

Diploma Thesis

Practically Oriented Development of Pre-dimensioning Matrices for Massive Timber and Massive Timber-Concrete-Composite Floor Constructions in Mid-Rise Buildings

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DIPLOMARBEIT

Praxisorientierte Entwicklung von Vordimensionierungsmatrizen für Massivholz- und Massivholz-Beton-Verbunddecken in mehrgeschossigen Bauwerken

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Abstract

In recent years massive timber products are gaining more and more traction as materials for floor constructions in residential and commercial buildings because besides their obvious low ecological impact and CO₂ storage, which is positively impacting more and more decision-making processes, it offers many advantages compared to other materials. They shall be mentioned here but are explained in the first pair of chapters of this thesis: vast prefabrication possibilities with consequent reduction of construction times, EDV-based precise planning, dry constructions, lightweight elements for earthquake sensible regions and availability of this regrowing material in most regions worldwide.

An analysis of the state-of-the-art of timber and timber-composite floors, as well as recent academic research and developments, form the next salient moment of this thesis. This in-depth review is of relevance, as paired with normative requirements from various European countries such as Austria, Germany, Italy, and Switzerland. It lays the foundation of the statical pre-dimensioning and analysis carried out in later chapters. These requirements, depending on the building's utilisation, mostly regard the building physics aspects, namely fire protection, sound insulation and protection against humidity.

The core of this thesis is represented by a statical analysis and pre-dimensioning tool of two different massive timber floors: a CLT panel and a massive TCC floor. Two different types of shear connectors are dimensioned for timber-concrete composite floors, resulting in three different analysed types of decks. This analysis intended to allow pre-dimensioning of floor constructions during the early planning stages given some restricting parameters, such as the building's utilisation and required fire resistance; the advantages for projecting teams and committers are evident since many decisions are related to the type and dimensions of floor constructions.

The results are pre-dimensioning matrices with listed possible floor constructions on the vertical axis and load combinations of dead and imposed loads applied on every span on the horizontal axis. This allows to choose from possible solutions, also having their maximum utilisation ratios in regard to the most relevant verification as an additional decision-making tool. The most cost-effective solution is the one with minimal overall depth (as less material is used) and the highest degree of utilisation for a given combination of span and depth. The results are graphically shown, discussed, and compared in the last chapters of this thesis.

Kurzfassung

Massive Holzprodukte für Decken in Wohnbauten bzw. Nutzbauten sind in den letzten Jahren wegen der vielen Vorteile, die sie gegenüber herkömmlichen Lösungen bieten vermehrt zur Anwendung gekommen. Diese Vorteile werden in den ersten Kapiteln dieser Diplomarbeit diskutiert: ökologischer Fußabdruck bzw. CO₂ Speichervermögen von Holz, weitgehende EDV-basierte Vorfertigung und Ausführung mit daraus resultierender Verringerung von Bauzeiten, nachwachsendes fast weltweit verfügbares Material mit reduziertem Eigengewicht im Hinblick auf Erdbebengefährdung.

Der Stand der Technik von Holz- bzw. Holzbetonverbunddecken und neueste akademische Entwicklungen bilden das nächste wichtige Kapitelpaar. Diese vertiefte Ausarbeitung ist mit einem Kapitel der normativen Anforderungen an Brand-, Schall- und Feuchteschutz unterschiedlicher europäischer Länder (Österreich, Deutschland, Schweiz und Italien) verbunden und bildet das Fundament für die Analysen und Berechnungen, die in den darauffolgenden Kapiteln angeführt sind. Die normativen Anforderungen beziehen sich auf Brandschutz, Schallschutz und Feuchteschutz.

Der Kern dieser Diplomarbeit bilden die statischen Berechnungen bzw. Nachweisführungen zweier massiven Holzdeckentypen: eine Brettsperrholzdecke (CLT) bzw. eine Holz-Beton-Verbunddecke (HBV). Die ermittelten Ergebnisse ermöglichen die Vordimensionierung massiver Holzdecken bereits während der Vorentwurfsphase in Abhängigkeit gewisser Randbedingungen, wie die Gebäudenutzung und die erforderliche Brandwiderstandsdauer. Die Vorteile für alle am Projekt beteiligten Planer und Bauherren sind klar, auch weil viele Entscheidungen vom vorhandenen Deckentyp und dessen Abmessungen abhängig sind.

Das Ergebnis bilden Vordimensionierungsmatrizen bestehend aus aufgelisteten Paneelen auf der vertikalen Achse sowie Nutzlasten bzw. Eigengewichte und Spannweiten auf der horizontalen Achse. Alle Spannweite-Last-Brettsperrholz Kombinationen die die Gebrauchstauglichkeit (SLS), Tragfähigkeit (ULS) und Tragfähigkeit bei Brand erfüllen befinden sich in den Tabellen während jener Möglichkeiten, die die Anforderungen nicht erfüllen automatisch eliminiert werden. Alle möglichen Kombinationen sind von ihrem Ausnutzungsgrad und dem Nachweis, der diesen verursacht, charakterisiert. Diese Möglichkeit kann als zusätzliches Element für Entscheidung dienen. Die wirtschaftlichste Konstruktion ist jene mit der geringsten Stärke und der höchsten Ausnutzung; die Ergebnisse werden anhand von Grafiken am Ende der Arbeit aufgezeigt, miteinander verglichen und diskutiert.

List of Abbreviations

BIM	Building Information Modelling
CLT	Cross Laminated Timber
c.o.g.	Centre of Gravity
CP	Camber and Prestress
DIN	Deutsche Industrienorm (German Industry Normative)
DLT	Dowel Laminated Timber
ETA	European technical approval
EWP	Engineered Wood Products
FAO	Food and Agriculture Organization of the United Nations
FRP	Fibre reinforced polymer
FTC	Fibre timber concrete
GL	Glue Laminated Timber
GWP	Global Warming Potential [CO ₂ /kg]
KVH	Konstruktionsvollholz (solid structural timber)
LVL	Laminated Veneer Lumber
MBO	Musterbauordnung (Template Building Normative)
M-HFH HolzR	Muster-Richtlinie über brandschutztechnische Anforderungen an hochfeuerhemmende Bauteile in Holzbauweise (Template normative about fire protection requirements for highly fire-inhibiting timber elements)
NLT	Nail Laminated Timber
OIB	Österreichisches Institut für Bautechnik (Austrian Institute for Building Technology)
OIB RL	Österreichisches Institut für Bautechnik – Richtlinie (guidance normative of the Austrian Institute for Building Technology)
OSB	Oriented Strand Board
RC	Reinforced Concrete
SCC	Steel - Concrete-Composite
SLS	Serviceability Limit State
STC	Timber - Steel-Composite
STCC	Steel-Timber - Concrete Composite
TCC	Timber - Concrete-Composite
TTC	Timber - Timber-Composite
ULS	Ultimate Limit State
ULS _{fi}	Ultimate Limit State under fire conditions
WLC	Wood Lightweight Concrete Composite

X-LAM	Cross Laminated Timber
w/c	Water to Concrete Ratio [-]
δ	slip [m]
γ	degree of composite action [-]

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1 Introduction

Wood has been the most widespread construction material over most of humanity's history but has been supplanted by concrete and steel over the last few centuries. During the last few decades, timber constructions are experiencing a *renaissance* riding the wave of ecological and sustainable developments becoming more and more relevant in our modern society. Timber is able to store CO₂ and only release it when it is burnt. Also, it has a lower carbon footprint during production but also over the whole material life span than concrete or steel and can be recycled better than concrete. On the downside, its burnability, its low sound insulation capabilities and sensibility to humidity shall be cited. Plenty of timber products (engineered wood products) have been developed recently to improve the capabilities of wood, especially in regard to mid and high-rise buildings. These systems are all very suited for prefabrication, which means that finished or half-finished products are transported to the building site (usually following the just in time delivery principles) and cast into place. By doing so, the total construction time can be sensibly reduced, along with the economic burdens coming from prolonged construction durations. The principal wood product on which this thesis bases upon is massive timber, namely cross-laminated timber, also known as CLT.

This massive material is composed of crosswise glued lumbers that together achieve very good load carrying performances and can be coupled with a load-carrying concrete layer placed above the panel itself. Such constructions are known as timber-concrete-composite (TCC) floors. The idea is to connect both distinct layers via shear connectors and thus achieve composite load-carrying behaviour. These connectors fulfil a very important role, as their slip modulus under shear stress defines the whole construction stiffness. A higher slip modulus (expressed by the γ -factor) results in a better resulting bending stiffness parallel to the span of the composite construction. Normally the static system of such systems is a statically determined single-span floor: this brings evident advantages since both materials are used to their best (timber is subject to tensional stress while concrete is subject to compression stresses). Therefore, material usage can be largely reduced compared to equivalent systems of concrete having the same geometrical dimensions. The main advantage is the reduced dead load due to self-weight since the concrete layer is not as deep as usual. For example, spans up to 9,0 m can be achieved with 120 mm screed coupled with 280 mm CLT panel depths. Given the same boundary conditions (span, load, fire resistance duration), the same CLT panel with 280 mm depth just achieves a span of 6,5 m, which is sensibly less. Just from this sneaky peak into results, the importance of composite floors is immediately visible because of their increased capability. The design process leading to such results is explained and furtherly discussed in the latter chapters of the present thesis. Two different types of shear connectors are implemented into this pre-dimensioning tool: inclined screws with an angle of 45° and

notches cut into the CLT panel itself. These are quite common shear connectors, but different types like adhesive connections working with glue are currently under development. Actual research and developments are also presented over the course of this thesis.

The types of floor constructions mentioned above are usually used as floors of mid- and high-rise buildings of timber because of their high presence of timber. The requirements in regard to fire protection duration of load-bearing elements, sound insulation capacity and protection from humidity vary a lot depending on the building's height above ground as well as its usage destination. This is especially true in regard to fire protection because of the prolonged evacuation time needed the higher the building is. Also, European countries have different requirements depending on the boundary conditions of the building (destination, height, dimension of commercial or residential units, etc.). Over the course of this thesis, four countries are analysed and compared: Austria, Germany, Switzerland, and Italy.

The ultimate scope of this thesis is to lay the foundation (or at least part of it) of a holistic evaluation system of timber and timber-concrete composite floor constructions. This means that starting from the fire protection and sound insulation capabilities of the structural core itself (load-bearing elements), the furtherly needed elements can be easily determined and implemented so that the floor construction as a whole package is able to fulfil the normative requirements. Obviously, the structural part is fully attributed to the load-bearing elements themselves. With the aid of this pre-dimensioning tool, the sound insulation and fire protection capabilities of only the structural core can be easily evaluated.

1.1 Research questions

The following research questions shall find an answer:

- a) How do CLT panels execute as statically determined one-way spanned floors perform in dependence of stringent parameters such as span length, resistance to fire duration and the constructive, concrete layer depth placed above the CLT panel?
- b) How do TCC floors (statically determined one-way spanned floors) coupled with the same CLT panels perform in dependence on stringent parameters such as shear connection type, span length, resistance to fire duration, the concrete layer above the CLT panel?
- c) How do these systems perform against each other?

1.2 Limitations

These limitations are implemented in order to keep obtained results easy to oversee and manage:

- a) Implementation of statically determined single-span floor constructions, which are idealised as one-meter width stripes and infinite length cross to span.

- b) Four different types of CLT panels are implemented: three, five and seven-layered panels are used during the analysis. Two subcategories of seven-layered with a different disposition of lamellas are part of the design.
- c) The lamella depths of CLT panels varies between 20 mm, 30 mm, and 40 mm.
- d) The analysed span ranges from 2,5 – 6,5 m for CLT panels and from 5 – 9 m for TCC floor constructions.
- e) Deflection limits are taken over from the normative recommendations
- f) Negative deflection (up-flection) has not been considered
- g) Sound insulation capacities of CLT and TCC floor are approximatively determined with empiric formulas basing on the mass per square meter.
- h) The buildings usage destination is contained in the imposed load range.
- i) Two different durations of fire that need to be fulfilled by the structural core of the floor construction are implemented: 30 and 60 minutes.
- j) Only the gamma-method is applied to determine the resulting bending stiffnesses necessary for the further design process.
- k) Only two connection types are included in the design process, namely inclined screws and notched connections.
- l) Screws are always distanced by the same length and have the same dimensions no matter the span length.
- m) Notches are dimensioned in order to achieve that every notch takes on the same amount of shear force; the resulting distancing is determined thanks to the results obtained by that approach, while the notch width and depth remain constant.
- n) One type of concrete has been implemented in the design process for TCC floors, while another type is implemented in the design of CLT floors.
- o) Pre-dimensioning tables are plotted with material coefficients and safety coefficients from the German Normative since they appeared to be strictest.

2 Timber as a construction material and its products

Over the course of mankind's history, timber has been used for multiple applications by every civilisation or population, which had it at its disposal. It was and still is utilised as a building material for housing, commercial buildings, schools, production facilities, etc. and also used to build everything we can think of, from the piece of furniture to the ship construction, from the utensil to a weapon and so on. Also, most of us are fascinated and attracted by this vivid material when it is made visible in the form of a parquet, furniture, cladding, doors etc. Buildings where the usage of timber is evident have very high habitat quality. Another of the many usages of timber is the production of combustible or coal. [1, p. 14] According to [2, p. 12], there are milliards of people that live thanks to the forest and its products: as a habitat, as a place to obtain food or burning material but also for *non-timber forest products*, such as rubber, cork, fruits, etc. Forests are important for our environment, as they hinder erosion of slopes, filter water flows into the soil, regulate air humidity and encourage the creation of micro-climates. For all the just mentioned reasons, we as humans have the task to protect and preserve the woodlands from fire, storms, snowfalls and ultimately from ourselves and our economy.

As it is widely known, wood is a natural building material, which we find in nature and doesn't need as much industrial processing under heat as concrete (cement) or steel (melting process). This processing happens by burning fossil combustibles and thus releasing carbon dioxide (CO_2) into the atmosphere, which speeds up the greenhouse effect and all its not particularly positive consequences [2, p. 24]. Wood absorbs carbon dioxide, transforms it into cellulose (the main component of wood) and releases oxygen: this phenomenon is called photosynthesis. The present amount of carbon remains stored until the tree burns out or decays. At this point, carbon is re-released as carbon dioxide. This process is defined as the *carbon cycle*. [3, p. 16]

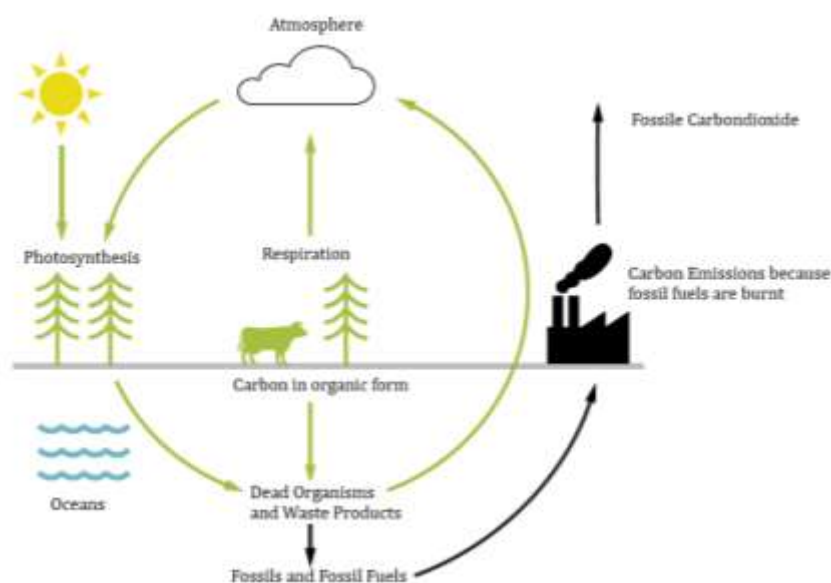


Figure 2-1: Carbon cycle applied to wood products used in timber buildings [3, p. 16]

According to [1, p. 14], at the beginning of the 20th century, the utilisation of wood in construction considerably slowed down when bricks, steel and concrete became the go-to materials. After the second world war, wood lost its importance for roof constructions and staircases because it had become scarce and its flammable properties didn't help during bombings. During the past 20-30 years, an ever-increasing number of built and projected timber buildings has been registered. This *renaissance* revolves around simpler structures, such as single houses but also taller buildings in cities, the so-called mid- or high-rise buildings. The advantages of this construction type are the following:

- p) Ecological advantages of a regrowing natural material
- q) Regional availability in many areas
- r) Innovative and efficient materials, which are obtained from natural wood
- s) EDV-based planning and production
- t) A very precise, fast prefabrication with high-quality standards is achievable
- u) Quick assembling on building site and therefore reduced building time [1, p. 14]

The FAO-Report of 2020 [4, p. 11] states that from 2010 to 2020, the worldwide stock of forests decreased by 4,74 million ha/year (-0.12 %/year), which is a considerable slowdown when compared to the decade 1990-2000 when the decrease amounted to -7,84 million ha/year (-0.19 %/year). Africa had the highest loss of existing forests. In Europe, there is a registered forest gain since 1990 even though during the last decade the increase eased up (see **Figure 2-2**).

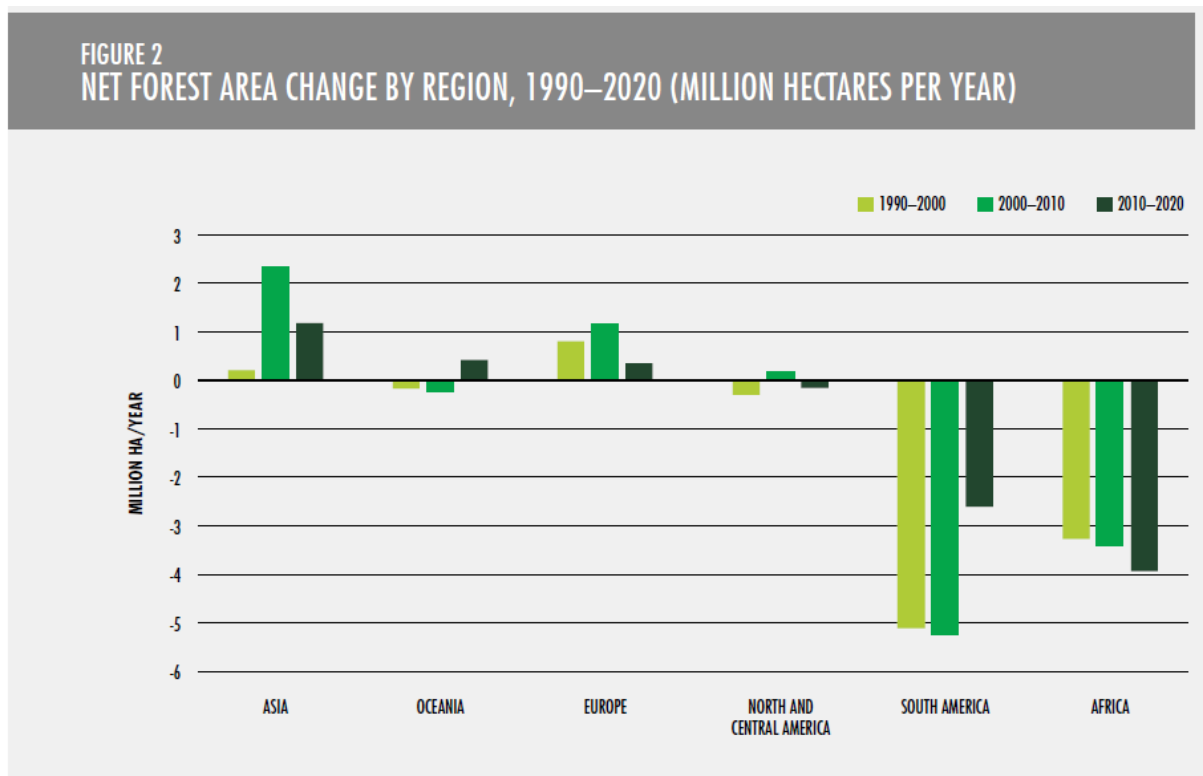


Figure 2-2: Increases and decreases of the forest stock worldwide [4, p. 12]

2.1 Properties of timber

As an organic material with cellular structure, wood has one very important material property: anisotropy. In such materials, the strength depends on the grain orientation. For instance, steel is an isotropic material with the same strength properties in every direction; concrete, at least from a calculational point of view, also has isotropic properties. [3, p. 27]

The now following properties are listed from [5, pp. 32, 33]

- Macroscopic properties: the colour and the visible texture depend on biological and physical procedures, from temperature, growth rings, branches, bork inclusions etc. Branches in the tree section mean a discontinuity in the properties and thus a weak spot.
- Density: this property depends on the tree sort; lighter softwood is used for structural parts while heavier hardwood is needed for stairs, tables, etc. Generally, we can say that timber has very good density-structural characteristics relation.
- Strength characteristics: the grains of a tree are pronounced in the longitudinal direction (growth direction), which means that in this direction, compressive and tensile strength are higher than perpendicular to it. It is also necessary to distinguish if the stress has the orientation of the growth rings (tangential) or if it is perpendicular to it (see **Figure 2-3**). The relative values for the Young's modulus and compressive, tensile, shear strength in the relative orientation depending on strength classes can be found in the European Norm EN 338:2016.

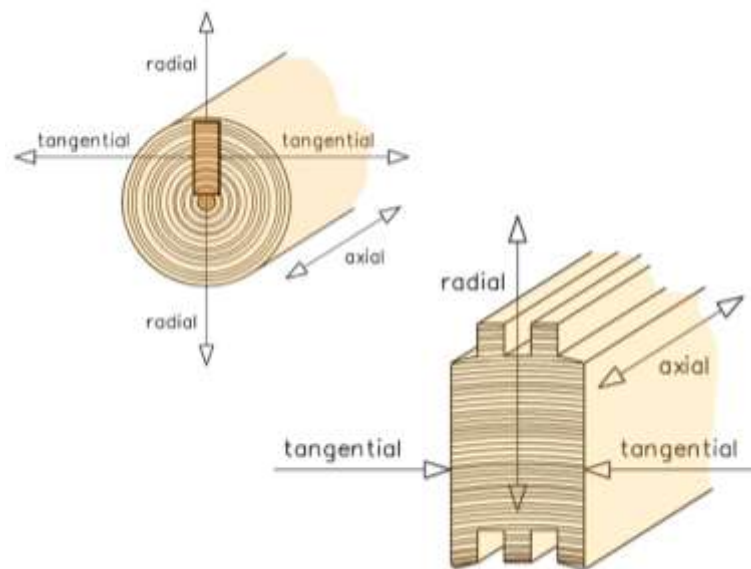


Figure 2-3: Strength directions of timber and its products [6]

The Young's modulus perpendicular to the grain direction (radial orientation) in this direction is relatively low. Settlements caused by compression forces depend on the behaviour of wood; at a certain point, it displays ductile behaviour, which means that minimal load rises cause a

lot of deformation. Before reaching that point, the load-deformation behaviour is linear (elastic behaviour). [7, p. 2]

- Reaction to humidity: thanks to its hygroscopic properties, wood can absorb water in vaporised form, which is then stored within the cell walls. In this case, timber swells while it shrinks when water is released. This volume changes strongly depend on the grain direction. According to [8, p. 23], the numerical relation between the axial, radial and tangential direction amounts to 1:10:20, which means that the longitudinal direction is the most subject to swelling or shrinking. Because of wood's hygroscopic properties, it makes sense to dry the used timber up to the humidity it will have as soon it is brought into place. The drying takes place in the open (air drying), which brings bounded humidity down to 20% or in specific ovens (kiln drying), where the present humidity is brought down to 8%. [3, p. 28]
- Durability: the resistance to external weather conditions (for example on claddings) depends on the tree sort.

