
            z_(j) = (j * zA_middle_1) ^ 2
            Az_perp = Az_perp + (A_perp * z_(j))
        Next j

    End If


' ### moment of inertia z ###

    ' there is no Steiner Anteil

' #### VERSION 2 ####
ElseIf Tabelle7.conn_choice_perp_ComboBox.Value = "version 2" Then
```

```vb
' ### moment of inertia y ###
    ' even numbers
    If n_perp Mod 2 = 0 Then
        nm_z1 = n_1 - 1
        nm_z2 = n_2 / 2

        ReDim z_(nm_z2)
        Dim i1 As Integer, i2 As Integer
        For i2 = 0 To nm_z2
            z_(i2) = ((i2 + 0.5) * zA_middle_2) ^ 2
            Az_perp = Az_perp + (A_perp * z_(i2))
        Next i2

        ReDim z_(nm_z1)
        For i1 = 1 To nm_z1
            z_(i1) = (((nm_z2 + 0.5) * zA_middle_2) + i1 * zA_middle_1) ^ 2
            Az_perp = Az_perp + (A_perp * z_(i1))
        Next i1

    ' uneven numbers
    Else
        nm_z1 = n_1 - 1
        nm_z2 = n_2 / 2 + 0.5

        ReDim z_(nm_z2)
        Dim j1 As Integer, j2 As Integer
        For j2 = 1 To nm_z2
            z_(j2) = (j2 * zA_middle_2) ^ 2
            Az_perp = Az_perp + (A_perp * z_(j2))
        Next j2

        ReDim z_(nm_z1)
        For j1 = 1 To nm_z1
            z_(j1) = ((nm_z2 * zA_middle_2) + j1 * zA_middle_1) ^ 2
            Az_perp = Az_perp + (A_perp * z_(j1))
        Next j1

    End If


' ### moment of inertia z ###

    ' there is no Steiner Anteil


' #### VERSION 3 ####

ElseIf Tabelle7.conn_choice_perp_ComboBox.Value = "version 3" Then

' ### moment of inertia y ###
    nm_z1 = n_1 - 1

    ReDim z_(nm_z1)
    Dim ii As Integer
    For ii = 1 To nm_z1
        z_(ii) = ((0.5 * zA_middle_2) + ii * zA_middle_1) ^ 2
        Az_perp = Az_perp + (A_perp * z_(ii))
    Next ii

' ### moment of inertia z ###

    ' there is no Steiner Anteil

End If

Az_perp = Az_perp * 2
I_y_perp = n_perp * I_y_perp
I_y_perp = Az_perp + I_y_perp
Tabelle7.Range("E41").Value = I_y_perp
I_z_perp = n_perp * I_z_perp
Tabelle7.Range("I41").Value = I_z_perp
```

```
End Sub
' ####### vertical plates #################################

Sub moment_inertia_conn_vertical()
n_1 = Tabelle7.n_1_perp_TextBox.Value
n_2 = Tabelle7.Range("I14").Value
yA_middle_1 = Tabelle7.Range("I25").Value
yA_middle_2 = Tabelle7.Range("I26").Value
n_perp = n_1 + n_2
Ay_perp = 0
Dim z_() As Variant
Dim y_() As Variant

' #### VERSION 1 ####
If Tabelle7.conn_choice_perp_ComboBox.Value = "version 1" Then
' ### moment of inertia y ###

    ' there is no Steiner Anteil

' ### moment of inertia z ###
    ' even numbers
    If n_perp Mod 2 = 0 Then
        nm_y = n_1 / 2

        ReDim y_(nm_y)
        Dim i As Integer
        Ay_perp = 0

            For i = 1 To nm_y
            y_(i) = ((i - 0.5) * yA_middle_1) ^ 2
            Ay_perp = Ay_perp + (A_perp * y_(i))
        Next i

    ' uneven numbers
    Else
        nm_y = (n_1 - 1) / 2

        ReDim y_(nm_y)
        Dim j As Integer
        Ay_perp = 0

        For j = 1 To nm_y
            y_(j) = (j * yA_middle_1) ^ 2
            Ay_perp = Ay_perp + (A_perp * y_(j))
        Next j

    End If



' #### VERSION 2 ####
ElseIf Tabelle7.conn_choice_perp_ComboBox = "version 2" Then

' ### moment of inertia y ###

    ' there is no Steiner Anteil
' ### moment of inertia z ###
    ' even numbers
    If n_perp Mod 2 = 0 Then
        nm_y1 = n_1 - 1
        nm_y2 = n_2 / 2

        ReDim y_(nm_y2)
        Dim i1 As Integer, i2 As Integer
        Ay_perp = 0

        For i2 = 0 To nm_y2
            y_(i2) = ((i2 + 0.5) * yA_middle_2) ^ 2
            Ay_perp = Ay_perp + (A_perp * y_(i2))
        Next i2
```

```
        ReDim y_(nm_y1)
        For i1 = 1 To nm_y1
            y_(i1) = (((nm_y2 + 0.5) * yA_middle_2) + i1 * yA_middle_1) ^ 2
            Ay_perp = Ay_perp + (A_perp * y_(i1))
        Next i1

    ' uneven numbers
    Else
        nm_y1 = n_1 - 1
        nm_y2 = n_2 / 2 + 0.5

        ReDim y_(nm_y2)
        Dim j1 As Integer, j2 As Integer
        Ay_perp = 0

        For j2 = 1 To nm_y2
            y_(j2) = (j2 * yA_middle_2) ^ 2
            Ay_perp = Ay_perp + (A_perp * y_(j2))
        Next j2

        ReDim y_(nm_y1)
        For j1 = 1 To nm_y1
            y_(j1) = ((nm_y2 * yA_middle_2) + j1 * yA_middle_1) ^ 2
            Ay_perp = Ay_perp + (A_perp * y_(j1))
        Next j1

    End If



' #### VERSION 3 ####

ElseIf Tabelle7.conn_choice_perp_ComboBox.Value = "version 3" Then

' ### moment of inertia y ###

    ' there is no Steiner Anteil

' ### moment of inertia z ###
    nm_y1 = n_1 - 1

    ReDim y_(nm_y1)
    Dim ii As Integer
    Ay_perp = 0

    For ii = 1 To nm_y1
        y_(ii) = ((0.5 * yA_middle_2) + ii * yA_middle_1) ^ 2
        Ay_perp = Ay_perp + (A_perp * y_(ii))
    Next ii

End If
Ay_perp = Ay_perp * 2
I_z_perp = n_perp * I_z_perp
I_z_perp = Ay_perp + I_z_perp

I_y_perp = n_perp * I_y_perp
Tabelle7.Range("E41").Value = I_y_perp
Tabelle7.Range("I41").Value = I_z_perp
End Sub
```

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