2.2 Engineered timber products for floor constructions

Green M. and Taggart J. explain why timber products are a smart invention: "EWPs [engineered wood products] are manufactured by bonding together wood, [...], veneers, small sections of solid lumber [...] to produce a larger and integral composite unit that is stronger and stiffer than the sum of its parts" [3, p. 29]. Also, smaller trees can be used, thus reducing the needed growth time if compared to the growth time of bigger trees that are just sawn into beams.

2.2.1 Glue-Laminated Timber (GL)

GL-timber is produced by gluing thin wood sections (usually 25 mm) together to form a bigger section that would not be obtainable from a normal tree (see **Figure 2-4**, left). Those sections are mainly used for beams or trusses, but also for columns. It is possible to produce single lamellas with better strength properties; in the case of a beam, these lamellas are located on top and bottom of the section. The element length is limited by the production company and transport. The single small sections (lumbers) are connected by finger joints and/or glue. In the case of floor constructions in multi-storey buildings, GL-composite sections are used for joists below flooring or be incorporated into the floor construction itself (hollow box, etc.).

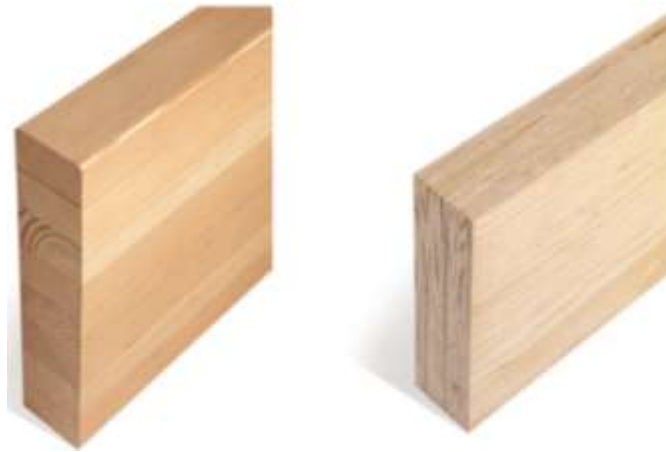


Figure 2-4: Glue Lam and LVL Sections [2, p. 105]

2.2.2 Laminated Veneer Lumber (LVL) and Mass Plywood Panels (MPP)

LVL is produced by gluing plenty of dried lumbers with a thickness of 3 mm together (see **Figure 2-4**, right); sometimes lumbers are applied with an angle of 90°, to reduce to anisotropic properties of wood. Normally LVL is used for 1D elements (beams) because of its very high strength properties. LVL panels or beams are usually made of softwood, but since a few years, beech is used (hardwood) because shrinkage and swelling are reduced by a lot. [1, p. 55]. LVL beam sections are used in hollow box floorings or for the beams of TCC floor constructions.

Mass plywood panels are produced in a similar way to LVL-Panels, with the difference that they are built up from 25 mm thick lamellas. They are used to a lesser extent but also don't have limitations in size except in production and transport. [3, p. 31] In the case of floor constructions in multi-storey buildings

2.2.3 Cross-laminated timber (CLT)

CLT (a.k.a. X-LAM) panels consist of multiple layers, stacked together, and placed perpendicular to one another (see **Figure 2-5**). They are held in their shape by glue that is applied to one or both faces. Single small sections that form a layer are also finger jointed. Instead of glue, sometimes wooden dowels in pre-drilled holes, which expand when humidity is absorbed and thus create a form-stable section, are used. CLT panels have two-way spanning ability and usually an uneven number of layers (from 3-7). In special cases, the bottom and top layers could have the same orientation. The thickness of a single layer varies from 16-51 mm. When CLT panels are used as walls, the grain of the outlier layers is running vertically. When CLT panels are used for floor constructions, the main grain direction is parallel to the span. [3, p. 32]

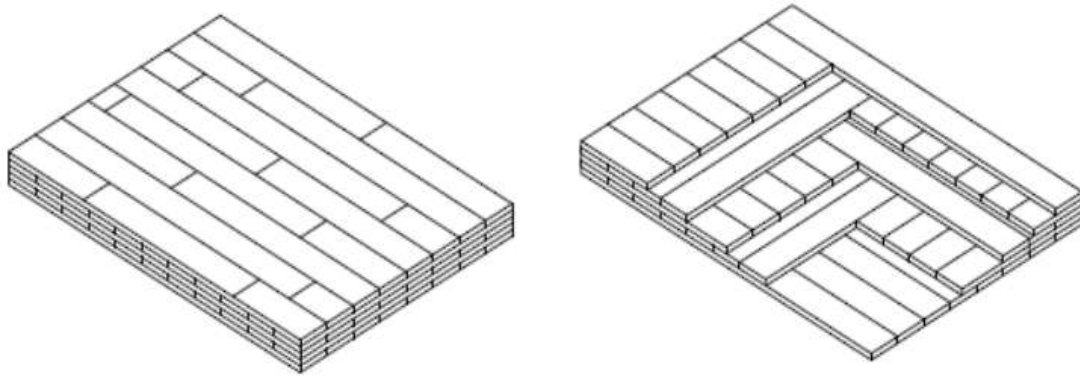


Figure 2-5: Left: CLT-Panel, Right: 3D-section through a CLT-Panel [1, p. 62]

2.2.4 Nail-Laminated (NLT) and Dowel-Laminated Timber (DLT)

Both these products are conceived differently than CLT panels; they are also known as lying GL-beams because of their identical production. [9, p. 26] The difference to CLT resides in the fact, that the single smaller sections, which this product is made from, are positioned in a vertical position, next to each other (see **Figure 2-6: a**). They can be fixed together with long nails (NLT), dowels (DLT) or glued together. These 8 mm dowels usually are out of hardwood because they are exposed to higher loads than the lumbers. [9, p. 26] **Figure 2-6: b** shows how not interconnected lumbers would carry loads, which is as series of single one-spanned beams. In **Figure 2-6: c**, the load-carrying of the connected lumbers as a massive panel is shown (so that the acting forces are spread among the lumbers). **Figure 2-6: d** illustrates the application of wood product panel (OSB, LVL, CLT) on top of the DLT/NLT panel itself to obtain sufficient lateral stiffness if the floor construction shall act as a horizontal diaphragm. Such panels keep the lumbers upright together and create the premise to transfer horizontal loads. [3, p. 33] This additional construction is required if the lumbers are mechanically connected by dowels; if the lumbers are glued together, such a measure is not necessary. [9, p. 27]

If there is need for longer panels, the DLT panels can be finger-jointed and glued together, where in the case of NLT panels, members next to each other are overlapped. These two types of panel have a disadvantage, which at the same time is an advantage: since the glue isn't applied continuously (horizontally seen), the sealing isn't continuous to prevent the upwards penetration of smoke; this property results in cheaper execution.

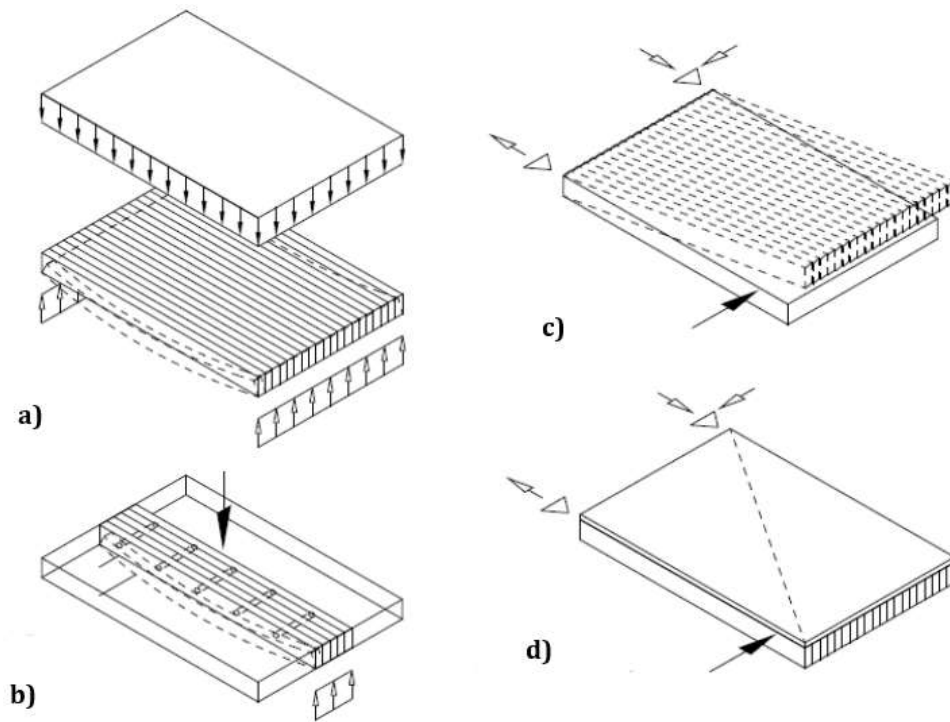


Figure 2-6: Nail and dowel laminated timber [1, p. 57]

In their state-of-the-art review, Sotayo et al. [10] explain how only wood products, such as DLT or NLT panels, are ecologically sustainable and fully recyclable for their lack of glue between the layers. This adhesive, usually utilised in timber construction, is based on formaldehyde and amine, which can harm the environment and human health because of toxic gas emissions. Formaldehyde gas is emitted during usage, high temperatures and changes of the relative humidity level [10, p. 2]. Sotayo et al. came to the following conclusions [10, p. 11]:

- 1) The number of used dowels influences the initial DLT panel stiffness while it has little effect on the load-bearing capacity. Additionally, the load-carrying of shear, axial and vibrational loads remain yet unexplored.
- 2) Bending maximum loads and initial stiffness of glued beams are 3-4 times higher than when welded fasteners (dowels) instead are used.
- 3) Hardwood can be advantageously used for timber-timber connections because its swelling properties (when exposed to moisture) provide a tight fit.
- 4) Generally speaking, by further developing EWP's cost-effective, sustainable, non-toxic, recyclable, and reusable products could be reached.

3 Construction types in mid-rise buildings

3.1 Brief history of multi-storey buildings

Since humans formed communities to live in enclosed villages or small cities, the exigence for the construction of multi-storey buildings arose. Especially civilisations which lived in regions where plenty of wood was available developed the construction of high timber buildings; those buildings had various functions: fortifications, representative buildings, temples, or residential buildings. [1, p. 10]

How where the floor constructions built up until the 20th century when they were substituted by concrete floors? In plenty of cases trees were cut, formed to squared sections and placed next to each other. To allow greater spans or bigger loads, there was the possibility to connect single sections through some specific connections made by expert builders and carpenters. Thanks to those experienced constructors this construction type improved a lot since the medieval age. Historically *half-timbered houses*, which consists of beams forming truss comprising the whole building while the empty spaces are filled with clay, wood, etc. were developed in medieval Europe [11, p. 4]. In the Alps and Scandinavian regions *log buildings* spread a lot; this construction consists of horizontally laid tree trunks. That are locked against each in the corners. In Switzerland, a 5-storey log house exists to this day; this feat is very impressive because all the loads are carried perpendicularly to the logs and thus to the grain, which coincides with the orientation of wood's weakest compressive strength orientation (see **chapter 2.1**). In China and Japan very filigree and aesthetic skeleton buildings were developed; they influence contemporary architecture to this day [1, p. 11]. In North America, the so-called *platform-frame* construction method established itself. During construction of such buildings every storey is fabricated singularly and then connected to the load carrying member of the storey below. The structure of *half-timbered houses* is conceived in a similar way [5, p. 181]. **Figure 3-1** shows prominent multi-storey buildings of the past:

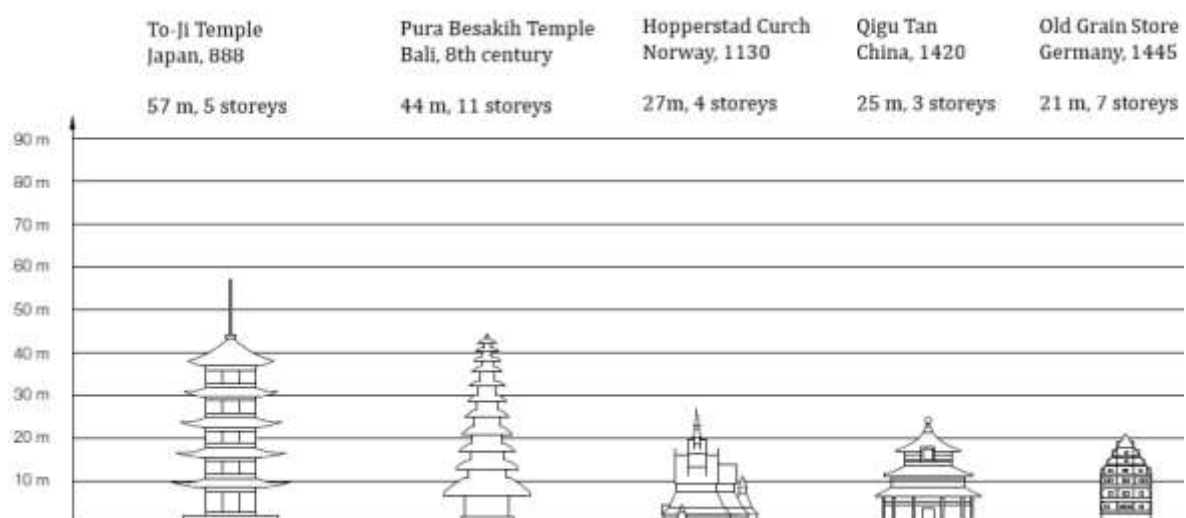


Figure 3-1: Heights reached by multi-storey building of the past [1, p. 12]

As stated in **chapter 1** of the present thesis, nowadays timber edifices are witnessing a *renaissance*, especially when it comes to medium-rise and high-rise buildings. This happens as the focus of architects, engineers and landlords shifts from concrete and steel to a renewable and ecologic material as wood is. During the last 20-30 years the now following structure types were adapted for multi-storey buildings in timber; the same thing can be affirmed for fire protection normative in Mid-Europe as the technical fire protection progressed. New developments in the field of noise insulations also help matters and so timber high-rise buildings have all tools in place for being an alternative to high-rise concrete buildings. The most diffused types briefly explained in **chapter 3.2**, **chapter 3.3**, **chapter 3.4** and **chapter 3.5**, but in a not so far future new structural systems will be developed. According to Kolb [5, p. 182], an increase in construction of timber buildings happened because of the following aspects, Kolb has stated:

- a) Ecology: environment protection and ecology are becoming more and more relevant for worldwide societies.
- b) Architecture: thanks to their modern projects globally leading architects defined a new culture in timber constructions.
- c) Technology: New composite materials and building methods allowed the development of new construction types.
- d) Scientific research: the safety levels for users and builders could be increased thanks to new improvements in the engineering and construction phases.

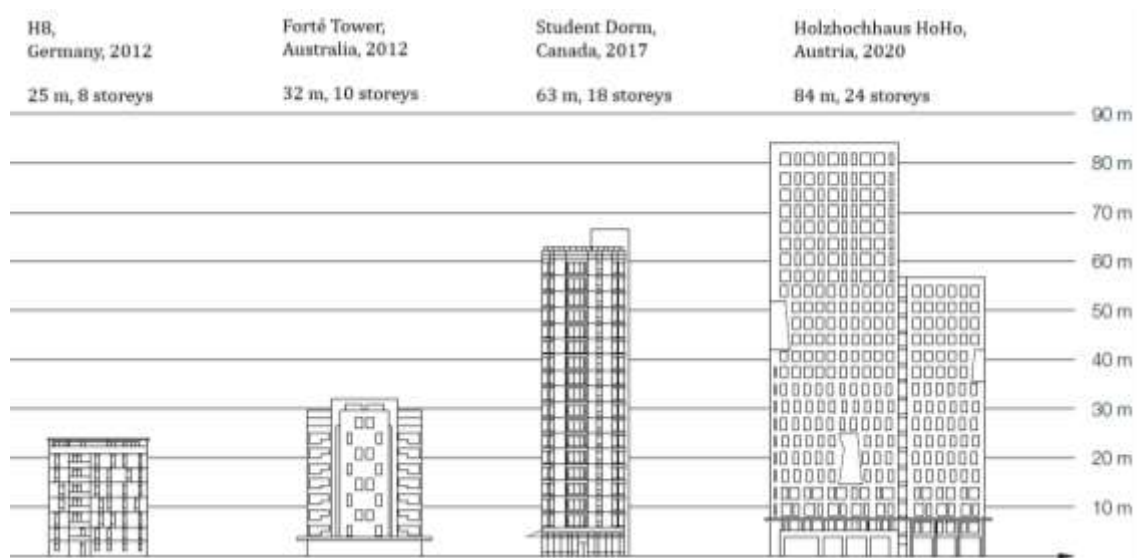


Figure 3-2: Heights reached by multi-storey building of the present [1, p. 13]

3.2 Timber Skeleton Structures

This system originated from medieval *half-timbered houses* or roofs [11, p. 279]. High-rise timber skeleton edifices accommodate commercial, institutional or assembly purposes. [3, p. 102] These structures consist of one-dimensional members, namely beams and columns of glue-laminated timber (GL); since these sections carry punctual vertical loads, there is need for a separated

horizontal load carrying system such as shear walls, cross bracings, or massive building parts (i.e., concrete staircases). As Dangel states in [2, p. 88] *timber skeleton* structures offer the following systematic advantages:

- a) It is possible to integrate glazing on the façade between the structural members because they are so far apart. This opens plenty of architectural possibilities, especially when it comes to commercial purposes.
- b) Distance between the columns usually is constant, therefore construction proceed faster.
- c) With an increasing distance between columns a lesser number of structural members is needed. This means the overall timber usage decreases and so do the costs; this happens even if the section dimensions increase.
- d) This construction type allows a very flexible and individual design of the floor plans because the structural members are in favourable positions. Interiors can easily be adapted since there is no need to modify the load carrying structure of the building.
- e) The structural parts can remain visible, especially if the architectural design of the building wants to express rhythm, character, and regularity. Of course, the structural elements can be made visible on the inside, on the outside (with protection against metrological agents), or not at all. If the elements are visible from the inside, an appropriate fire protection needs to be ensured.

The disadvantages of timber skeleton structures are also listed by Pech in [11, p. 280]:

- a) Because of element multitude, skeleton structures aren't suitable for prefabrication purposes, thus eliminating one deciding advantage of timber constructions. When executorial planning is terminated, the single components are be produced.
- b) With an increasing number of connected members, interconnecting details rise in complexity and costs. The nodes in **Figure 3-3** look simple, rational, cost effective even in their dimensions. Thanks to the oval section they transmit vertical and horizontal but cannot rotate due to lateral load. [3, p. 63]



Figure 3-3: Skeleton structure (Tamedia Head Office Zurich, CH) [2, p. 95]

3.3 Massive timber constructions

Compared to *frame systems* described in **chapter 3.2**, *massive timber constructions* or *panel systems* are quite the opposite, as they rely on two dimensional structural members. These systems were originated from the traditional log house, which sometimes is built to this day. The difference resides in the fact that a single log, as a one-dimensional member, carries the logs above and structural loads while the composed panels carry vertical and horizontal loads and themselves as a two-dimensional unity. These panels, which i.e. are CLT, DLT, NLT panels (see **chapter 2.2.3** and **chapter 2.2.4**), are generally used for walls, floor constructions and roofs and often combined with concrete and steel to obtain composite systems. [2, p. 88] Quite often these 2D-Elements produced by the executing company are assembled into modular elements (3D elements) after being transported to the building site. In this case the modular units should be almost ready for usage. Such an option makes sense if the construction time shall be minimised as much as possible and the building's geometry allows it. If the assembly into units is carried out before the transportation to site, just 1-2 units can be moved at once and plenty of transportable volume is lost. **Figure 3-4** shows how plenty of 2D panels have been transported together and assembled on site, obviously increasing the building time compared to modular units which directly can be directly positioned. The construction of modular units requires plenty of planning and usually *just in time* delivery.

Pech [11] illustrates advantages of this construction type: [11, p. 283]

- a) The panel are form stable, thanks to crosswise glued lumbers. According to [12, p. 20] it is more cost effective to produce a single panel and to cut the needed openings, even though there is material waste, rather than assembling smaller elements to a big panel with openings with no waste material.
- b) It is possible to let a panel overhang in two directions, because it has two-way spanning ability. Still, the overhang length is limited load, geometry, and quality of the panel section. In the case of a skeleton construction such a feat would be difficult, but achievable.
- c) The usage of panels also simplifies the load paths, the construction itself and fastens so the building site assembly. A high degree of prefabrication is possible, as i.e., the thermal insulation, the cladding or the windows could be applied.

Pech [11] tells us something about the disadvantages of this construction type: [11, p. 283]

- a) As soon as the spans increase larger amounts of this precious material are needed, which results in significant costs and so the loss of the cost effectiveness.
- b) Logically seen, the disposition of these massive panels results in a floorplan that doesn't provide much flexibility or reconfiguration possibilities. Mainly for this reason the massive timber constructions tend to be used for residential building, where flexible floorplans are not required. [3, p. 64]
- c) As soon as the executional planning is terminated, the single components can be produced. For this reason, no last-minute changes can be made.



Figure 3-4: Building site assembly using 2D CLT panels [2, p. 96]

3.4 Timber frame constructions

The Timber Frame Construction have something in common with both **chapter 3.2** and **chapter 3.3**, also with the timber skeleton structures and the massive timber constructions. This "mixed" type of two-dimensional panels consists of a series of sections, as tall as the panel and usually distanced by 625 mm. Clearly, the number of sections varies as the length of the panel varies. This sections usually are KVH, but when higher strength properties are needed, the used material is GL or LVL. To obtain lateral stability wooden panels are applied on both sides and on top/bottom and the whole construction is now a plate. This way, walls, floor constructions and roofs can be produced. In a floor construction panel, the vertical section carries vertical loads, while the horizontal planking on both sides carries the lateral forces. This planking also prevent that the vertical sections buckle and bend under load, therefore those sections are smaller than if there wouldn't be a planking. [5, p. 87]

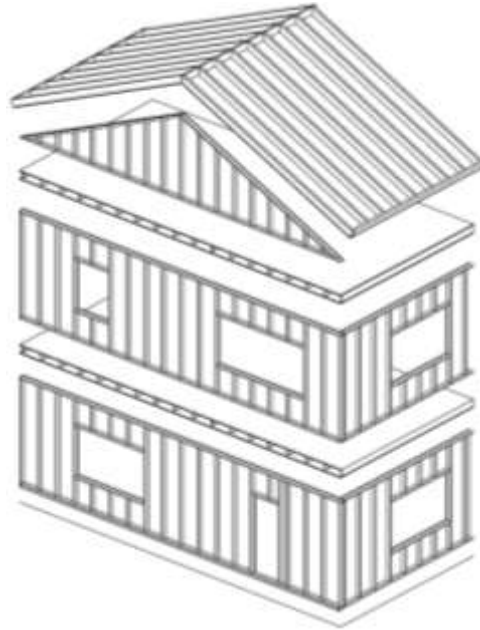


Figure 3-5: 3D sketch of a timber frame walls, floors and a roof [2, p. 94]

According to [11, p. 137] this construction type offers the following advantages:

- a) A very high degree of prefabrication can be reached. Between the single columns there is enough room for thermal insulation and installation. Also, claddings and other layers can be applied before the transport to building site happens. Because there is not a lot of wood consumption this construction type is quite cost effective. Also, the self-weight is not a problem.
- b) This system is very adaptable to the buildings boundary conditions, i.e., room height, wall length, building site transport, etc. Openings for doors and windows are easily achievable.

The disadvantages are the following: [11, p. 137]

- a) As soon as the executional planning is terminated, the single components can be produced. For this reason, no last-minute changes can be made.
- b) In the case of medium-rise buildings the compression of the horizontal elements and the following settlements need to be taken in account. To avoid that, the system can be changed into one were the settlements have any influence (hyperstatic system).

3.5 Mixed Constructions

A building where every single part is made wood could theoretically exist; a pure timber construction also contains nails, bolts, and other steel elements. [2, p. 108] When nowadays a wooden structure is defined as such, it is meant that the main construction material is wood, but of course other materials have been used too. It also makes total sense to do so, because each material has a different function because their performance together is better than the sum of their single performances. In other cases, the usage of other building materials is mandatory, especially when it comes to fire protection. Following now are some examples [13, p. 20] ; [2, p. 108]:

- 1) Bigger buildings are divided into fire compartments; for a horizontal division floor that resist to fire for a certain time are needed, while for a vertical division concrete walls could be used too. Staircases and lift cases must be in concrete to form a compartment that is safe from fire.
- 2) In many cases hybrid beams or columns are implemented, where timber is under compression and the steel parts are under tension. Both materials are used to their best and so the sections dimensions can be reduced and the whole building looks more filigree and elegant.
- 3) In the case of multi-storey buildings, the ground floor is in concrete, because the building needs to be protected from ground humidity, insects, and accidental traffic crashes.
- 4) The existence of tensioned beams or frames shall also be noted: the timber is either GL, LVL or CLT which has drilled holes for tensioning cable. As soon as the structural member is in place, the steel cables are tensioned. Thanks to this system this system can transfer moments and its dimensions are reduced.
- 5) Carbon, glass, or aramid fibres are placed on the tensioned side of a wooden beam to improve its tensional capabilities.

Another example for a mixed construction is now cited: there are some examples of mid-rise buildings, where massive timber constructions have been mixed with framed constructions. The system bases on load bearing CLT inner walls, floors, while the external, not load-bearing walls are timber framed. The advantage is that the thermal insulation is placed between the wall posts, which makes the walls thinner and so plenty of wood has not been uses. This construction type allows also smaller timber construction companies to realise multi-storey buildings, while making good use of their inner resources. [14, p. 5]

4 Floor Construction types for Mid-Rise Buildings

Which requirements do floor construction have to meet in mid-rise buildings? The following aspects need to be listed (not in order of relevance):

- a) Load bearing and transfer (ULS): As users of a timber building, we absolutely expect that the floor constructions we are walking and staying on is able to carry loads due to the building's destination.
- b) Serviceability (SLS): As users we expect that the floor constructions can be used during the whole life duration of the building. From a planning perspective it means that vibrational and deflectional parameters are to be respected. The *serviceability limited state (SLS)* needs to be ensured over the whole building life span.
- c) Noise insulation: norms of European countries define maximal sound pressure levels that a given floor construction needs to absorb. They depend on the type of building (residential, commercial, etc.).
- d) Fire protection: when a fire breaks out, the floors and walls delimiting fire compartments are required to block the fire there for a certain span of time. This amount of time depends on the building height (needed evacuation time) and the buildings utilisation.
- e) Delimiting interior spaces: timber floors delimit single floors and apartments. This is especially valid in hindsight of previously stated a), c), d).
- f) Thermal insulation in summer and winter: these aspects is just relevant for floor construction that act as a roof or floors to non-heated interiors. To avoid overheating, an air-cooling interchange system or interior shading system is implemented. [15, p. 22] During winter under-cooling is prevented with the application of thermal insulation.
- g) Airtightness: During winter, rooms undercool because air is in movement; therefore, the perception of cold rather than warm changes as the activities in this given room change.
- h) Room for installations: Depending on the buildings purpose, some, or no room for installations (pipes, cables, etc.) shall be provided.
- i) Wood protection: Wood is very sensible to the prolonged presence of water and humidity; in these conditions that wood attacking mushrooms grow fast. The wood shall remain dry, or water should flow away quickly. This is achieved by proper executional design and detailing, i.e., by cantilevering the roof above wood façade. [2, p. 138]
- j) Prefabrication: different systems allow different degrees of prefabrication, which may be utilised to their fullest. The prefabrication depends a lot on the project itself, such as the possibilities of the executing company rather the transport to the site's location.

According to Graf [16, p. 5] floor constructions of mid-rise buildings are a complex field of timber engineering. Every planner must know and fully utilise those advantages the picked floor construction system offers, and which systematic disadvantages must be counterbalanced. For this reason, next to the usual planners (architects and engineers) a floor specialist of the executing company is absolutely needed. This means that executional planning and coordinating starts earlier and the whole process is more complicated, but also more precise than usual.

Generally speaking, the decision to build timber floor constructions brings advantages, but also systematic disadvantages, which can't be avoided. Pech [17, p. 79] sees the following positive and negative aspects of timber floor constructions (see **Table 1**):

ADVANTAGES	DISADVANTAGES
Dry element installation	Prone to vibrations
Easy element connection	Sensible to prolonged humidity
Low self-weight	Sensible to insects, mushrooms
Safe earthquake behaviour	Bad structure-borne sound insulation
Low energy use in production	Fire resistance
Good thermal insulation	Low warmth storage
Good airborne sound insulation	

Table 1: Advantage – Disadvantage comparison for timber floors [17, p. 70]

4.1 Established Floor Constructions

These ceiling types have spread to different degrees over the last years; what they all have in common is the fact, that they can concur with concrete floors and concrete-steel composite floors. Nowadays, concrete constructions are still cheaper than timber ones, but sometimes ethical decisions should prevaricate over economical ones.

4.1.1 Light-weight timber floors

Generally speaking, all of the now following floor construction types have some things in common, such as reduced self-weight and not so brilliant sound insulation properties. A floor construction in a mid-rise residential building is an important component, it is one that often fails to meet structure-borne sound requirements (especially footsteps) [18, p. 92]. The sound insulation values are determined in labours or building sites, with or without sound transmission through secondary paths. There are two main measures which, directly and indirectly, improve the sound insulation qualities of light-weight timber floor constructions:

- a) Frequencies of music instruments and electro-acoustic systems produce loud and deep frequencies. Obviously, to improve sound insulation properties it is important to reduce the noise source, because so the airborne sound insulation improves. [18, p. 91]
- b) A filling above or in the floor itself to increase the floor's mass needs to be brought in place. Above that a very soft and elastic layer is placed (footfall sound insulation), while the top layer is formed by a concretes screed, where pipes for floor heating could be placed; in sum the whole package is a mass-spring-mass system, which is optimal for insulation of structure-borne sound. The CLT-panels depth has small influence as its mass is low compared to the mass-spring-mass system. To avoid structure borne sound from below, a suspended ceiling has become a valid option. [19, p. 120]

4.1.1.1 Timber Joist Ceiling

Timber framed ceilings are still used today; they consist of a series of beams as long as the primary span. Depending on the loads and the span these beams are made from structural timber (KVH) or GL-timber. To interconnect the beams, planks are placed perpendicular to the beams over the whole area. When these beams are placed 60-90 cm apart, the planking isn't supposed to carry loads; if the distance increases the panels are required to transmit forces to the beams below, which makes the use of an LVL, or CLT panel necessary. The deflectional and vibrational behaviour depends on the floor decking. They are most cost effective for spans between 4 - 5 m. It is possible to prefabricate timber beamed ceilings into two-dimensional panels. [1, p. 58]

ADVANTAGES	DISADVANTAGES
Very cost effective for spans 4-5 m	Construction depth is high
Low self-weight	Prolonged montage if no prefabrication
Easily adaptable to different loads	Limitations for KVH section dimensions
Beams can be protected from fire	
Noise insulation improves with weight	
Plenty of material choices	

Table 2: Advantage – Disadvantage comparison for timber beamed ceilings [5, pp. 171-172]

4.1.1.2 Hollow Box Flooring

Hollow box ceilings are developed from timber beam ceiling, with the difference that the panels on top and bottom are part of the structural system: by doing so they partially carry loads and altogether form boxed sections. These panels could be either CLT, LVL or OSB while the ribs are either KVH or GL-timber. In order to transmit horizontal forces, the ribs and panels are industrially bolted or glue-pressed together. If an opening in the floor construction is required (i.e., staircase) the beams are interrupted and two other beams, perpendicular to the main beams, are mounted at the delimitations of the opening (see **Figure 4-1**). [20, p. 28]

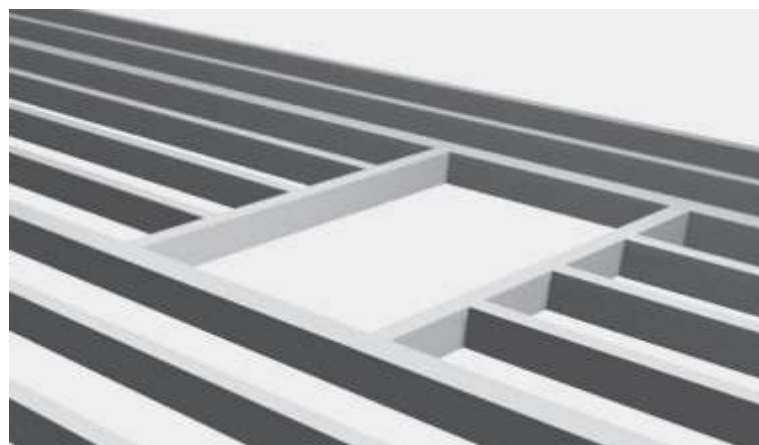


Figure 4-1: Opening in floor construction [5, p. 163]

The hollow interiors of the floor construction can be used variously: they could be filled with thermal insulation to improve thermal properties or with fill to improve sound insulation properties. Also, pipes and cables could be installed in those hollow spaces. Dimensions of these panels are limited by transport, with max. widths of 2,5 m and lengths between 5-15 m. [20, p. 28]

If we isolate one rib and parts of the upper and lower panels in the middle of the floor constructions, we notice that a turned *h-like* section has formed, with the rib as vertical element and the panels above and below as upper and lower flanges, respectively. This remembers steel profiles (like HEA, HEB or HEM series profiles), with its depth given by the distance between the panels (see **Figure 4-2**). If the depth increases, the load bearing capacity increases too. Also, thanks to the panels, the ribs, which are parallel to the span, can't buckle because of normal force. Thanks to this upper and lower flange moments can be transmitted too. [1, p. 60]

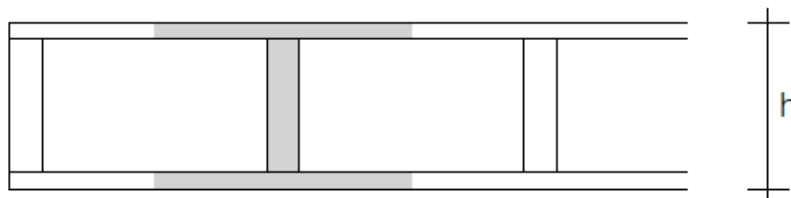


Figure 4-2: Section through hollow box flooring [1, p. 61]

ADVANTAGES	DISADVANTAGES
Low section depth	Not adaptable for complex floor plans
Composite load bearing (ribs + panels)	Exact planning (production, installation)
Low self-weight	
Industrial prefab. and fast installation	
Properties are exactly known	

Table 3: Advantage – Disadvantage comparison for hollow box flooring [5, p. 173]

4.1.1.3 KVH Boxed Elements

Sometimes, planners wish to have visible floor construction surfaces, but in mid-rise buildings this is prevented by the fire protection normative. KVH boxed elements could function as an alternative to TCC floors due to the equivalent fire resistance. [20, p. 31] This system (see **Figure 4-3**) works similarly to hollow box floorings, with the difference, that all elements are out of KVH (which makes them cheaper). In the hollow interiors there is enough space for installation, thermal insulation, or fillings to improve sound insulation properties. After installing an impact sound insulation and a screed, sound insulation properties further improve. The quite interesting thing about those elements is the fact, that they can cover spans up to 12 m with a section depth of 320 mm, because the load carrying scheme is very close to the one shown in **Figure 4-2** [21, p. 47]. This section type is well conceived, because material is placed where the highest stresses are located: in the case of

a single spanned floor the critical points are the extremities of the section for bending stress and the symmetry section for shear force. No material is to be found where there is no need for it and so the self-weight is starkly reduced. The pros and cons of this floor construction type are very similar to the ones listed in **Table 3**. Openings in the floor construction are executed similarly to **Figure 4-1**. These panels are prefabricated into panels and brought to site; their dimensions are again transport and production limited.



Figure 4-3: KVH Boxed Element [21, p. 46]

4.1.1.4 LVL Composed Section Floors

For longer spans or higher loads, there is the possibility to compose section out of single LVL elements, such as rib panels, hollow boxes, or open box floors [22, p. 61]. By using composed sections an advantageous load carrying mechanism is achieved (see **Figure 4-2**). The load carrying behaviour depends on how the section is conceived, see **Figure 4-4**. If the floor construction is meant to stay visible after construction, the LVL elements need to have better optic qualities than usual. Two-way spanning ability is ensured by LVL panels on top connected to rib panels by glue (glued joint) [22, p. 61]. This type of floor construction is very depth efficient, since for a span of 6,0 m a section depth of 268 mm (open box section) is required for the following loads: 2,0 kN/m² imposed load, 1,6 kN/m² self-weight and 0,3 kN/m² partition load. [22, p. 62]

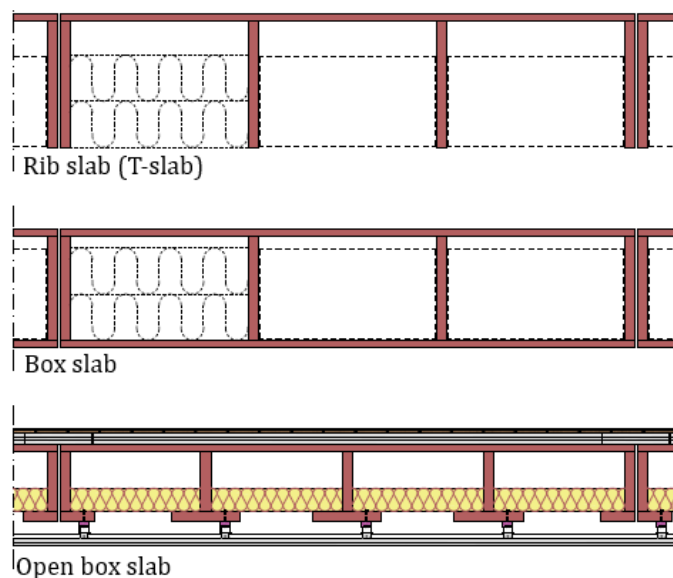


Figure 4-4: LVL Floor Constructions consisting of composed sections [22, p. 61]

4.1.2 Massive timber Floors

4.1.2.1 CLT Floor Constructions

Because the material CLT has already been explained in chapter 2.2.3, in this chapter the focus is on its utilisation for floor constructions. Dimensions realistically are defined by production and transport; the panel width (max.) is 2,95 m, while the maximum length reaches 20 m. In many cases, when CLT is used for floor constructions, the walls are also of the same material. This decision simplifies the wall-floor connection and so the execution too. A massive timber element weighs way less than a concrete one of equivalent dimensions; this makes assembly and transport easier, reduces self-weight loads on the structure itself and has a better seismic performance.

Generally, if the section depth rises or the fire protection measures improve, so improves the fire resistance. The strength and stiffness values of wood decrease as its inner temperature rises; this aspect has to be considered when the load bearing capacity of a CLT-panel with reduced section (because over 30, 60 or 90 minutes some wood is burnt) is calculated. [14, p. 18] Thanks to the odd number of crosswise disposed layers and the glue between them, the swelling and shrinking movements under humidity increase and decrease respectively; they can be controlled and kept to a minimum. The result is a form stable floor construction with two-way spanning ability, in-plane and out-plane spanning ability bearing capacity and high stiffness to transmit lateral loads to the load bearing walls. Thanks to the spanning ability along both axes, this floor types can be supported punctually. To keep swelling and shrinking to a minimum the utilised lumbers contain bounded water, which amounts to 12% of the total weight (bounded humidity).

ADVANTAGES	DISADVANTAGES
Element connection easily achievable	High timber consumption
Possible horizontal diaphragm	"OK" load bearing compared to timber consumption
Low sectional depth / stiff section	Floor plans should not be too complex
Two way spanning ability	
Rapid installation	

Table 4: Advantage - Disadvantage comparison of CLT [5, p. 177]

4.1.2.2 DLT & NLT

As mentioned in chapter 2.2.4, DLT and NLT floor constructions consist of vertically lumbers, one next to the other and connected by dowels or nails. Such a construction is cost-effective because the single sections aren't expensive, if compared to the timber beamed ceiling, where the sections have better strength, quality, and so higher costs. This floor type is not difficult to construct, so it can be executed by craftsmen directly on site too. But it's also possible to prefabricate DLT/NLT panels (obviously to different degrees) and install them directly on site. As massive floor constructions they share the same advantages/disadvantages of CLT floors (see Table 4). To gain

horizontal load bearing capacity, a OSB or CLT panel is placed on top (see **Figure 2-6 d**). Because of the low stiffness of DLT/NLT floors perpendicular to the span, a steel construction for support around slab openings needs to be designed. In lowly loaded areas openings for installations (max. 20x20 cm) are executed by strengthening the slab with screws [9, p. 24].

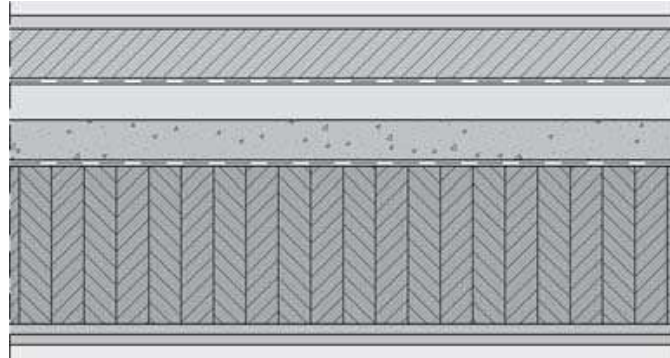


Figure 4-5: Section through NLT panel with bulk material and screed [17, p. 101]

Because of the swelling and shrinking movements, enough room for these motions at floor level needs to be provided. For the same reasons, during the element transport they should not be exposed to any rain [17, p. 102].

4.1.2.3 Massive LVL Floor

The existence of massive LVL panels for walls and floor constructions shall be noted. It consists of 3 mm veneers glued together to obtain the wished panel dimensions (multiple glued). Normally softwood veneers are used, but since a few years also hardwood ones are produced. **Figure 4-6** shows the veneers application and the grain direction, which is parallel to the span. These panels carry loads as homogeneous panels do, but it's also possible to apply perpendicular veneers to obtain two-way spanning ability [1, p. 63]. According to [22, p. 60] to span over 4,5 m a panel thickness of 144 mm or 48 veneers á 3 mm each is required. If properly connected to load bearing walls, these panels act as horizontal diaphragms.

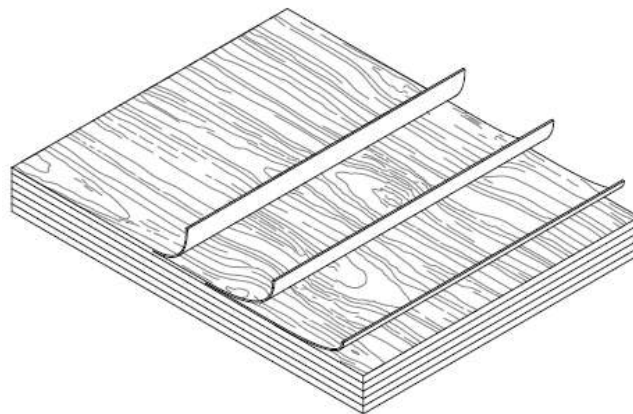


Figure 4-6: LVL massive panel [1, p. 63]

4.1.3 Timber-Concrete Composite Floors (TCC)

Generally speaking, a composite construction consists of at least two materials combined together and both involved in load bearing. To achieve this simultaneous bearing effect, an interconnection is needed, in this case a shear connection. In construction, the two most diffused composite constructions are steel-concrete and timber-concrete ones. All the to this point described floor construction types (see **chapters 4.1.1** and **4.1.2**) can be executed with a concrete layer on top and a proper shear connection but doesn't contribute to composite load bearing action. In the case of a single spanned beam or floor construction, the concrete section carries the compression stress while the timber below is under tensional stress. In this case both materials are used to their best and so two main aspects of the floor construction improve by a significant margin if compared to a normal timber floor: load bearing capacity and bending stiffness [20, p. 28]. TCC constructions are utilised when the floor construction's required span and/or the loads on it increase. Other benefits in the usage of TCC hybrid floors are an improvement in the sound insulation properties, especially in the low-frequency sector and an improvement in the fire protection. TCC floors are usually implemented when a fire protection concept for buildings higher than the normative standards is needed. [23, p. 7] Another benefit regards the improved resistance to vibrations, which becomes an important factor as soon as spans become longer. This susceptibility to vibrations is especially valid for pure timber floor constructions, because of their reduced mass and stiffness (and so the reduced eigenfrequency). The seismic performance is also improved compared to massive concrete slabs, because of their reduced weight and so less seismic active self-weight. [24, p. 2] In such cases, this type of construction is a cost-effective alternative to the well-known concrete slab.

The composite behaviour is decisively influenced by the type of shear connector. Choosing this connecting element is absolutely crucial in regard to the system effectiveness and economic competitiveness. There are two ways to achieve composite load carrying, the first system with interlockings between timber and concrete, while the second system works with bolts, dowels, plate notches, perforated plates, or combinations of different connectors to transmit shear stress. For the last 20 years the usage of glue as shear connector has been explored too, because of the very high strength and stiffness and the cost-effectiveness during production. [25, p. 443] The used adhesive is a two-component epoxy resin, that is suitable for transmission of compression and shear stresses. Sometimes the usage of these glues is problematic because while pouring in the concrete, the glue could be moved; climatic and local conditions influence the gluing behaviour; after some time, the glue becomes brittle and could fail because of that. For these reasons, these adhesive connections are mostly applied if the floor construction is prefabricated [26, pp. 68-69]. [27] states that the simplified theoretical model is applicable (in the case of TCC beams with adhesive connection) for practical design in the case of short-term loading. The long-term behaviour is not yet investigated in detail. [27, p. 949] The most recent and successful achievement is the pouring of wet concrete on a still wet glue ("wet on wet") [23, p. 11]. One of the ongoing

discussions is if the concrete topping needs to be poured in on site or if it makes more sense to prefab the whole package. Because building site manufacturing is still more-cost effective than prefabrication of TCC floors, there have been first attempts of concrete prefabrication companies to produce TCC floor elements, which ultimately failed. [20, p. 28]

ADVANTAGES	DISADVANTAGES
Ideal usage of both materials	Detailed Preplanning
Ductile behaviour	Difficult design process
Bigger spans are possible	Precise production
Timber as design element	TCC floor needs static supports
Horizontal diaphragm	Difficult transport/installation
Low vibration susceptibility	Costs
Good fire protection properties	Little installation room
Reduced building time	Needs protection against rain, wind
Good load distribution	Bad sound insulation ⁽¹⁾
Good airborne sound insulation	Bad fire protection ⁽²⁾

Table 5: Advantage – Disadvantage comparison of TCC [11, pp. 140-141]; [28, p. 24]

Recent developments use the prefabrication of timber and the automatised production of concrete to their strength. The timber elements and the concrete panel are prefabricated separately and connected afterwards. The main advantage is that the concrete slab can shrink separately without additional stress (eigenstress) for the timber elements, as it would be the case if fresh concrete would be brought in. Afterwards, the shear connections, bolts in this case, create the connection between the two materials. This product reintroduced the usage of bolts, as they weren't used a lot to create effective shear connections, because lots of them were needed. [20, p. 30] Another advantage, which shall not be forget, is the very fast and dry montage, which has a positive influence on the total building time. This solution is also fully demountable, which is important if changes in the structure are needed or the structure is transported and mounted elsewhere. [24, p. 2] To achieve such feat sound insulation, parquet, tiles, etc. need to be quickly demountable.

4.1.3.1 Timber beamed Ceiling – Concrete

This type of TCC floor was the first one developed because it's the closest to floor construction of 19th century buildings; it consists of beams (KVH or GL) with a concrete slab on top. In order to achieve composite action, shear connectors between timber and concrete need to be implemented (see **chapter 4.1.3**). The used types of shear connectors are screws, dowels, or notches; as already

¹ If directly compared to reinforced concrete slabs [28, p. 24]

² If directly compared to reinforced concrete slabs [28, p. 24]

mentioned, the slip-modulus is crucial for the connector's stiffness. Because of the composite action, this TCC floor construction has 2-5 times higher stiffness and load bearing capacity compared to usual timber beamed ceilings. [29, p. 3] These shear connectors can be also mounted before bringing the elements to site. [11, p. 142] The concrete topping can be poured in on site or prefabricated separately (see **Figure 4-7**); in this case concrete needs to be fixed to the below lying timber beams separately by i.e. screws. To activate the whole floor as diaphragm, the single composite elements need to be interconnected by pouring concrete between elements and so creating stiff connection. Also, the space between beams or below them can be used to improve the sound insulation properties. [29, p. 4]. The used concrete should be fast-drying and have low-shrinkage properties. Otherwise, the concrete should dry slowly and steadily, to reduce its shrinkage as much as possible and so to reduce additional stress on the timber elements. Still, this option is favoured because of the cost-effectiveness and the quick and well-known execution. [30, p. 12]



Figure 4-7: Prefabricated TCC floor element, LCT-One Tower [31, p. 4]

4.1.3.2 CLT – Concrete Composite Floor Constructions (one-way spanning)

This type of floor construction is very simple, as it consists of a CLT panel and a connected concrete layer, placed above the panel. Thanks to the CLT panel and the concrete slab, this floor construction can carry two-axial loads. The panel acts as formwork for concrete if it is cast in-situ. According to Setragian et al. [32], another aspect that needs to be considered is the effect of concrete humidity on a CLT panel. To minimise the risk of mould growth because of moisture some measures might be necessary: TCC floors with concretes of water to cement relation of 0,38 and 0,60 are dry enough to avoid wood damages, while 0,50 w/c is humid enough to do some damage. After lowering the relative humidity to 95% or below the results improved and wood damages because of humidity

could be avoided. [32, p. 73] As mentioned previously, the shear connection might be achieved later, by bolting together a CLT and a concrete panel.

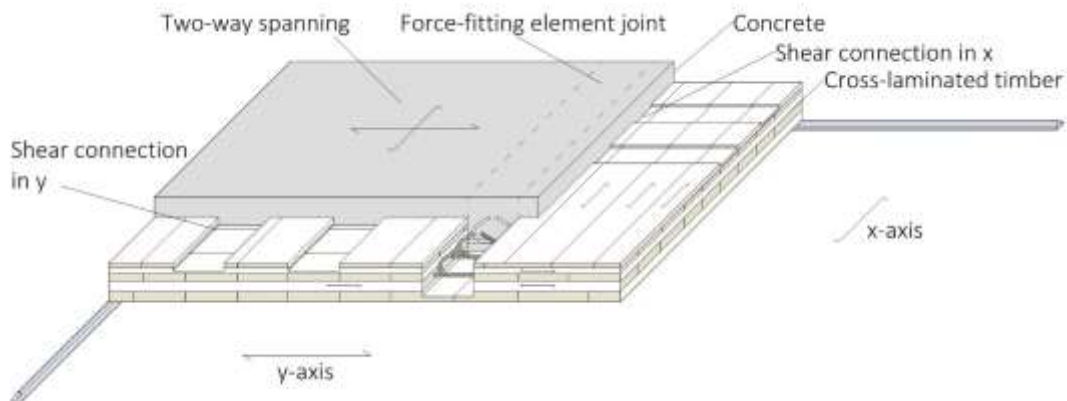


Figure 4-8: CLT-Concrete-Composite floor with notched connections [33, p. 263]

For such mass timber constructions, different shear connector types have been developed; the two main groups are notched and adhesive connections. As stated previously in **chapter 4.1.3**, this interconnection is very important, as it defines the degree of composite action. Thilén states, that two of the connection with the highest slip-modulus are the notched and adhesive connections; a high slip-modulus minimizes the horizontal displacement (see **Figure 6-1**) because of shear forces between timber and concrete [34, p. 14]. These notched connections (see **Figure 4-8**) are executed by cutting grooves in the panel's top surface, which later are going to be filled with concrete and so create the shear connection. A larger notched connection area provides a better slip-modulus and so strength [34, p. 15]. Gutkowski recommends, that when notched connections are used, mechanical connections between concrete and timber (for example dowels) should be provided to prevent the concrete slab from lifting [35, p. 1061].

4.1.3.3 Board stack – Concrete

This type of mass floor construction coupled with concrete is similar to a CLT with concrete deck, with the difference residing in the fact that the lumbers are stacked vertically one next to the other and glued together. The shear connection is created by different heights of the lumbers positioned next to each the other. Another possibility to achieve composite action is to create rectangular or triangular notches with or without coach screws, like the notches described in **chapter 4.1.3.2**. The advantages this system offers are similar to what described in the previous chapter.

In their paper Lehmann, et al. [36] developed a different system of shear connectors for board stack concrete composite slabs. The connectors consist of small steel plates (40 x 5 mm) that are almost placed vertically (angle of 5°). Contrary to screw shear connectors, these steel plates are placed every here and there, therefore creating locally concentrated composite action. [36, p. 386] After performing a push-out test, it was found out, that the steel plates performed the composite action

through bending, because the extremities of the steel plate are mainly fixed by concrete. This is valid as long as the concrete is not cracked; the by then resulting tensional force on the concrete itself needs to be considered in the dimensioning of the concrete's steel reinforcement. Because the concrete's compression, the shear connectors are secured against pulling-out forces. [36, p. 386] The shear connection collapsed because the concrete around the steel plate desegregated, the first signs of it were observed after increasing the maximal load by 30%. [36, p. 388] After performing the bending test of a board stack concrete composite slab similar shear connection collapses because of concrete desegregation were observed. In their paper Lehmann et al. concluded, that this type of shear connectors is very cost-effective in installation, since few preparing cuts in the DLT/NLT slab are needed. [36, p. 389]

A particular problem should not be forgot: the weak compressional properties of timber perpendicular to its grain. For this reason, board stack ceilings, but also of CLT composite floors must be continuously supported. For the cases where such a support is not achievable, Kuhlmann et al. [37] developed special steel-concrete beams within the floor construction allow to support the slab in concentrated points. The so called slim-floor profile, applied perpendicular to span and grain, consists of an UPE profile, a welded steel plate and welded headed studs to ensure shear force transmission (see **Figure 4-9**). [37, p. 175] Kuhlmann et al. noted a few things about the load carrying behaviour of the node timber-steel-concrete [37, p. 177]:

- 1) The effective acting width of the steel-concrete composite section (SCC) can be determined according to EC4.
- 2) Because of the possible concrete core splitting, the headed studs of the SCC beam have to be designed as studs on the edge according to EC4.
- 3) During design of the TCC slabs a hinge is assumed at the supports, whereas while designing the SCC section a continuous TCC slab should be considered.

Because of the reduced self-weight compared to a concrete slab of the same depth with integrated slim-floor profiles, such a system allows larger spans and bigger column-free areas. [37, p. 177]

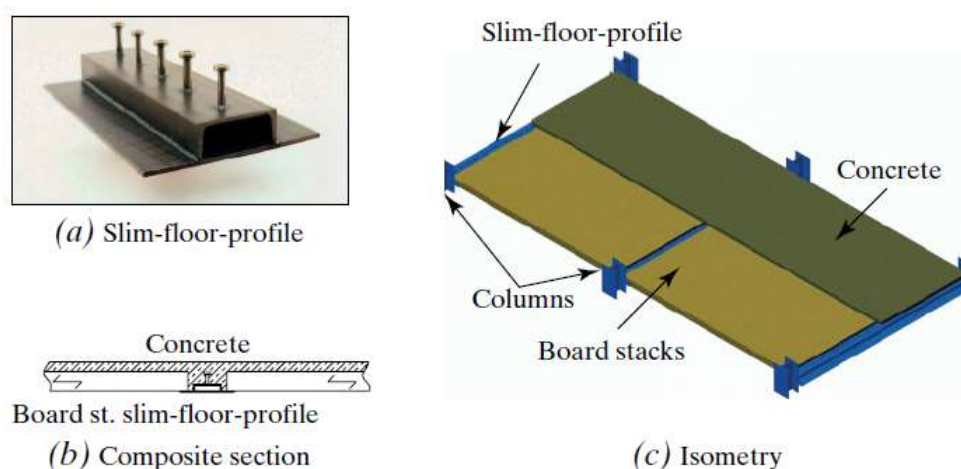


Figure 4-9: Slim-floor profile (a), section (b) and isometry (c) of composite DLT [37, p. 175]

4.1.3.4 LVL – Concrete Composite Floor Constructions

In most cases, this floor construction type consists of LVL beams and a connected concrete topping, which results in a T-formed section and semi-prefabricated element. [24, p. 2] In rare cases, massive LVL panels are used in combination with concrete slabs, to form something similar to what described in **chapter 4.1.3.2** (see [1, p. 64]). Depending on the distance between the single LVL elements, they have section's dimensions of joists or beams. As explained in the previous chapter, the composite action is given through stiff and strong shear connectors. However, to be cost-effective, the shear connectors need cheap in production and fast to install. [24, p. 2] In his papers Yeoh [24], [38] describes the possible shear connectors that are cost-effective in such a floor construction. Different connector types were analysed: toothed metal plate fasteners and notch connectors (rectangular, triangular and dovetail shape) with or without screws (12 or 16 mm) with varying penetration depth. After performing the push out test the following things were observed [38, pp. 229-230]:

- 1) The notch length positively affects the connection's shear strength, i.e., a 50 mm notch has 60% of the strength of a 150 mm notch.
- 2) A connection with coach screw has increased strength and stiffness 1,5-2,0 times higher than connections without coach screw. The only present ductility is the present screw, which increases the load resistance.
- 3) In a few cases it was observed how the connection's stiffness rapidly decreases after reaching the SLS limit in a way described as the post-peak behaviour.
- 4) The screw dimensions affect the strength but not the stiffness.
- 5) A triangular and rectangular notch have similar strength and stiffness performances.
- 6) The notch depth has either positive nor negative effects on strength and stiffness of the shear connection.
- 7) The 2 mm thick toothed metal plate showed ductile behaviour coupled with high strength and stiffness.

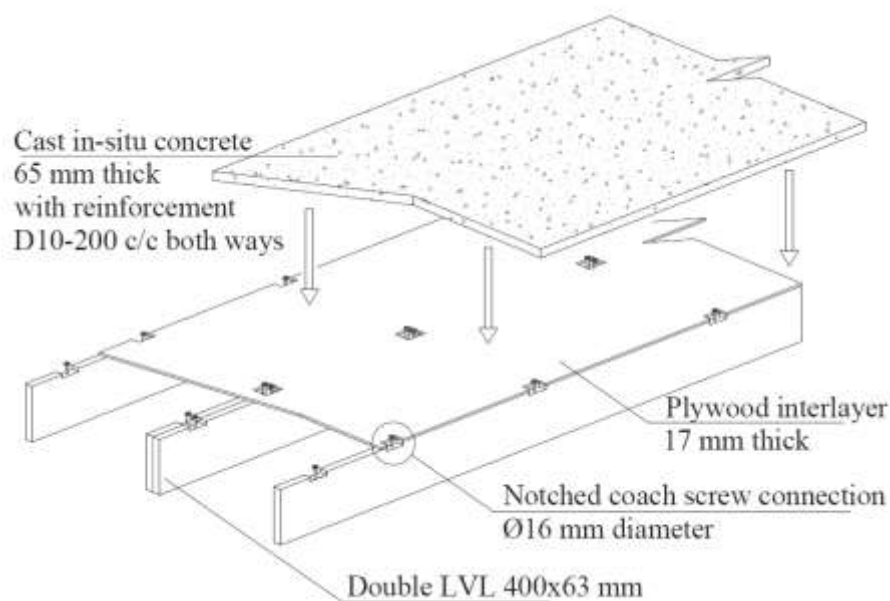


Figure 4-10: 3D figure of LVL - Composite Section [24, p. 2]

According to [24] and [38] the best connection types are the following: notched triangular (137 mm long) or rectangular (150x25 mm and 300x50 mm with 16 mm screw) with coach screw connections and toothed metal plate (2x333 mm). Still, the metal plate has a stiffness by 1,8 times higher than the rectangular notch, while the bigger rectangular notch is 1.9 times stronger and 3 times stiffer compared to the 150 mm rectangular notch [38, p. 233]. Floor construction systems as the one showed in **Figure 4-10** are used in mid-rise and high rise buildings because of the avoided pressure perpendicular to the timbers grain (see **chapter 2.1**); the system shown in the figure above is suitable for spans of 8-10 m and needs 6- 8 connectors per joist. [24, p. 3] The concrete topping, also needed to interconnect the joisted elements, is poured in after all elements composing the floor construction are brought in place by a crane.

4.2 Floor Types in research

These floor constructions are in development stage, because their short- and long-term behaviour is still researched in papers, doctoral theses, or diploma theses. Given the advantages of composite constructions, this modern floor constructions normally combine two or more materials. Prefabrication possibilities are explored, because it is thanks to that property that TCC floors are able to compete against other building materials. According to Holsmacher the research focuses a lot on high-effective shear connectors and load bearing behaviour of TCC structures. Usually, for the concrete's reinforcement of a TCC floor a steel mesh is used; because of the required concrete covering the minimum depth is 8 cm. If steel fibres are used for reinforcement purposes, there isn't a required covering. The concrete's depth decreases, and the shear connectors bear loads better too. [39, p. 103] Another investigated aspect is the load behaviour of TCC slabs under concentrated loads on one composite beam. Depending on the concrete panel stiffness, the load transmits to the next beams and deflects them too. This effect is defined as lateral load bearing and should be considered in the design of TCC floors. [39, pp. 104-105]

4.2.1.1 Two-way spanning CLT-Concrete composite floors

This modern, two-way spanning floor construction without reinforcement for concrete is easily adaptable to various boundary conditions such as: floor geometry, noise insulation, fire protection, installation, and montage. The result is a floor construction that covers considerable spans without much section depth with on-site casted concrete. [40, p. 65] It makes sense for the following applications [40, pp. 68-69]:

- 1) High noise insulation requirements,
- 2) Spans above 7,5 m for simply supported beams and 10 m for more-span beams respectively,
- 3) Acting two-way bending forces,
- 4) Unregular floor plans are achievable, plenty of required installation in the floors themselves
- 5) Visible bottom side of the floor construction

According to Schuler, the depth of the concrete section is determined by the installation, sound insulation but usually not static requirements. The main characteristic of this shear connectors is their two-way load bearing capacity because they have to warrant a nearly slip-free composite action. Structural failing comes because of shear failing of the glued connectors; this happens when loads are 15x higher than the projected loads. Reinforcement of the concrete slab are necessary when the span reaches 7 m or concentrated loads are brought in. When the single elements are interconnected, this floor construction acts as diaphragm. [40, pp. 65-70]

Loebus et al. [33] analysed how shear connection systems that are widely researched and developed for uniaxial TCC floor would behave in two-way spanned (bi-axial stress) composite CLT-Concrete systems. They examined screws with an angle of 45° to the grain and rectangular notches. [33, p. 263] In the case of rectangular notches, an asymmetric layer disposition in the CLT panel is needed, because the shear force in the fugue (timber to concrete) has to be applied parallel to grain, which means that the notch is perpendicular to grain (see **Figure 4-11**).

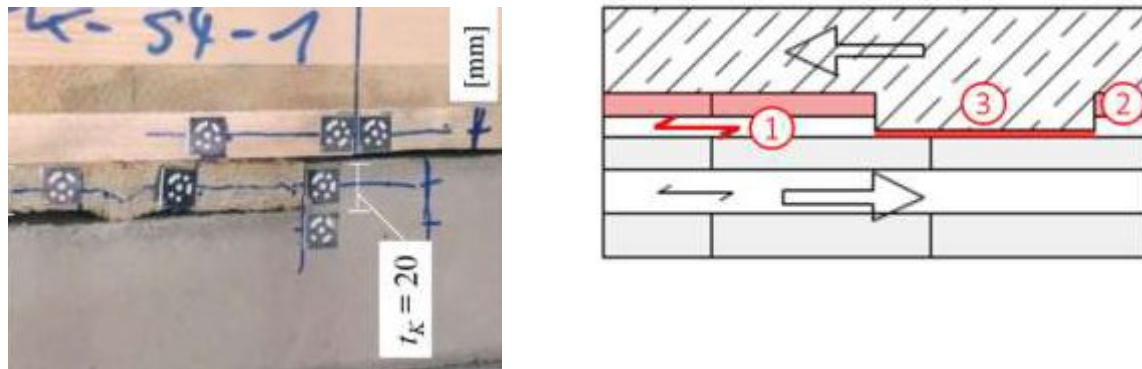


Figure 4-11: Shear force application for notch perpendicular to grain [33, p. 266]

Loebus et al. analysed screws with an angle of 45° to the grain and overall aligned parallel to the main shear forces directions. By doing that, every screw is under axial and lateral loading and so resulting slip-modulus parallel to the force direction. This resulting slip-modulus is then used during the following design process. [33, p. 269]

4.2.1.2 Timber - Wood Lightweight-Concrete composite floors

This type of floor constructions makes usage of three different materials, from top to bottom disposed in the following order: concrete, wood lightweight concrete (WLC) and timber. To interconnect these layers and to warrant the composite action of the floor construction shear connectors such as adhesives and/or screws are used. As visible in **Figure 4-12**, the middle WLC layer increases the distance between the centres of gravity of timber and concrete panels, respectively thus increasing the sections moment of inertia. The resulting panels are lighter and easier to manoeuvre and mount than corresponding concrete panels, thus reducing the self-weight of the floor construction. [41, p. 18] The EWP used in the tensional area normally is CLT, DLT or

NLT and self-compacting concrete layer on top. Such a layered construction can be prefabricated easily, obviously to different degrees. [42, p. 198]

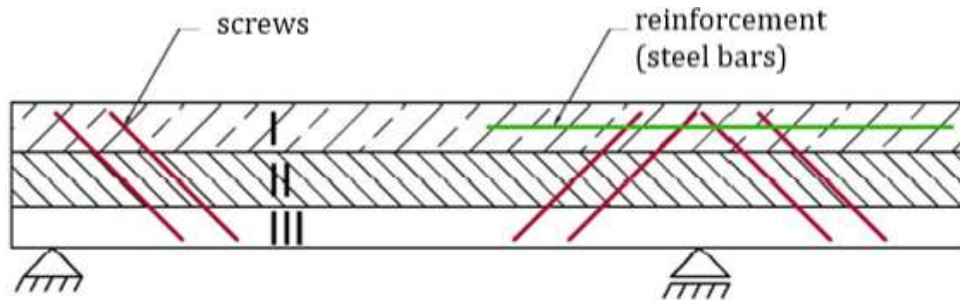


Figure 4-12: Schematic drawing of Timber-Wood Lightweight Concrete Composite Slab [41, p. 18]

WLC, which is a light-weight concrete, is obtained by mixing cement, water, and various wooden industrial waste products (i.e., wood chips, shavings, and sawdust) together. Depending on the variable amount of used cement vs. wood chips, the strength and the self-weight increase or the exact opposite happens. Additionally, WLC panels have high thermal and good acoustic insulation values, which allow different uses of this material. [42, p. 197] Another aspect which needs to be considered, is the lower primary energy usage during production compared to CLT panels (ca. 50 %), because of the utilization of wooden waste products. [42, p. 199]

One may think, that with the addition of a light-weight concrete layer the section depth increases too much, thus being a big disadvantage in comparison with other TCC floor constructions. The floor constructions analysed in [42, p. 198], spanning 8 m, have a total depth of 338 mm. On top of that, the depth of tiles and a screed shall be considered, thus having a total depth of 400 mm. An RC slab, also spanning 8 m, has similar section depth and total depth too. [43, p. 147] So why one should choose Timber - Wood Lightweight-Concrete composite floors? Such floor constructions have less ecological impact, lower self-weight and can easily be prefabricated and so a reducing total building time. On the other hand, RC floors are still cheaper.

4.2.1.3 Hybrid FRP-timber-concrete floor panels (FTC)

This panel, designed by Ou et al [44], aims to reduce the concrete amount under tension and improve the ratio of load to weight of this floor system. As all TCC floors, also this FTC floor panel has better load/weight ration than normal reinforced concrete (RC) floors. [44, p. 1] This panel, shown in **Figure 4-13**, consists of a tensile timber on the bottom, the FRP-timber core made out of plywood and a concrete topping. Such a construction reduces the needed concrete by 35 %. [44, p. 2] The composite action is achieved by gluing the FRP-timber core on both sides, one towards the wooden tensile member while the other towards the concrete. Obviously, the adhesive is applied before the concrete is cast into the framework. [44, p. 3]

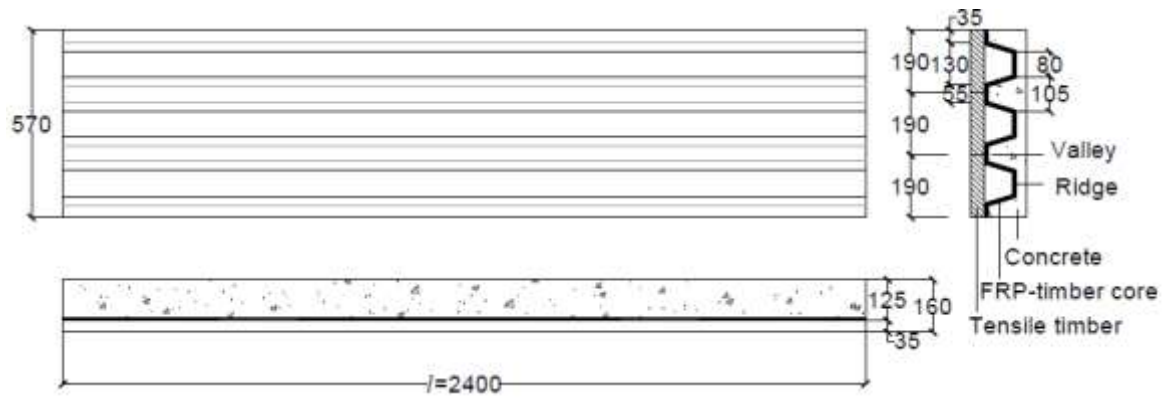


Figure 4-13: Schematic drawing of Timber-Wood Lightweight Concrete Composite Slab [41, p. 18]

The FTC floor construction ultimately fails because of flexural shear cracks, which developed across the whole section. [44, p. 4] After performing the bending test, it was found out, that the present FTC floor construction has much better moment capacity compared to similar TCC section or T shaped TCC floors, tested in other papers. Only T-shaped sections with RC showed better moment per weight capacity than FTC floors. [44, pp. 5-7]

4.2.1.4 Timber to Timber Composite Floors (TTC)

As their name states, this floor type uses timber instead of concrete in the compression zone. This means, that the self-weight is furtherly reduced while the performance in case of an earthquake is enhanced. Still, the fire resistance and noise insulation need to be taken care of separately. Because of the stated properties, this floor type is preferred in refurbishments of existing timber floors but could be interesting for mid-rise buildings floors. [45, p. 1] Timber to timber composite floors and beams have not been researched as much as their counterpart with concrete (TCC floors). There are some possibilities to achieve composite action, i.e., thanks to external propping systems, thermal treatments, or tendons. [46, p. 1] Another possible way to achieve composite action, is to camber and prestress (CP) by inserting the screws with an angle of 45° to the horizontal element axes. Riccadonna et al. explain: "All tests were characterized by a fastener inclination to the grain of 45° , [...] to ensure adequate levels of horizontal *screw induced* compression without penalizing the fastener withdrawal capacity" [45, p. 2]. By tightening the screws, an inner compression force is generated (see **Figure 4-14**). This compression force induces resulting shear forces between the two timber elements, thus creating uplift forces on the beam (negative deflection). If the screws are not inclined, the present shear force between the single elements is opposed, which results in a positive deflection of the beam itself as soon as vertical loads act. (see **Figure 4-14**). [47, p. 2] In order to increase the composite action, the fasteners need to be inserted starting from midspan and alternatively toward the beam supports. [46, p. 1] Riccadonna et al. [46] applied the CP technique on most of the T-sectioned TTC floors, in order to compare it other shear connectors used in timber-to-timber composite floors. The following floors were tested: CLT-LVL (hybrid), LVL-LVL, CLT-GL and LVL-GL (hybrid).

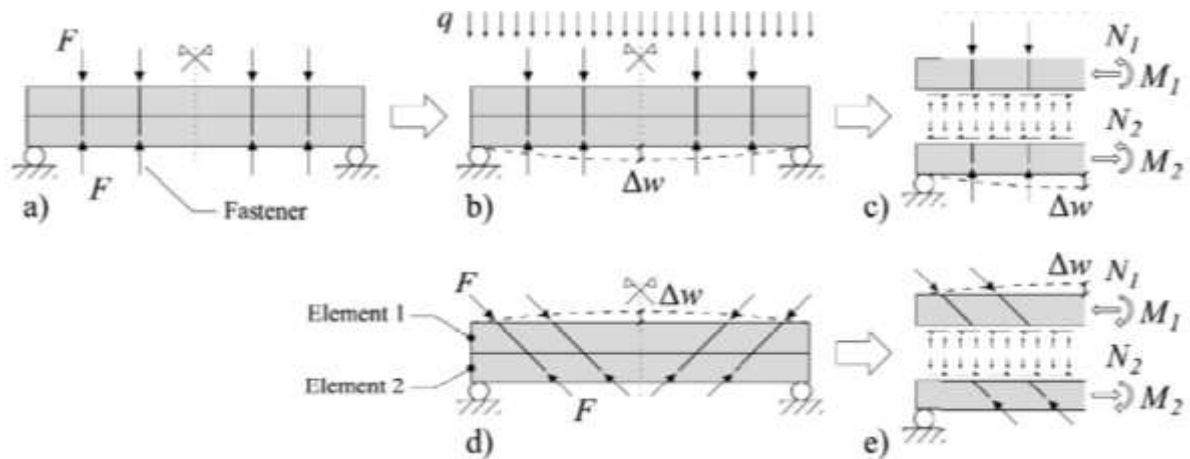


Figure 4-14: Camber and prestress with not inclined and inclined screws [47, p. 2]

After all the executed test, it was found out that the CP procedure is versatile and performant, while it allows to reduce the floor cross section depth. All the tested sections (with a span of 6,4 m) did not fulfil the SLS requirements before reaching the ULS limits. Double threaded screws perform well in softwood and hybrid sections, while single threaded screws work well in hardwood-hardwood sections. [47, pp. 13-15] Long-term behavioural tests found out, that the CP procedure persists over the analysed time with minimal losses in the uplift deflection of the beam. The impact of humidity variations shall be taken in account, as it can drastically change the effects of a CP procedure. [45, pp. 11-12]

4.2.1.5 Steel – Timber Composite Floors (STC)

This usually prefabricated floor construction is obtained by the connection of a very slim CLT panel on top and a pair of steel beams (of different shapes) below. This construction is suitable for modular buildings as it can be produced in 2D modules and transported as such to building site. [48, p. 695] The first thing that comes to mind, is that this construction is fully demountable and built under dry conditions (see **Figure 4-15**, left). The reduced self-weight compared to a TCC floors and the reduced execution costs because of prefabrication shall not be forgotten. Thanks to the steel beams the single panels can be connected to a steel frame system and so become a stiff diaphragm for the transmission of horizontal loads. The composite action is achieved by special connectors such as fully threaded screws (see **Figure 4-15**, left) or epoxy adhesives (**Figure 4-15**, right), which are mounted in variable spacing between them. [49, p. 696] As explained in **chapter 4.1.3**, the glue is sensible to high or low relative air humidity and temperature, hence these atmospheric conditions need to be considered. [49, p. 701]

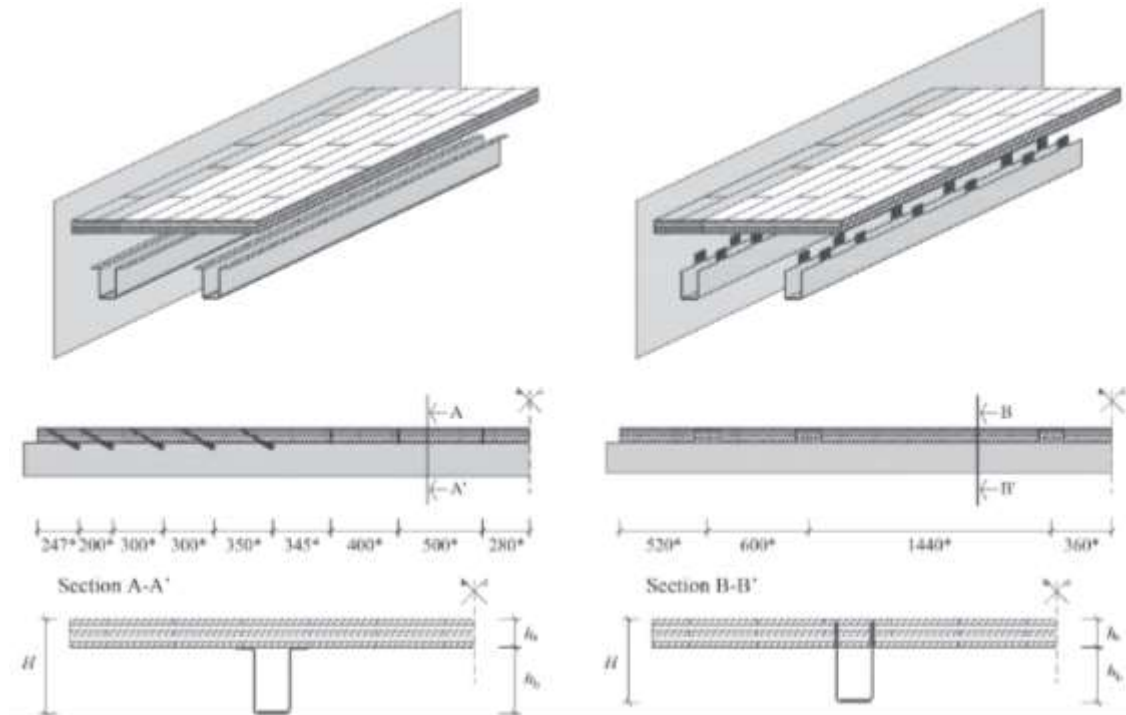


Figure 4-15: Different types of STC floor constructions [49, p. 697]

Because of the present steel members, this very innovative floor construction has good ductile behaviour but also a very good load carrying capacity while maintaining a small cross-section depth and thus a reduced material usage. Indeed, a 6 m spanned floor is composed by 82% of wood, 17% of steel and 0,1 % adhesive, which is the only, not recyclable material. At very high loads (4-5 times higher than design loads), the connections show plastic behaviour, while the CLT panel remains elastic. The instability of timber and steel is prevented by the shear connectors because of their very high ductility even under large deformations. If the panels have fixed restraints, stiffness and load-carrying capacity rise by ca. 40%. [49, p. 712] These panels behave as diaphragm because they act like a truss system or a deep beam because of the shear connections. Diaphragms that act as deep beams are to be preferred because of their higher in-plane stiffness; still, these elements cannot be thought of as fully rigid. [48, p. 243]

4.2.1.6 Steel-Timber-Concrete Composite Floors

This combination of different materials offers an interesting alternative, from a static and especially ecological point of view to the already used STC or TCC floor construction. STC beams have been extensively analysed and developed by Riola [50] in his doctoral thesis. Steel-timber composites beams and floors offer lightness, low section depth and reduced timber creeping. Timber-Concrete constructions offer enough mass for sound insulation, in-plane stiffness, and fire protection of the timber elements. The idea behind steel-timber-concrete composite (STCC) floor decks is to conjugate all these positive properties into one system. [51, p. 1] It consists of two symmetrical GL timber beams and I-shaped steel beams that together form a steel-timber composite beam; finally, a concrete floor decking (usually self-compacting concrete) is placed on top in order to form a floor

construction with STC ribs interconnected by a concrete floor on top (see **Figure 4-17**). The GL sections have horizontal grooves to accommodate the steel beam's flanges. [52, p. 25] Another advantage of this floor construction is that it can be partially prefabricated (just the hybrid beam) or fully prefabricated and transported to the site. [53, p. 2]

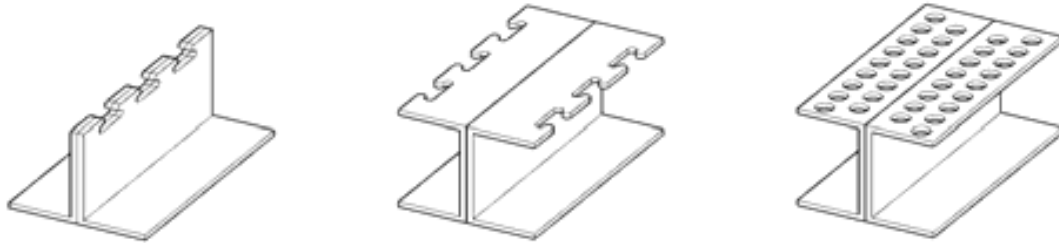


Figure 4-16: Puzzle strip plate, puzzle strip girder and perforated girder [52, p. 30]

The composite action can be achieved either timber-concrete or timber-steel by different usage of shear connectors. In the first case, the shear connection consists of 3, 4 mm steel sheets, which have their top laser-cut or perforated into the needed shape (see **Figure 4-16**) and afterwards connected together in order to form a steel beam. For the connection between timber and concrete notches that are cut on the upper part of the GL beams are used. The notch number increases the closer they are located to the supports because the total shear force increases too. [51, p. 9]

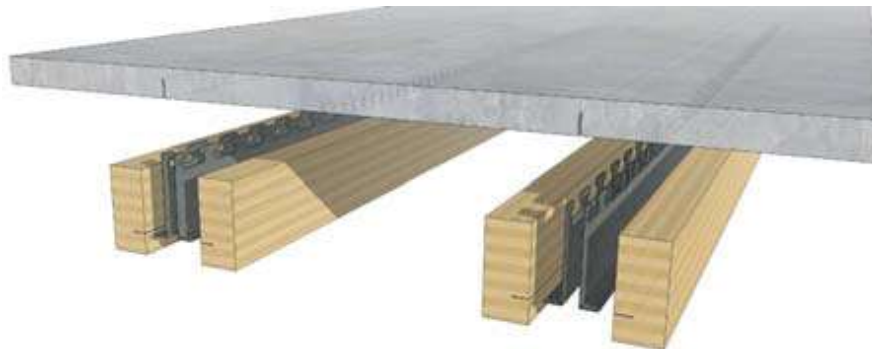


Figure 4-17: 3D scheme of Steel-Timber-Concrete Composite Ribbed Floor [53, p. 2]

After performing the push-out test, the timber-concrete shear connection (notches) failed due to shear failure in the timber along the GL lamellas. In the case of the steel concrete the failing depends on the metal sheet thickness: if it amounts to 3 mm, the sheet fails due to buckling and so to compression. If it amounts to 4 mm, the failure happened because of cracks in the concrete. [53, p. 8] After performing of push-out test, the highest composite stiffness is achieved by the perforated girder shear connection type, while the puzzle strip girder has a higher stiffness compared to the puzzle strip plate. [53, p. 9] The stiffness of the steel-concrete connection is higher than the timber-concrete. The highest ductility is offered by steel plates (3 mm thick) and a puzzle strip plate.

5 Boundary conditions & Requirements for Timber Floors

The present chapter summarizes different requirements that timber floors of mid-rise buildings need to fulfil, aside from the load-carrying capacity (ULS, SLS). Hence, on the one hand, the normative requisites are given by legislators of European countries based on a common norm, while on the other hand, execution and productional requisites drastically influence the design process and execution (i.e., prefabrication possibilities, transport to site, etc.). Another aspect which is getting more and more attention is the ecological aspect of timber floors and, more generally, whole buildings. In his diploma thesis, Marx states: “This [climate change emergency] situation calls for new design proposals and material compositions that improve sustainability, energy efficiency and reduce the [...] global warming potential [GWP] of our built environment [...]”. [54, p. 2]

5.1 Normative Requirements for European Countries: Austria, Germany, Italy, Switzerland

In choosing the different European countries and their related regulations of fire protection, noise insulation, thermal insulation, and protection against humidity, a comparison of similar “building cultures” intends to be achieved. Most of the modern mid- and high-rise timber buildings are located in countries such as Germany, Switzerland, Austria and Italy but also northern Europe, Canada and Australia (see **Figure 3-2**) [1, pp. 12-13]. Switzerland’s building standards is analysed because of their leading role in the development and application of modern materials, elements, and constructions. [5, p. 12] In Austria, Italy, and Germany, the implementation of modern mid-rise buildings is similar and also in the action sphere of the *Rubner* company. In her article, Isopp mentions the following fact: during the year 2018, around 24% of the built area in Austria was used for timber buildings of various dimensions and heights, while in 1999, this percentage was around 14%. This simple data comparison shows that the trend is so going upwards [55, p. 3].

Normative requisites defined by norms intend to warrant the comfort and safety of building users (noise insulation, thermal insulation, vibrational and deflectional behaviour), they ensure buildings are evacuated in certain time spans in case of a fire (fire protection) and ensure its durability over time (timber protection in the case of persistent humidity). All the just mentioned aspects are relevant for timber floors not in contact with the outside; roofs and walls are required to fulfil additional requirements such as protection against atmospheric agents, sealing-off against air movements but also offer volume for air movement above the load-bearing elements in order to ensure air exchange through the wall or floor construction. This allows residual humidity to dry up and thus prevents damages due to prolonged humidity presence. Single or bonded layers composing the whole analysed element package are required to assume the just mentioned functions, be it for walls, roofs, or floors. [5, pp. 203-206]

5.1.1 Fire Protection

From the prehistoric ages until a few decades ago (WW2), humanity has seen plenty of devastating fires in cities and settlements caused by disparate reasons. The buildings of the past, which fell victims to extended fires, were mostly entirely out of wood or had wooden floors. [14, p. 9] As humans, we are still scared of these uncontrolled fire outbreaks and irrationally think that in modern wooden buildings, this still represents a high-danger source. Fires that break out in buildings are dangerous, especially if they are allowed to spread over interconnected interiors. To delimit fires and prevent further spreading, so-called fire compartments are implemented. [3, p. 42] A fire can break out for many reasons [56, p. 2]:

- 1) Natural causes (i.e., lightning),
- 2) Self-ignition caused by big quantities of flammable organic material (coal, flour, etc.) without enough ventilation or other chemical processes,
- 3) Technical causes such as short circuiting, malfunctions, or overloading of devices.
- 4) Human behaviours

For a detailed description of the burning process of wood, see [3, p. 43]. Fires normally develop following the same scheme consisting of two different moments. During the ignition phase, the fire develops in the building itself and depends on the flammable behaviour of coverings, furniture, layers etc. If there is enough burning material to be found and the fire is ventilated after 7-15 min, temperatures rise drastically in a short period of time (*flash over*), and every flammable material is now burning, resulting in a fully developed fire. [14, p. 10] The development of a fire in timber buildings is shown in **Figure 5-1**. In such conditions, fire protection duration and performance of structural elements under fire become relevant. The behaviour under fire of materials, which includes ignition properties, burning properties, smoke development, flame spreading and its velocity, depends on a number of factors. In the case of timber buildings, the coverings of load bearing elements assume a crucial role as they protect structural timber during fires in order to warrant its structural properties. [14, p. 11]

The resistance under fire of composed elements for a certain time (usually 30, 60, 90 min, more rarely 120 or 150 min) is defined by different classes in the R.E.I.-System; the higher the obtained time, the better the fire protection. The most important parameters are **R** (Resistance under reduced loads and fire), **E** (Interior enclosing to avoid fire spreading) and **I** (Insulation avoids that interiors on the other side of the analysed elements start to burn and endanger present users) and **K** (capsulation is the protection of a load-bearing element in the form of a covering). Other performance parameters regard radiation (W), resistance against mechanical impacts (M) and smoke tightness (S). Obviously, building elements have multiple functions at the same time, whereas different layer fulfil different functions but together express, i.e. REI 90 parameter (Resistance, Interior enclosing, and Insulation). [57, pp. 33-34] Also, the behaviours under fire of single materials are classified by European normative: firstly, the contribution of the materials to

fires, where the categories A1, A2 have no effects while the category E, F have considerable to relevant contributions. The categories B, C and D, are located between the extrema and have moderate impacts. Additionally, every material under fire has related smoke development (classes s1, s2 and s3) and drop formation of melted material (d0, d1 and d2). The lower number in the indices denotes lower smoke development and drop formation of melted material, while higher indices numbers denote the opposite. The just explained material or composed elements behaviours under fire are catalogued in EN-13501. [57, pp. 32-33]

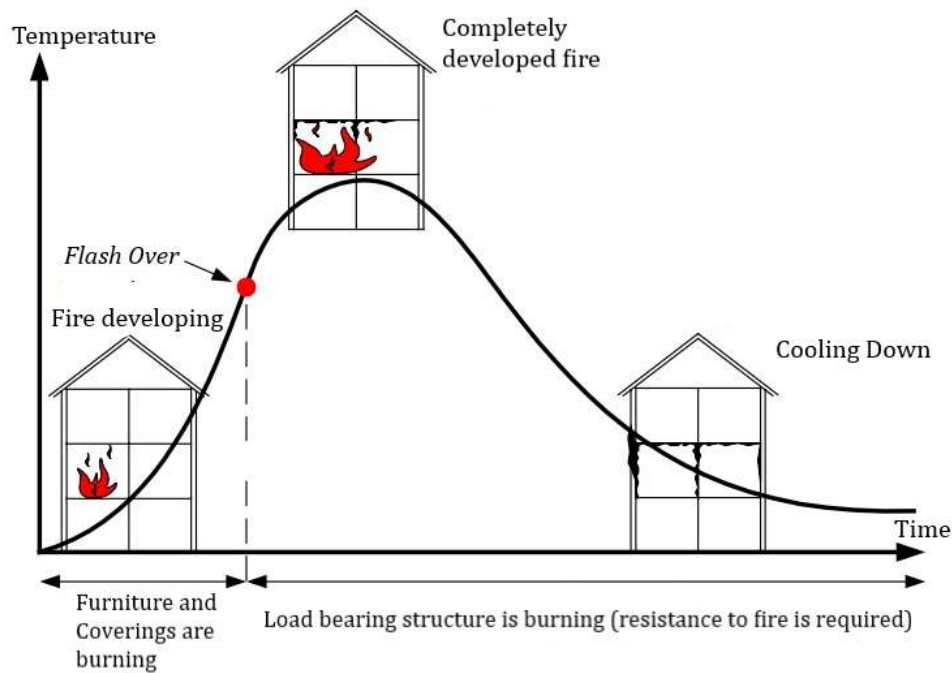


Figure 5-1: Development of fire in a timber building over time [56, p. 3]

In the specific case of mid-rise buildings, the requirements regarding evacuation time and so required resistance time of the load-carrying and the above-explained parameters depend on the height above ground and on the building usage (commercial, residential, or industrial). These parameters are defined in the relative national normative. [14, p. 25] It is needed to distinguish between active and passive fire protection; the active protection includes fire alarm, smoke sensors, sprinklers, etc. while passive protection is defined by physical attributes of a building such as used materials, fuel load, fire compartment dimension, escape routes and exits. These two different methods are complementary to each other, which means that they can be combined together, obviously in accordance with the valid norm. [3, p. 43]

5.1.1.1 Austria

The OIB RL 2 (*Österreichisches Institut für Bautechnik*) is the fire protection normative valid for the whole national territory. Buildings are divided into five classes depending on their evacuation level above ground (highest located floor construction), their number of floors above ground as well as the amount of residential and commercial units per building (see Table 1 in [58]). The

buildings analysed in the present thesis are mid-rise buildings with 5 - 10 storeys; after assuming an approximate depth of 3 m per floor, the height above ground would be between 15 - 30 m. For example, the height of the last floor (30 m) is more than 22 m which is the maximum floor height allowed by OIB RL 2. The 22 m marks can be surpassed when fire protection measures of equivalent or better safety standards as defined in the normative itself are implemented [58, p. 3].

When timber floors are used as the delimitation of fire compartments, they need to satisfy at least REI 90 exigencies. If the building is class 5 and has more than six floors, the covering materials need to have at least A2 fire behaviour (it means little to no effect on total fire loading). Additionally, any opening in such a floor construction needs to exhibit the same fire resistance properties as the slab itself; in this case, it is EI 90 coupled with A2 behaviour of the covering materials. If the building is class 5 with six floors or less, just REI 90 requirements need to be satisfied. [59, p. 22] In the case of commercial usage, fire requirements depend on the area of the fire compartment and on the number of connected floors. In the worst case ($1800 < \text{area} < 3800 \text{ m}^2$), the needs are REI 90 and A2. [59, p. 26] To avoid fire spreading over the façade class 5 buildings with more than six floors (excluded residential ones) at the height of every floor at least 1,20 m high stripes or 0,80 m cantilevering elements along the façade with the following requirements: EI 30 and A2 or EW 30 coupled with A2 burning behaviour. Other fire protection measures can substitute these stripes on the façade if they fulfil the same requirements. [59, p. 4] *OIB Richtlinie 2.3* gives further details when the height of the last floor is higher than 22 m: load-bearing floor constructions need to be at least REI 90 coupled with A2 fire behaviour. The main difference to *OIB RL 2* lies in escape routes, safe staircases, etc., while the previously explained requirements remain the same. [60, p. 3]

5.1.1.2 Italy

According to Wabl, concerning fire protection, there is no specific distinction of materials in load bearings structures of mid-rise buildings. From a normative fire protection perspective, a timber building equals a concrete building, and there are no particular difficulties as there are in Austria or Germany. [56, p. 44] The Italian normative distinguishes between building for residential use and for commercial and productional use. [61, p. 6] In D.M. 30 November 1983 [62], the “anti-fire” height is defined as the height between the lowest ground level where the firefighter truck can stand and the lower part of the highest window of a residential unit in a high building. The presence of another floor on top for solely technical purposes (i.e., heating) doesn’t increase the “anti-fire” height of the building. [62, pp. 3, 12]

In D.M. of February 2006 [61] basing on the number of present people, five different office buildings are defined. This normative describes the building layout of a new and existing office building, its load-bearing and not load-bearing elements and maintenance in regard to fire protection [61, p. 6]. All structural, non-structural elements and openings in walls or slabs that define fire compartments in office buildings need to show diverse properties basing on the building’s height.

In the case of mid-rise buildings, the need to fulfil its REI 60 when the maximum “anti-fire” height is 24 m; these requirements rise to REI 90 when the “anti-fire” is between 25-54 m. [61, p. 8] The dimensions of fire compartments depend on the building height and if the building has lone or multiple-use destinations. [61, p. 9] In addition to the fire resistance of structural (REI) and non-structural elements (EI), D.M. of February 2006 defines behaviour under fire of installed covering materials to avoid flashovers and quick fire-spreading. The following things are valid regarding slabs: floor constructions and walls in corridors, atriums, entrances, etc. can be covered with class 1 materials (moderate burnable) to max. 50% of the total area while the other 50% must be class 0 material (not burnable). The cover layers of walls and floors can be either class 1 or class 2 when automatic fire-extinguish systems are in place in all the other rooms. Burnable layers and isolating materials above structural elements of class 0 need to be glued or mounted very close to avoid empty interiors between single layers. This doesn't apply to suspended ceilings or raised floors if they fulfil class 1 requirements. It is possible to install burnable insulation layers if they are comprehended between elements with fire resistance of at least REI/EI 30. It is allowed to cover structural elements (floors and walls) with treated timber layers that achieve minimum class 1 fire protection. [61, pp. 8-9]

As mentioned in the previous paragraph, the present thesis looks at a building with a maximum height above ground of 35 m. This means that D.M. 16 May 1987 [63] looks at **class A** (“anti-fire” height 12-24 m) and **class B** (“anti-fire” height 24-32 m) buildings. The maximum fire compartment area that may be extended on multiple floors [63, p. 10] for **class A** is 8000 m², while it amounts to 6000 m² for **class B** buildings. Every fire compartment delimiting structural and non-structural element, every staircase wall and stair, every elevator wall and floor needs to fulfil at least REI/EI 60 requirements. The REI requirements increase up to REI/EI 120 as the building “anti-fire” height increases. [63, p. 9] To avoid fire spreading along the façade stripes with fire resistance E 60 above every floor and along transversal walls are placed. In the case of a *curtain wall*, also where the façade is not directly connected to the floor construction, the junction between the wall and the façade needs to fulfil EI 60 requirements. It is also possible to create horizontal panels cantilevering by min. 0,60 m. or to create a vertical parapet above or below the floor to create a vertical distance of 1 m between windows of separate fire compartments. [63, p. 37]

5.1.1.3 Germany

The German normative also works with building classes as the Austrian does (see **chapter 5.1.1.1**). The “Musterbauordnung” (MBO) is a building law valid for the whole country which defines fire protection, noise insulation, technical equipment of the building, barrier-free construction etc. The given standards are to be fulfilled no matter which constructing material or combination is used for structural elements. [64, pp. 1-4] This norm, which has similar targets as the Austrian OIB norms, is the starting point of the building laws of the single federal states. The fixed standards are mandatory and taken over in federal laws [65, p. 5]. The building classes are defined in the MBO

depending on the number of residential and commercial units, the evacuation level as well as the maximum storey area (for more details, see [64, pp. 5-6]).

The relevant classes for this thesis are class 4 and class 5. In class 4, all fire compartment delimiting structural and non-structural elements, floor constructions, staircase walls and firewalls need to fulfil REI/EI 60 needs. The fire compartment delimiting elements in the basement are required to fulfil REI 90. [65, p. 12] In regard to fire protection of highly fire-hindering elements are defined in normative “M-HFHolzR” [66]. This norm exclusively is valid for class 4 buildings structural and non-structural elements with the following characteristics:

- 1) Every side shall be covered with non-burnable materials (capsulation).
- 2) Timber parts of the section shall be highly fire-hindering.
- 3) Thermal insulation of the element shall not burn under fire.

This normative can be applied to prefabricated timber floor constructions, such as hollow boxed floors (see **chapter 4.1.1.2**) and KVH boxed elements (see **chapter 4.1.1.3**). This norm doesn't extend to mass timber floors because at the time of writing of “M-HFHolzR” these products did not exist except to DLT and NLT ceiling. [66, p. 2] The protective covering on every exposed side (capsulation) needs to withstand fire and prevent the ignition of the covered timber structural elements for at least 60 min. If diverse protecting layers are applied, the joints should not overlap to avoid fire transmission through these continuous joints. [66, p. 5]

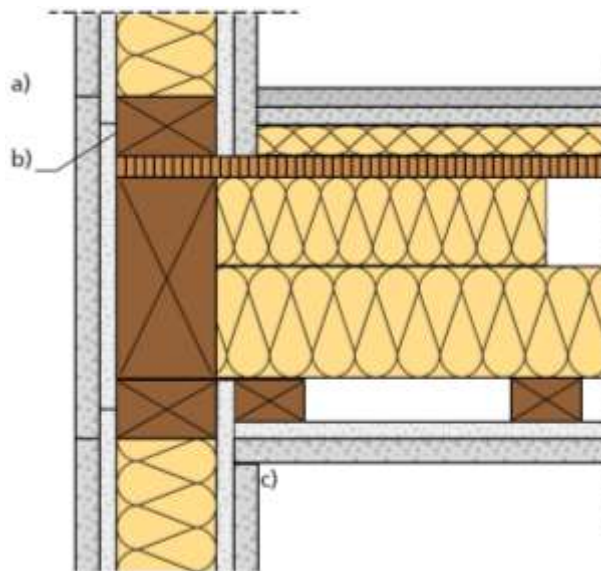


Figure 5-2: Capsulated wall-floor node according to “M-HFHolzR” [65, p. 30]

Offset joints (a), fixed plasterboard panels (b), closed joints with non-flammable materials (c)

For class 4 buildings, the required capsulation class is K₂60 (defined in DIN EN 13501-2). [66, p. 3] The capsulation criterium was introduced to give firefighters enough time to locate and extinguish the fire completely, especially if it may be hidden in rear ventilation layers. Because of economic reasons, the capsulation of all structural elements could be reduced to K₂30 or K₂45 if a rapid fire-

locating and report system is installed. In some cases, this might be more cost-effective than a capsulation, which theoretically reaches REI 120 protection levels. [65, pp. 23-24] The guideline defines the following for floor constructions [66, pp. 4-5]:

- 1) The bottom of highly fire-hindering floors is to be plastered with fire-resisting layers (capsulation)
- 2) In the case of KVH boxed floors and beamed ceilings, no burnable and melting point above 1000°C thermal insulation is to be placed between the single-beam elements.
- 3) The screed (placed in dry or wet conditions), including the joints on top, must fulfil the capsulation requirements. The screed must be placed on at least 20 mm, not ignitable insulation material and have a minimum depth of 30 mm.

The newest relevant guideline for fire protection in mid-rise buildings (class 4 and class 5) is the “M-HolzBauRL” [67, p. 1] which is currently under discussion; the last version dates back to May 2019. Similar to “M-HFH HolzR”, it discusses structural, bracing, and interior delimiting elements with highly fire-hindering or fire-resisting properties. The main difference is that this norm tractates skeleton structures, framed structures and is extended to massive timber constructions (TCC floors are here comprehended). [67, p. 3] The fire protection standards for class 4 skeleton and framed structures are identic to what defined in “M-HFH HolzR”. This guideline draft sets that the covering of structural and interior delimiting elements must be at least 18 mm plasterboard layers. In alternative, max 25% of the walls (not along escape routes and fire compartment delimiting walls) or the bottom floor construction side may be covered with burnable material. [67, p. 11] In the case of adjacent floor elements sufficient protection against smoke penetration is warranted when multiple layers below the structural elements are present. In this case, the floor package as a whole is supposed to comprehend mineral filling, a normally ignitable footfall sound insulation, a non-flammable concrete screed with related non-flammable perimeter strips and division foil between the single present layers. If the element joint runs along the fire compartment dividing walls, a 20 mm stripe of non-igniting material needs to be placed between the two massive timber elements before placing the diagonal mechanical connection. [67, p. 13] It is allowed to have wooden claddings on façades even with rear ventilation on class 4 and class 5 mid-rise buildings. To avoid vertical fire spreading along the façade in the case of rear ventilated cladding, the presence of horizontally cantilevering fire breaking elements (steel elements, minerally bounded plates and timber sections) at the height of every floor placed between the outer wall and the cladding is required. Fire breaking elements may also be placed vertically instead of horizontally. [67, pp. 14-16, 19]

As previously mentioned, the “M-HolzBauRL” guideline is the newest in the field of timber and fire protection. Because it is not fully promulgated, plenty of discussions are going on that matter. The association of project engineers in fire protection discussed the guideline’s draft and countered it in [68, p. 2] with the now following principal arguments:

- 1) The guideline loses sight of its political and social aims, i.e., the increased implementation of wood in construction for ecological reasons. The limitation of visible wood in interiors and the required constructive standards are uneconomically, thus discouraging projects of timber mid-rise buildings.
- 2) Timber is still seen as a more dangerous material in regard to fire when compared to concrete or steel. The by the legislator wanted requirements (smoke tightness, stability, strength, etc.) are higher than what defined for other materials.
- 3) The “M-HFH HolzR” of 2004 should have implemented class 4 safe multi-storey buildings, but the capsulation criterium and the usage of not flammable insulations proved to be not cost-effective.

5.1.1.4 Switzerland

In Switzerland, the normative and subordinated guidelines (latest edition in 2015) against fire are defined by the establishment of cantonal fire protection insurances, the so-called VKF (“*Verbund kantonaler Feuerversicherungen*”) [69, p. 8]. Differently to other European states, the VKF norm does not contain proper building classes in regard to the building’s geometry: edifices of smaller dimensions (max 11 m above ground), medium dimensions (max 30 m above ground) and bigger dimensions (30 m -100 m above ground). The fire protection normative, to which guidelines are subordinated, states that requirements depending on the building’s geometrical dimension, floor number and use destination (shopping, hoteling & hosting, interiors with high human presence, car parking, interiors with shelf for industrial purposes, etc.) are defined in fire-protection guidelines. [70, p. 8] In the VKF fire protection normative [70] the building height and number of present floors influence plenty of factors, such as:

- 1) Use of materials with certain flammable properties (§ 25 VKF norm),
- 2) Resistance to fire of structural elements and fire compartment delimiting elements (§ 32),
- 3) Fire compartment dimensions (§ 34 VKF norm),
- 4) Escape route length (§ 36 VKF norm),
- 5) Usage of technical devices for fire protection (§ 9 VKF norm)

Concerning the application of materials and relative behaviour under fire, swiss guideline 13.15 [71, p. 5] defines four different RF categories (from French: “*reaction au feu*”). The guideline distinguishes between RF1 (no contribution to fire), RF2 (small contribution to fire), RF3 (acceptable contribution to fire) and RF4 (non-acceptable contribution to fire). These categories take account of smoke development under fire, of eventual melting and forming of burning material drops and the related corrosivity. In some cases, materials are classified according to the European (see **chapter 5.1.1**) and Swiss guidelines, thus being part of different classes; the use of such materials is allowed with no distinction. The association tables between European and Swiss norm are to be found in [71, pp. 8-12].

Guideline 15.15 about fire protection of structural and non-structural elements [72] defines fire protection requirements for low-, mid-and high-rise buildings separately. These mandatory

requirements depend on the building's destination: an industrial building where production does take place has higher demands on fire protection than residential buildings. Depending on the building's destination and fire protection type (constructive or fire extinguishing system), these specifications do change: Residential buildings, schools, offices and sale stores need to fulfil REI 60 with constructive fire protection while the requirement is lowered to REI 30 when fire extinguishing systems are present. In commercial buildings, the requirements are lowered from REI 90 to REI 60, depending on the fire protection concept. In addition to fire compartment delimiting floors, Table 2 of [72, p. 12] defines static resistance (R) under fire of structural elements (walls), horizontally and vertically delimiting escape routes from the building. Complementary to the table above, fire protection guideline 15.15 defines that floors in the last storey of low and mid-rise buildings are not supposed to fulfil any fire protection. [72, p. 8] In such cases, RF3 materials are sufficient. [73, p. 12]

The focus of the present thesis is on floor constructions in mid-rise buildings. Thus the fire behaviour of structural elements along escape routes and interiors is of interest. [73, p. 3] Again, we have to distinguish if a fire extinguishing system is present (which reduces the necessary RF class) or not (fire protection at building level) and the destination of the interior itself (high number of presences, hosting and other uses). If the interior has other destinations than the escape route, RF3 requirement is enough in most cases. This doesn't apply in hosting interiors for structural and non-structural elements, thermal insulation and dividing layers and textile coverings of floors where the RF1 requisite are mandatory. RF2/RF3 demands are to be applied when textile coverings (in hotels and interiors with a high number of presences) on the bottom side of floor construction depend on if a fire extinguishing system is implemented or not (RF2/RF3, respectively). In the case of locations along escape routes (vertical and horizontal), the needs rise, therefore mostly using RF1 materials in vertical escape routes, when fire protection happens at the building level. RF3 materials are used for fire compartment delimiting elements and thermal insulation layers for horizontal escape routes and vertical ones when fire extinguishing systems are present. Here RF1 coverings resisting for at least 30 min are necessary to protect these elements. In the case of suspended ceilings, double floors, textile coverings are required to fulfil RF1 needs; RF2 materials may be used when fire extinguishing systems are present. [73, p. 11] For more details see guideline 14-15 [73, pp. 10-12]. Guideline 15.15 defines that openings in floor constructions for installation pipes need to be sealed with RF1 to avoid fire spreading between different storeys. [72, p. 10]

5.1.1.5 Concluding considerations about fire protection of mid-rise buildings

As illustrated in the previous chapters, the fire protection normative across European countries such as Austria, Germany, Italy, and Switzerland differ from state to state and, in some cases, from federal state to federal state (Germany - **chapter 5.1.1.3**). The first thing that the author noted after reading the normative is that every country links the building height to the required fire resistance. Hence Austria and Germany define building classes by height, number of floors and unit dimension,

while the Italian normative defines building elevation with the height of the last floor. Switzerland simply distinguishes between buildings below 11 m and below 30 m, thus defining three different classes (see **chapter 5.1.1.4**). Italy does not limit the height of any tall building, be it concrete timber or steel. Switzerland follows this trend, as the maximum allowed height is 100 m. Germany and Austria actually limit heights to 22 m (actually the height of the last floor), but higher buildings are allowed if additional fire protection measures warrant similar protection levels to smaller buildings.

The second notable thing is the influence of the building's utilization on fire protection requirements. The German MBO doesn't specifically deal with the utilization and its consequences, while the normative of the other countries do. Austria distinguishes between residential and industrial buildings, garages & parking, and buildings with last floor heights of more than 22 m. Italy just distinguishes between industrial or residential use; Switzerland is more precise in the distinctions as the following utilization types are defined: shopping, hoteling & hosting, interiors with high human presence, car parking, interiors with shelf for industrial purposes. Germany is the only country with a specific normative on timber elements under fire, while the other countries define requirements regardless of the utilized material. Still, Austria and Switzerland do not allow any kind of burnable materials along escape routes, thus prohibiting the usage of timber there. The REI 60 requirement for fire compartment delimiting floor constructions in mid-rise buildings is valid across every country's norm. Should the height increase, so do the fire protection requirements regarding resistance to fire of elements and behaviour under fire of covering layers of these elements. This last aspect is handled differently by these norms, as they all base on the European Norm. Every country has strict demands of materials along escape routes, while this is not valid for the other interior rooms.

Thirdly and lastly, the better conditions in regard to mid-rise timber buildings and timber floors are offered by the Swiss and Italian norms, respectively, because the restrictions regarding heights or wooden coverings or timber elements without covering (no capsulation) in regard to fire protection are not as present when compared to the Austrian and German norms. This is one of many reasons why Switzerland is a pioneer nation in the timber multi-storey building sector.

5.1.2 Acoustic Performance

Sound consists of waves that propagate in air, liquids, or elastic mediums under mechanical oscillation. In such mediums, these waves may be of the transversal type, Rayleigh type and most importantly (from an acoustic perspective in buildings) bending waves with related compression and tension along the wave direction. The range the human ear covers a range of 20-20000 Hz. Excessive sound is defined as noise and sometimes might negatively influence human wellbeing and health. [11, p. 84]. The minimal sound pressure level is 25 dB, which corresponds to a situation where normal talks happen. Noise is subdivided into airborne sound, which is transmitted through

air (i.e., music, speech, general noise from outside, etc.) and structure-borne sound, (footsteps, dropping objects, vibrations caused by mechanical equipping etc.). Structure-borne sound is quite audible because vibrating surfaces irradiate it, principally directly through floor constructions and ceilings and afterwards transmitted as airborne sound in the receiving room. [3, p. 47] Contrary to airborne sound insulation, where higher values mean better insulation properties, structure borne sound has lower values the better the insulation properties. [5, p. 269] Additionally, sound propagates through indirect secondary ways. In the case of a floor, it would be mainly through the slab itself and secondarily through the nearby wall-wall, walls-slab, slab-walls, [1, p. 82]

The impact of airborne sound on elements depends on if the element is multi-layered or monolithic and their relative density. The following is evinced from [14, pp. 33-36]: In the case of monolithic heavy components, sounds transmission takes place when sound wavelength and frequency coincide with the resonance frequency of the elements itself (depending on its mass relative to the elements' area, bending stiffness and panel dimensions). Airborne sound of multi-layered lightweight building elements can be reduced to a system of two or more different masses connected by springs with relative stiffness. These springs are cavities and elastic connections; the weaker the connection, the less energy is transmitted between layer and thus, the more insulation properties improve. If acting sound shares similar frequency and wavelength resonance takes place, thus sensibly reducing insulation properties. It is possible to improve airborne sound insulation by using soft, non-stiff panels fixed on the elements face. [11, p. 92] The case of massive but lightweight elements (i.e., CLT) is special because the resonance frequency is encountered exactly in the most relevant range for constructions (250-500 Hz), while in the aforementioned cases, the resonance frequency resides outside of the relevant range for construction. This important aspect needs to be considered during the element's projection. [14, pp. 33-36]

Structure borne sound or, in the specific case of floor constructions, "footfall sound" is normally handled as follows: it is reduced by implementation of concrete screed on elastic bedding (i.e., rock wool layer), thus creating a so-called "mass-spring-mass" system (see **Figure 5-3**). Beneath that and above the floor itself, fill is placed to damp structure-borne sound. In timber floor constructions, fillings above the timber elements themselves are needed to increase the floor's self-weight and improve structure-borne sound insulation performance. Footfall sound energy is transformed into warmth after deflecting from the screed itself, hence making the use of an unbounded fill preferably (because of their better damping properties). The type of screed has an influence on the overall insulation quality: mastic asphalt and dry screed are better than cement ones. If these different screeds share the same mass and elastic bedding, the footfall sound insulation of the cement screed is the best. [14, pp. 37-39] In the case of timber beamed ceilings, soft insulation is placed between beams coupled with a suspended ceiling just below. If mass timber floors are executed, plasterboard ceilings are implemented. The connection between them is crucial for sound insulation: we distinguish between direct montage, rigid connection, and elastic

suspended connections. The direct montage is used when fire protection is required, while when the ceiling is fixed perpendicular to the beams, we are talking about rigid connections (improvement of 15 dB). If the connection is elastic and suspended, thus decoupled from the structural elements, structure-borne sound insulation improves of 25 dB. [74, p. 40]

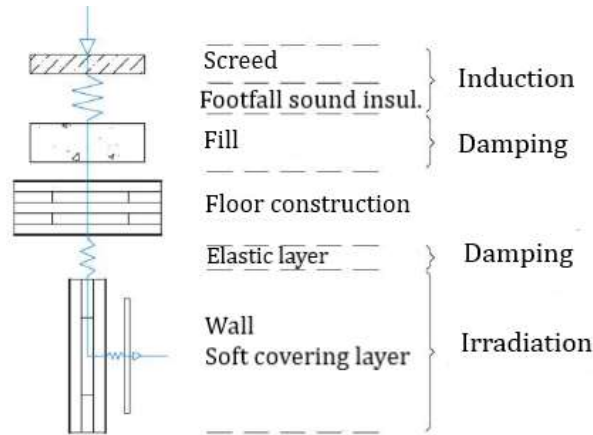


Figure 5-3: Spring-Mass-Spring system for structure-borne sound insulation [14, p. 38]

If a suspended ceiling is present below a beamed ceiling, sound insulation properties (airborne and structure-borne) improve. This improvement increases airborne sound insulation by 15 dB and structure-borne sound insulation by 18 dB, thus underlining the importance of multi-layered sections. This acoustic ceiling shall have many layers, high mass per square meter and low bending stiffness to achieve good acoustic insulation performances. [5, pp. 270-271]

5.1.2.1 Austria

In Austria, sound insulation requirements, distinguished in airborne and structure-borne (footfall) sound, are defined by OIB RL 5 [75]. The minimum needs are referenced to normal parameters. Additional measures depend on the building's location in regard to airports, railways, busy roads, etc. In the case of airborne sound insulation between elements in contact with the outside (like walls), the minimum requirements depend on the outside noise level (day and night). Here, the relevant requirements for floor constructions in residential buildings, schools, hospitals, etc., are the following: 60 dB for floors limiting garages or passages and 47 dB for floors below non-extended attics. In commercial buildings, it is 42 dB for floors below non-extended attics and 60 dB for floors limiting garages or passages. [75, pp. 2-3] Also, requirements are defined for air-borne sound for elements in buildings, thus distinguishing between main interiors, secondary rooms and hotel rooms, classes, hospital rooms etc. The needs vary between 50-55 dB if there are no openings in the wall, otherwise 35-50 dB (for more details, see [75, p. 4]). Footfall sound insulation is also defined dependently to main and secondary rooms: 48-55 dB for main rooms, 53-60 dB for secondary rooms (for more details, see [75, p. 5]). In this case, there isn't any distinction if the usage of the building is residential or commercial.

5.1.2.2 Italy

In Italy, the sound protection parameters are defined in “D. P. C. M. 5 dicembre 1997” [76]. This normative defines different usages: residential (A), offices (B), hotels (C), hospitals and related structures (D), schools (E), recreational or religious activities (F) or commercial activities (G). For floor constructions, no matter which material is used, the now following parameters are important [76, p. 3] and **Table 6**:

- a) R'_w : Airborne sound insulation between different properties or units.
- b) $L'_{n,W}$: Footfall sound (structure-borne) insulation between different properties or units.
- c) $L_{AS,max}$: Airborne or structure borne sound emitted by machines that work continuously.
- d) L_{Aeq} : Airborne or structure borne sound emitted by machines that work non continuously.

Class	R'_w	$L'_{n,W}$	$L_{AS,max}$	L_{Aeq}
	[dB]	[dB]	[dB]	[dB]
1: D	55	58	35	25
2: A, C	50	63	35	35
3: E	50	58	35	25
4: B, F, G	50	55	35	35

Table 6: Sound Insulation Requirements according to [76, p. 3]

5.1.2.3 Germany

In Germany, sound requirements regarding airborne sound and structure-borne sound insulation, at least the minimum exigencies, are defined by DIN 4019-1:2018-01 [77]. The distinction is on one hand residential, office buildings and on the other non-residential buildings (hotels, hospitals, schools). The now following **Table 7** summarizes noise protection exigencies in the offices, multi-party buildings and mixed buildings. Both the airborne sound (R'_w) and structure-borne sound ($L'_{n,W}$) are to be found. Also, requirements for single party buildings are defined in DIN 4019:2018-01. [77, pp. 12-14] Increased needs compared to DIN 4019-1:2018-01 are defined in DIN 4019-5:2020-08 [78]; an increased performance is registered when airborne sound insulation increases by min. 3 dB, while structure-borne sound, especially footfall sound insulation decreases by minimum 5 dB and noises from building specific technical devices are reduced by min. 3 dB. After the application of this more restrictive norm, sound insulation is significantly improved. [78, p. 5]

Floor type	R'_w	$L'_{n,w}$
[-]	[dB]	[dB]
Floors below used attics (storeroom and relative entrances, etc.)	≥ 53	≤ 52
Delimiting floors between flats (also stairs)	≥ 54	$\leq 50^3$
Delimiting floors between offices (also stairs)	≥ 54	≤ 53
Floors above basements, cellars, corridors	≥ 52	≤ 50
Floors above passages, garage ramps	≥ 55	≤ 50
Floors above/below community rooms	≥ 55	≤ 46
Floors below terraces, loggias above common rooms	/	≤ 50
Floors below arcades, pergolas	/	≤ 53
Balconies	/	≤ 58
Floors and stairs in one flat extended over two floors	/	≤ 50
Floors below bathrooms and WC's	≥ 54	≤ 53
Floor below corridors	/	≤ 50

Table 7: Minimum requirements for sound insulation of floor constructions [77, pp. 12-13]

Floor type	R'_w	$L'_{n,w}$
[-]	[dB]	[dB]
Floors below used attics (storeroom and relative entrances, etc.)	≥ 56	≤ 47
Delimiting floors between flats (also stairs)	≥ 57	≤ 45
Delimiting floors between offices (also stairs)	/	/
Floors above basements, cellars, corridors	≥ 55	≤ 45
Floors above passages, garage ramps	≥ 58	≤ 45
Floors above/below community rooms	≥ 58	≤ 41
Floors below terraces, loggias above common rooms	/	≤ 45
Floors below arcades, pergolas	/	≤ 48
Balconies	/	≤ 58
Floors and stairs in one flat extended over two floors	/	≤ 45
Floors below bathrooms and WC's	≥ 57	≤ 47
Floor below corridors	/	≤ 45

Table 8: Increased requirements for sound insulation of floor constructions [78, pp. 12-13]

In DIN 4109-33 [79, pp. 39-52] a construction catalogue is integrated by given different layer successions and depths, in order to achieve certain sound insulation (airborne and structure-

³ In the case of lightweight structures and so timber this requirement rises to $L'_{n,w} \leq 53$ dB

borne) properties. The variable is the floor construction type itself: timber beamed ceilings with or without suspended ceilings and board stack floors are defined. **Table 8** illustrates increased exigencies for multi-party buildings, offices, and buildings with mixed destinations.

5.1.2.4 Switzerland

In Switzerland, the SIA 181 «Schallschutz im Hochbau» (2006) defines noise insulation exigencies. Noise sources are subdivided into internal (including noise from specific technical devices) and external sources. Another defined thing is the sensitivity to noise, i.e., a workshop, canteen, or a restaurants kitchen have way lower susceptibility to sound than study facilities in libraries or specific rooms in hospitals (high). Middle sensitivity to noise is wanted in bedrooms, living rooms, classrooms, normal hospital rooms. [5, p. 217] The L_r factor to be found in **Table 9** expresses the exterior sound levels at day- or night-time according to swiss noise protection guidelines (LSV).

	Degree of disturbance caused by exterior airborne noise			
Noise Amount	Small to considerable		Medium to very strong	
Receiving room location	Far from noise or traffic		Close to noise or traffic	
	Day	Night	Day	Night
Limit values	$L_r \leq 60$ dB	$L_r \leq 52$ dB	$L_r \geq 60$ dB	$L_r \geq 52$ dB
Noise susceptibility	Required sound insulation values D_i			
Low	22 dB	22 dB	$L_r - 38$ dB	$L_r - 30$ dB
Medium	27 dB	27 dB	$L_r - 33$ dB	$L_r - 25$ dB
High	32 dB	32 dB	$L_r - 28$ dB	$L_r - 20$ dB

Table 9: Requirements for exterior airborne sound insulation building elements [5, p. 218]

	Degree of disturbance caused by interior airborne noise			
Noise Amount	Small	Considerable	Strong	Very Strong
Examples	Archive, sanitary room, ...	Living room, kitchen, bedroom, WC, office, conference room, ...	Classroom, restaurant, garage, commercial area, common room, ...	Workshop rooms, restaurant, bars, productional areas, gyms, ...
Susceptibility	Required sound insulation values D_i			
Low	42 dB	47 dB	52 dB	57 dB
Medium	47 dB	52 dB	57 dB	62 dB
High	52 dB	57 dB	62 dB	67 dB

Table 10: Requirements for interior airborne sound insulation building elements [5, p. 219]

	Degree of disturbance caused by footfall sound			
Noise Amount	Small	Considerable	Strong	Very Strong
Examples	Study room, Archive, sanitary room, ...	Living room, kitchen, bedroom, WC, office, conference room, ...	Classroom, restaurant, garage, commercial area, common room, ...	Workshop rooms, restaurant, bars, productional areas, gyms, ...
Susceptibility	Required sound insulation values L'			
Low	63 dB	58 dB	53 dB	48 dB
Medium	58 dB	53 dB	48 dB	43 dB
High	53 dB	48 dB	43 dB	38 dB

Table 11: Requirements for footfall sound insulation building elements [5, p. 219]

5.1.2.5 Concluding considerations

As underlined in the previous chapters related to single countries, sound insulation requirements are similar everywhere. Every country’s normative distinguishes between airborne and structure-borne sound. Let us take the example of the sound insulation requirements for a living room floor delimited by other units in different EU countries.

- 1) Austria: 55 dB airborne sound insulation and 48 dB footfall sound insulation.
- 2) Italy: 50 dB airborne sound insulation and 63 dB footfall sound insulation.
- 3) Germany: 56 dB airborne sound insulation and 46 dB footfall sound insulation.
- 4) Switzerland: 52 dB airborne sound insulation and 53 dB footfall sound insulation.

5.1.3 Protection against humidity

As described in **chapter 2.1**, wood has hygroscopic properties, which means it assumes or releases humidity to be in balance with the room’s humidity. This property is advantageous for an equilibrated interior climate while simultaneously it is disadvantageous for timber’s dimensional stability and drying process. Thanks to constructional precautions such as the following, these disadvantages may be eliminated to increase wooden structures durability:

- 1) Choice of wood sort
- 2) Ensure that meteoric water flows away from the façade
- 3) Avoid water penetration in joints and end-wood and water-storing angles and joints
- 4) Humidity exposed elements are to be rear ventilated
- 5) Avoid timber elements in constant contact with humidity
- 6) Avoid melting water congestions on roofs

A fast-changing exposure to humidity provokes cracks in timber elements, and so more exposure to humidity and attractive habitat for insects while prolonged, stagnating condensation water or earth humidity incentivises mushrooms growth. Considerable negative effects on façades are registered when direct exposure to rain and sun (UV rays) happens. [5, pp. 285-289] Short-term

higher humidity concentrations aren't problematic when timber can dry up afterwards. [1, p. 79] The chemical protection of timber, which is a debatable topic on its own, sometimes is the only possibility when high humidity concentrations are present. Anyways, such chemical protections increase timber's durability and so the cost-effectiveness of local wood sorts in regard to other less ecological building materials, even though these chemicals aren't properly eco-friendly on their own. Additionally, the reusability and recyclability possibilities are lessened. In past years, some non-toxic methods for timber protection have been developed: acetylation and furfurylation. The first procedure creates form-stable, insect-resistant, and strong wood suitable for load-bearing structural elements. The second procedure works with furfuryl alcohol (obtained from biomass) and improves resistance against insects or microbes and form-stability of wood. [2, pp. 138-139]

Another example is the utilization of wet screed placed on timber without any intermediate layers, as would be the case in TCC floors. In this case, with the hardening and thus strengthening process happening in the concrete part, the present humidity reduces over time. If a timber floor construction is used as delimitation against a non-heated area or the outside, the thermal performance and humidity convection or diffusion need to be considered. [14, p. 49] Diffusion, as less important process, takes place when different partial water-vapour quantities (depending on the outer and inner temperatures) are present. In timber constructions, the inner layers are more resistant to diffusion, while the outer layers have less resistance to diffusion. Hence, water amounts because of diffusion are unproblematic. When the delta between inner and outer temperature is high, a warm convection airflow goes through the delimiting element itself to balance the colder temperature. During this process of air cooling, water condensates because of convection (sometimes 100 times higher than the water amount due to diffusion). This phenomenon is prevented by airtight constructions, which also have the advantage of limiting thermal and humidity leaks. A thermal leak is found when, i.e. the connection between window and wall is not tight: the air rapidly flows in on short distances, cools down to condensation level outside of the element, thus without provoking condense water. Humidity leaks happen on longer distances, where the air cools down to condensation level in the construction; thus, considerable water amounts occur. Humidity leaks happen when water bringing pipes have leaks or in bathrooms. These constructions shall offer two distinct tight layers, one airtight on the inside and the other wind-tight on the outside. [1, pp. 79-81]

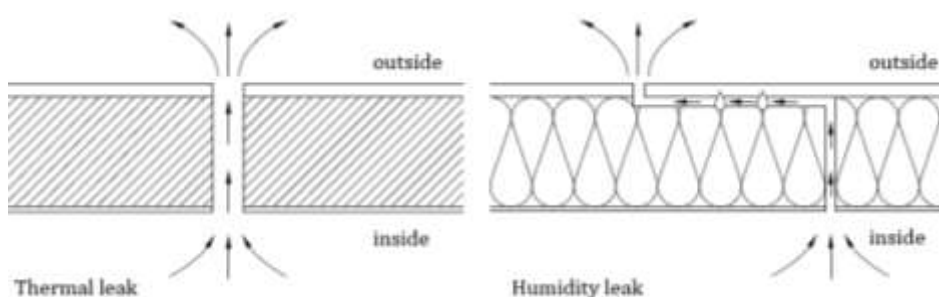


Figure 5-4: Leak types where water condensation takes place [1, p. 80]

6 Internal force determination considering shear connector deformability

This brief chapter shall introduce readers to the behaviour of composite constructions and how this special behaviour is taken into account during the design process. Such notions about deformability of the joint are then applied in the design of a CLT panel floor as well as two types of TCC floor constructions executed in **chapter 7**. On a theoretical level, the composite behaviour has two opposite extreme cases: an infinitely stiff connection ($\gamma = 1$) and no connection at all ($\gamma = 0$) (see **Figure 6-1**). The more rigid the shear connector is ($0 < \gamma < 1$), the less slip (δ) will it allow and the more the load resistance improves towards a section with infinite stiffness. [25, p. 444] As visible in **Figure 6-1** if $\gamma = 0$, the loads are carried by two separate beams, one above the other, but there is no interaction between the two of them. If the friction (and so thus the factor γ) increases, the two beams cooperate in the load carrying. Should the friction increase to the level where it equales the inner shear-force of the material itself, the two beams act as one, with all the deriving geometrical benefits.

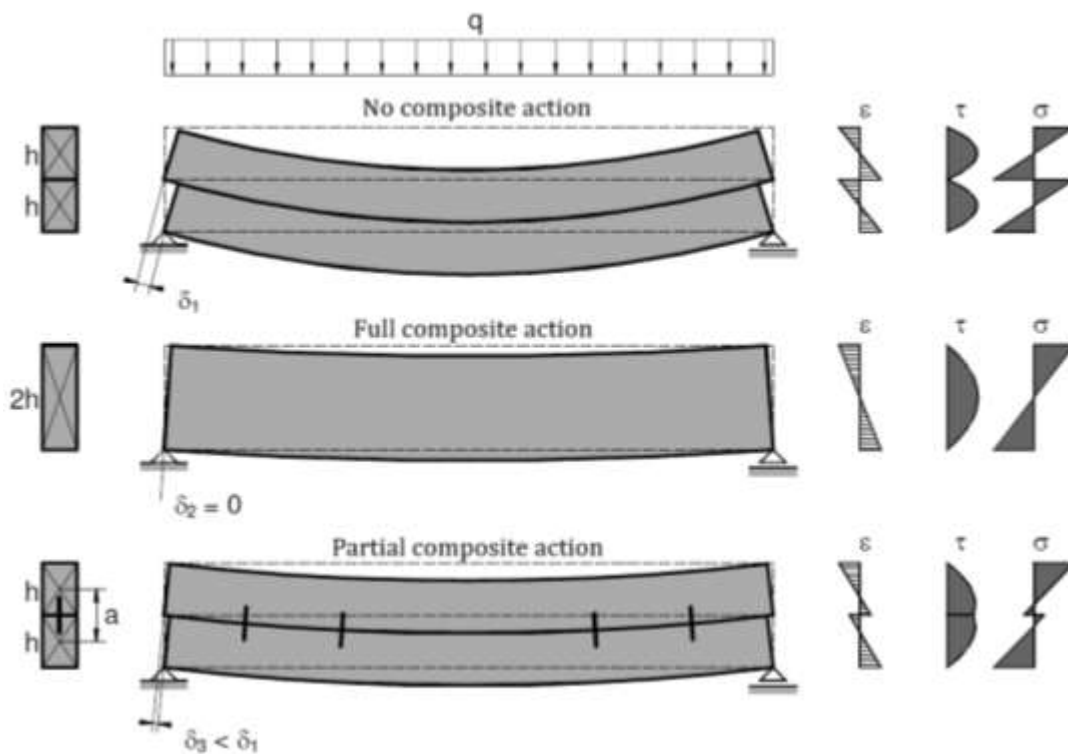


Figure 6-1: Composite behaviours depending on shear connection stiffness [80, p. 41]

6.1 Methods for determination of internal forces

There are various methods used to determine the internal bending stiffness of composite sections and its repercussions on the internal loads. All these methods have their range of application, their advantages but also their disadvantages. The following pages intend to give an overview of these methods concluding on why a certain method has been used for the design process in **chapter 7**.

6.1.1 “ γ -method”

This rather simple method is provided in Annex B of EN 1995-1-1 under the following basic assumptions listed by [81, p. 41] and [9, p. 13]:

- 1) The analysed beam or floor construction is a one-way, statically determined one. If the system consists of numerous spans, the relevant span shall multiply by the factor 0,8 or by the factor 2,0 if the gamma-factor of a cantilevering part is determined.
- 2) The Bernoulli hypothesis is valid for the partial sections.
- 3) The elements composing the composite beam or floor are connected by shear fasteners with a related slip modulus δ ensuring a continuous connection along the span.
- 4) The spacing between shear connectors is constant or smeared along the length (see **Equation (7-44)** and **Equation (7-75)**).
- 5) External loads act in the vertical z-direction, causing moments M and shear forces V around the horizontal x-axis.
- 6) The simplified γ -method is valid for calculating the γ -factor a maximum of three separated sections. If this is not the case, the expanded γ -method needs to be applied (see **chapter 7.1.4**).
- 7) The shear deformation in the partial sections is neglected.

As visible in **Equation (6-1)** the gamma factor (calculated in **Equation (6-2)**) influences the Moment of Inertia (parallel and cross to span) and thus on the bending stiffness of the panel.

$$EI_{eff.CLT} = \sum_{i=1}^n E_i \cdot I_i + \sum_{i=1}^n \gamma_i \cdot E_i \cdot A_i \cdot a_i^2 \tag{6-1}$$

$$\gamma_i = \frac{1}{1 + \frac{\pi^2 \cdot E_i \cdot A_i \cdot s_{i,eff}}{K_i \cdot l^2}} \tag{6-2}$$

$$a_2 = \frac{\gamma_1 \cdot E_1 \cdot A_1 (h_1 + h_2) - \gamma_3 \cdot E_3 \cdot A_3 (h_2 + h_3)}{2 \cdot \sum_{i=1}^3 \gamma_i \cdot E_i \cdot A_i} \tag{6-3}$$

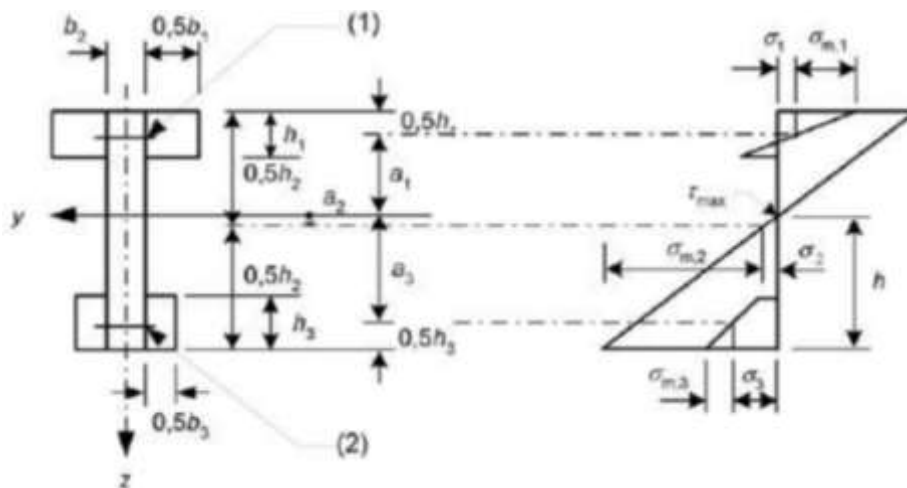


Figure 6-2: Composite section and related stress distribution in a tri-area section [82, p. 163]

The distance a_2 calculated in **Equation (6-3)** is the distance between the centre of the whole composed section and the centre of gravity of the central partial sections, whereas the distances a_1 and a_3 are the distances from partial sections 1 and 3 to the main centre of gravity. If the composite section has just two partial sections, the distance a_3 and the depth h_3 automatically become zero. [82, p. 163] As we can notice from **Equation (6-1)**, the gamma factors just reduce the parallel axis moments.

6.1.2 Shear Analogy method

This method, which can be found in the national annexe of DIN EN 1995-1-1, subdivides symmetric sections into two partial sections. It can be used for any type of composite section and any number of layers contributing to the composite action. The partial section or plane A contains the own sections moment of inertia, and its shear stiffness is seen as infinite, while section or plane B contains the moments determined according to the parallel axe's theorem (also known as "Steiner's Theorem"). Plane B also contains all the section shear stiffness. Both planes are ideally connected by stiff elements so that they both have the same deflectional behaviour.

The layered sections (see **Figure 6-3.a**) is transformed into an idealized system of two beams (planes A and B), whereas plane A has infinite shear rigidity and exclusively contains the own sections moments of inertia while plane B represents the composite action. Therefore, the moments of inertia determined with the parallel axe's theorem as well as the total section's compliance are attributed to plane B. Both planes are connected via rigid elements so that their deflections are analogue.

$$EI_{Ax} = B_{Ax} = \sum_{i=1}^n E_i \cdot I_i \quad (6-4)$$

$$GA_{Axz} = S_{Axz} = \infty \quad (6-5)$$

$$EI_{Bx} = B_{Bx} = \sum_{i=1}^n E_i \cdot A_i \cdot a_i^2 \quad (6-6)$$

$$GA_{Bxz} = S_{Bxz} = \left[\frac{1}{a_x^2} \cdot \left(\sum_{i=1}^{n-1} \frac{1}{k_{x,i}} + \frac{h_1}{2 \cdot b_i \cdot G_{xz,1}} + \sum_{i=2}^{n-1} \frac{h_i}{b \cdot G_{xz,i}} + \frac{h_n}{2 \cdot b_n \cdot G_{xz,n}} + \right) \right]^{-1} \quad (6-7)$$

Like for the gamma method, the distances a_i represent distances between the partial section centroid and the total centroid, while a_x is the distance between the outer lamella centroids. These stiffnesses determined in **Equation (6-3)** to **Equation (6-6)**(**6-7**) are used for the determination of idealized forces on an idealized system like the one shown in **Figure 6-3**. This idealized system

is usually modelled in a structural analysis software because it consists of two beams with attributed bending and shear stiffnesses interconnected with rigid members so that they achieve the same deflection.

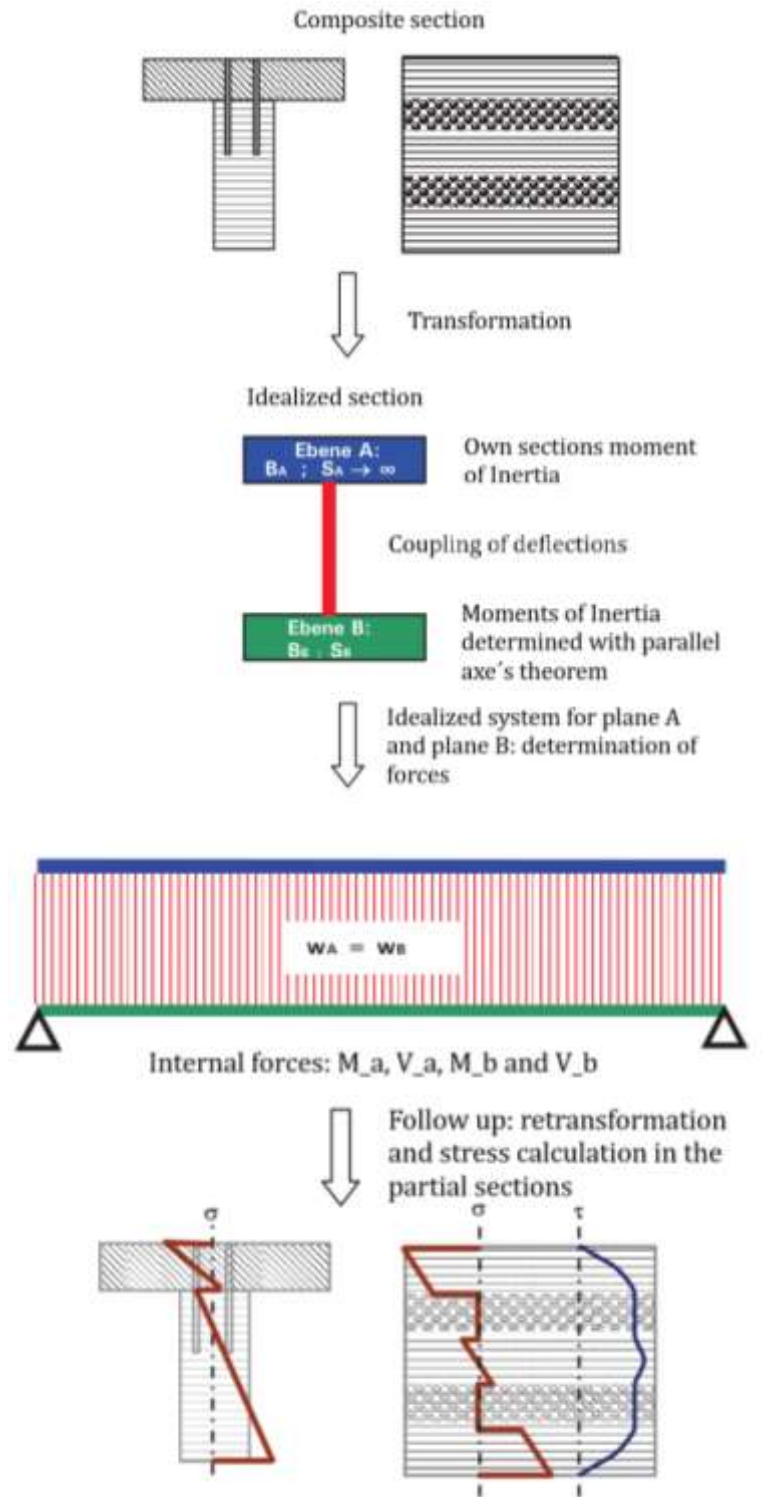


Figure 6-3: Schematic representation of shear analogy method [9, p. 16]

After determination of the virtual forces and moments, real forces and moments are to be determined like it has been performed in Equation (7-54) to Equation (7-61), with the main

difference, that in the quotient of the fraction, the idealized bending stiffnesses B_{Ax} and B_{Bx} are to be used. For further details see [9] and [83].

6.1.3 Solution of the differential equation

The differential method is an analytical solution, which has the main advantage to allow changeable boundary conditions, like varying shear stiffness of the connection, varying section dimensions and loading conditions without losing any precision in the result calculation. The differential equation describes the normal force causing the slip between the elements making up the composite section.

$$\frac{d^2 N}{dx^2} - \beta^2 \cdot N + \alpha \cdot M(x) = 0 \quad (6-8)$$

$$\alpha = \frac{c}{E_v} \cdot \frac{a}{n_1 \cdot I_1 + n_2 \cdot I_2} \quad (6-9)$$

$$\beta^2 = \alpha \cdot \frac{I_s}{S_s} \quad (6-10)$$

$$S_s = a \cdot \frac{n_1 \cdot A_1 + n_2 \cdot A_2}{n_1 \cdot A_1 + n_2 \cdot A_2} \quad (6-11)$$

$$I_s = n_1 \cdot I_1 + n_2 \cdot I_2 + a \cdot S_s \quad (6-12)$$

Since the strength of this method is its universality and possibility to program but it's “weakness” the considerable amount of work that has to be put in, the reader might refer to the following sources: [84, pp. 207-216], [85, pp. 16-17] and [86].

6.1.4 Strut-and-tie model

This method establishes that both elements composing the composite section shall be modelled separately as beams and attached using “struts and ties”, which are members connecting both beams through compression and have a hinge at the height of the shear connector (see **Figure 6-4**). Their length corresponds to the distance between the centres of gravity of both materials. Result precision depends on the number of connecting members simulating shear connectors [9, p. 200].

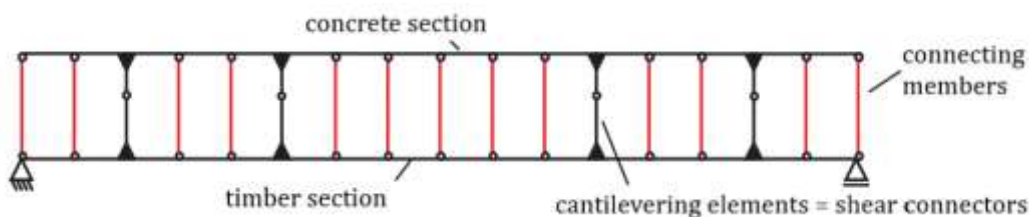


Figure 6-4.: Schematic representation of strut-and-tie modelling method [9, p. 200]

The shear stiffness of the connection is idealized and attributed as bending stiffness to those tying members. This shear stiffness is determined depending on the connection's slip modulus K_s as well as the TCC floor geometry [87, p. 2]; this means that the equation for calculating the cantilevering member's idealized bending stiffness changes whether the stiffness of concrete is ignored (see **Figure 6-5** left) or not (see **Figure 6-5** right). For further details and explanations, consult [87].

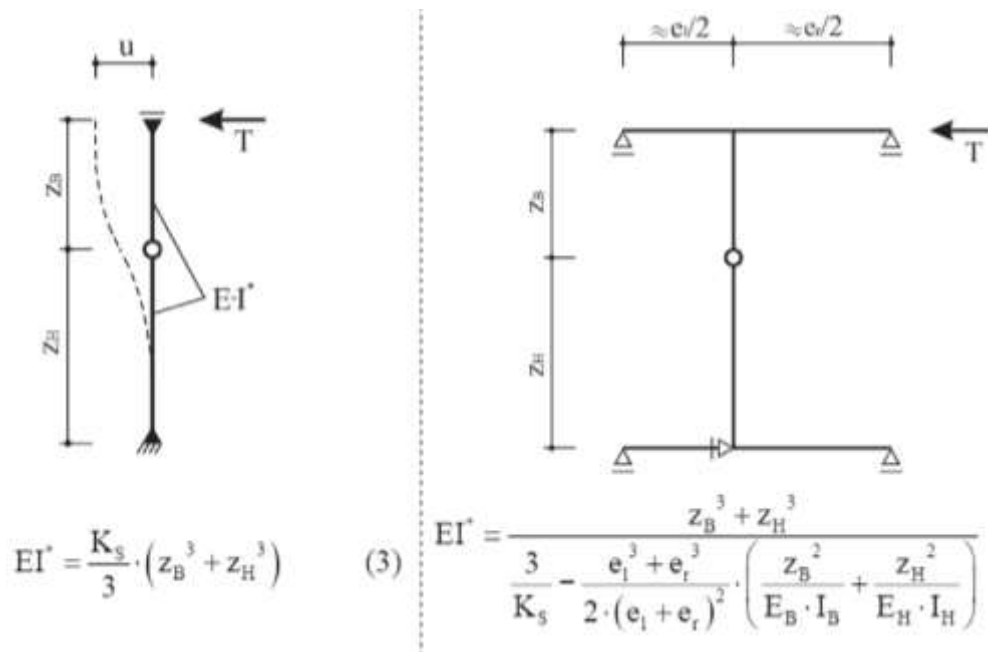


Figure 6-5.: Representation of idealized static system for shear connectors [87, p. 3]

6.1.5 FE-modelling

It is also possible to create a very detailed and capable model of the composite system thanks to the application of finite elements with the main advantage that a very precise and realistic model is achievable. The idea is to subdivide the TCC floor construction into a finite number of elements of given dimensions. These elements are connected by nodes, on which loads and/or support reactions are to be applied. Solving the equilibrium and deformability conditions for the single element gives a solution for the whole system [88, p. 11]. Given its high precision and the possibility to calculate complex system with variable sections, shear connector stiffnesses and/or variable loads, considerable time and effort have to be put into the realization of such models, making them less suitable for everyday dimensioning purposes but rather for research and developments [84, p. 227]. It is also possible to consider the non-linear behaviour of involved materials and shear connectors [88, p. 11].

6.2 Comparison between methods

Table 12 intends to give a brief overview of the possibilities and limitations as well as advantages and disadvantage of these methods perform when compared to one another. It is also intended as help for designing engineers to decide when to apply which method and when not to apply it.

Ultimately, the author elected to use the γ -method: firstly to determine the resulting bending stiffness of the CLT panels themselves (see **chapter 7.1.4**) and secondly to calculate the resulting bending stiffness of a two area section, composed by the CLT panel (with the bending calculation obtained from the previous calculation) and the reinforced concrete layer placed on the top (see **chapter 7.2.6** and **chapter 7.3.6**). The γ -method is picked because the system is statically determined as well as having just one span. In addition to that, since plenty of different CLT panel and concrete screed configurations are analysed at once, modelling in static software would have been too onerous. Also, since it is key for further evaluations, the influence of single parameters is clearly visible. In addition to that, the future European normative for TCC constructions [89] requires engineers to use the γ -method.

	Differential equation	γ -method	Strut-and-Tie model	Shear analogy	FE-model
Time consumption and effort	medium	low	medium	medium	high
Easy to adapt to comparable systems	Yes, only input changes	Yes, only input changes	No, all elements have to be adapted	Yes, two beams have to be modified	The whole model needs to be updated
Result evaluation method	With analytical problem-solving software	By hand	Software	Software	software
Clear influence of single parameters	Yes	Yes	No	No	No
Number of layers	2	3	With increasing number effort increases	No limits	With increasing number effort increases
Multi-span beams	Yes, effort increases	No	Yes	Yes	Yes
Statical undetermined system	Yes, effort increases	No	Yes	Yes	Yes
Variations along the span (i.e., varying cross section)	Yes, effort increases	No	Yes	Yes	Yes
Different connector spacing	Split in subsystems increases effort	Approximation with average distance	Yes, often connectors are summed up to one element	Yes, when split system into subsystems	Yes
Single connectors	Yes, effort increases	No	Yes	Yes, connectors smearing along length	Yes
Part of normative standards	No	Yes	No	Yes	No

Table 12: Methods for determination of internal forces [84, pp. 79-82]

7 Program routines

As explained in the aims of this thesis, it is necessary to create a pre-dimensioning tool that is able to calculate the optimal version of the wanted floor construction given restricting parameters (see **chapter 7.1**). This pre-dimensioning program bases upon artificially created CLT sections with varying lamella numbers. This matrix (see **Figure 7-2**) containing all the different CLT panel dimensions with an attributed systematic span and load situation is used to perform all the required calculations for dimensioning in *ultimate limit state* conditions (*ULS*), *serviceability limit state* conditions (*SLS*) and structural fire conditions are performed at the same time. The in-depth explanations of the executed calculations are to be found in **chapter 6** as well as the annexe. After running through the whole program routine, automatically all sections that simultaneously fulfil ULS, SLS and dimensioning under fire conditions time are computed. If a given section is not able to fulfil requirements, it is eliminated from the CLT-panel matrix, leaving us with a list of suitable solutions. This schematic explanation of the program routine is best illustrated in **Figure 7-1**.

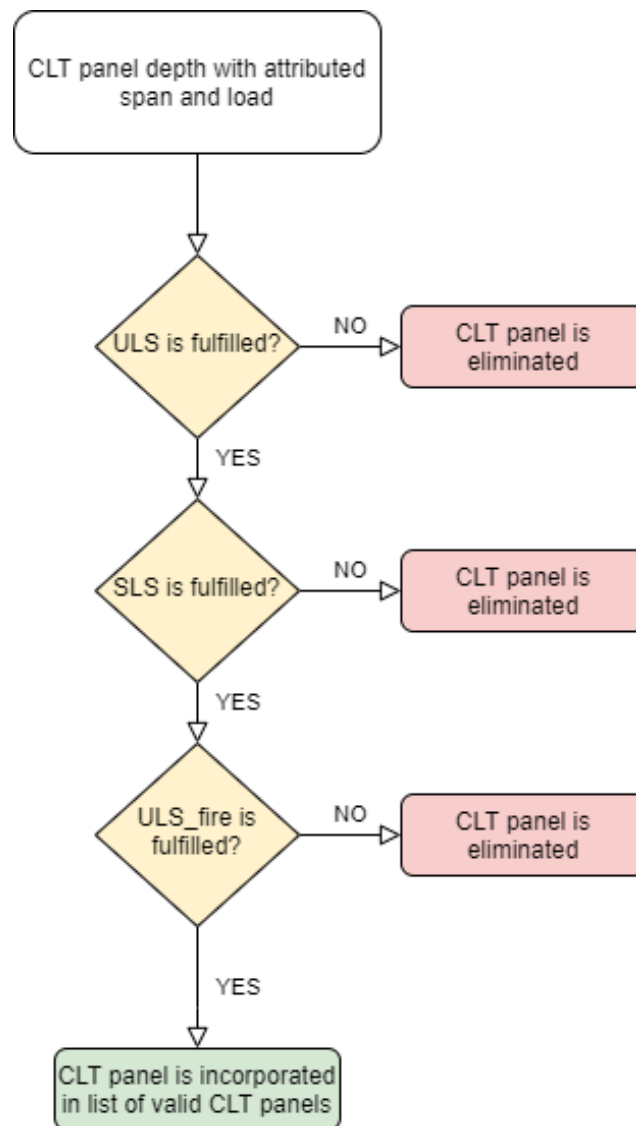


Figure 7-1: Schematic program procedure

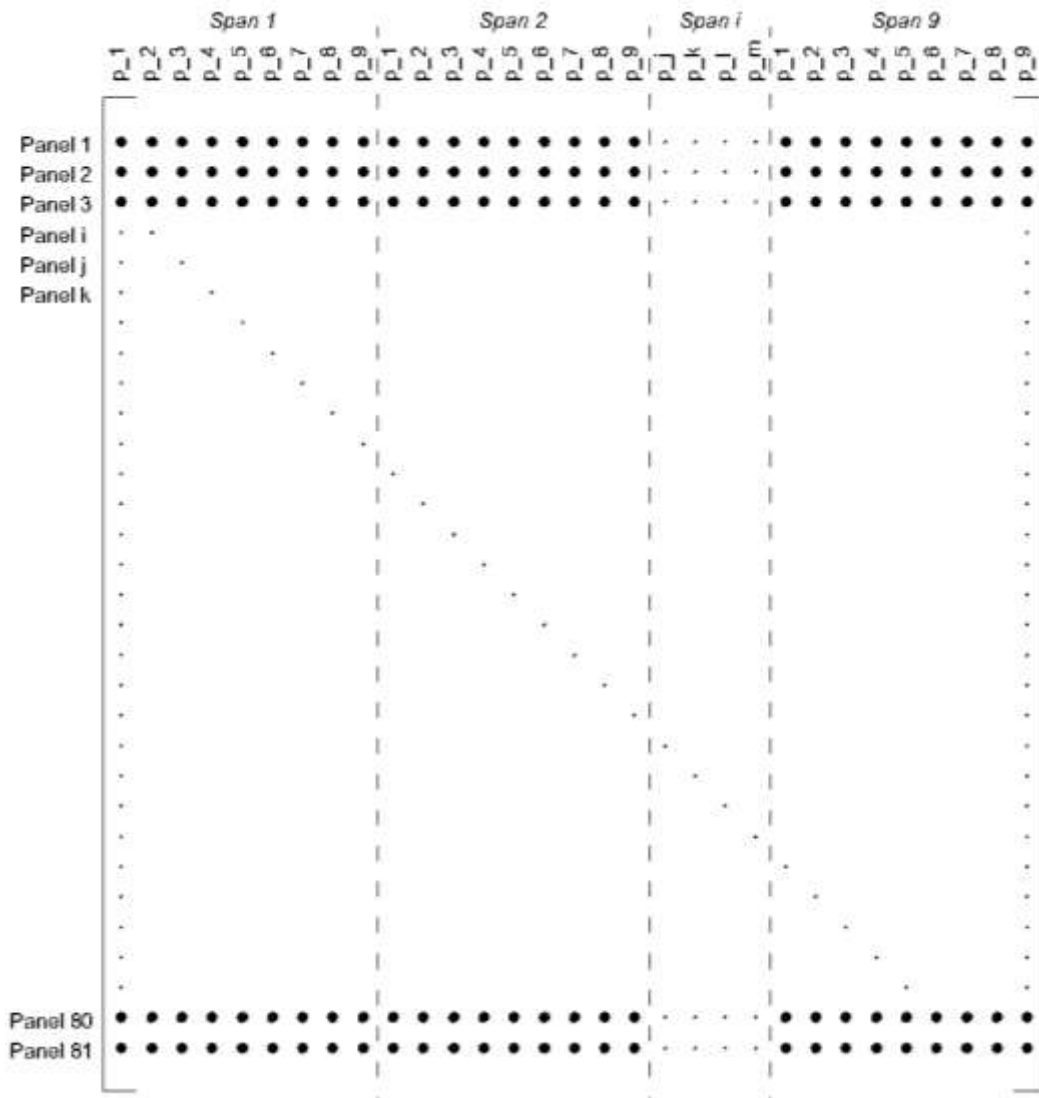


Figure 7-2: Schematic matrix representation

The optimized solution is primarily characterized by its minimum total section depth and thus minimal material consumption. The reduced material consumption has positive repercussions on the cost-effectiveness, as a tailored section is obtained for a given span, load condition and needed fire resistance. This system ensures that the used materials are used to their full capabilities, ensuring high technical and economic efficiency. It is therefore known that the structural core of just determined dimensions is able to fulfil fire protection requirements. The also needed noise insulation capabilities of the remaining sections are calculated using an approximative approach basing on the panel mass. This approach allows a first evaluation of the noise insulation properties of the panels, but it is obviously no substitution for more detailed experimentation and calculation, which obviously would be beyond the scope of this thesis. Subsequently, the enounced properties give a starting point in the evaluation of which additional measures regarding specifically noise insulation but also fire protection (R.E.I.) are needed so that the whole floor package is able to reach the required standards. Generally speaking, this dimensioning tool focuses on the structural core of the floor construction with its mechanic, fire protection and sound insulation capabilities; these

results are just the starting point of a “full package” analysis. Having knowledge of the core abilities a detailed, layered floor package comprehending additional layers (i.e., loose concrete screed, footfall sound insulation, plasterboard covering, elastic fill, etc.) can be elaborated. This full-floor package is then able to completely satisfy normative requirements according to what referred to in **chapter 5.1.1**, **chapter 5.1.2** as well as **chapter 5.1.3**.

7.1 System description for simple panel floor construction

The first system consists of a bare CLT panel which is simply supported on both sides. There is a distinction basing on the presence of a concrete screed placed above the panel itself or not; it shall be noted that the panel is not attached to the CLT element but is rather separated by a filling layer. As noted at the beginning of **chapter 6**, the program routine is based on restricting/characterising parameters, which are listed and explained in the following:

- 1) **System span**: this tool just analyses simply supported floors spanning over one field since this configuration is the most common for massive timber floor constructions. The chosen system spans vary between 3,0 m - 6,0 m in 0,5 m steps and are estimated thanks to Table 1 in [14].
- 2) **Self-weight loads**: these loads caused by dead loads depend on the panel weight, the presence of a concrete screed on top as well as the weight from layers part of the floor package. A detailed estimation of typical dead loads acting on massive timber floors is contained in **chapter 7.1.2**.
- 3) **Imposed loads**: Minimal imposed loads are defined in European normative EN 1991-1. To further improve the precision of the pre-dimensioning tool, the variation of imposed loads was also implemented (see **chapter 7.1.2**).
- 4) **Fire protection**: Hereby, just the structural resistance (parameter R) is considered. According to the needed fire resistance of 30, 60 or 90 minutes a remaining section after subtraction of the burnt parts is calculated. Further calculations under structural fire circumstances are carried out with the reduced section.
- 5) **Depth of concrete screed**: the presence of a loosely connected concrete screed atop of the CLT panel (separated by sand or fill so that no composite load-bearing action can happen) is considered. It simply adds weight to the total dead loads but positively affects the total bending stiffness and the sound insulation properties because of the added mass. The bending stiffness of this concrete screed is simply added to the one of the CLT panel itself, thus improving structural properties.

This pre-dimensioning tool has an artificially implemented database of four different CLT panel types; the single lamellas composing these panels having thicknesses of 20, 30 or 40 mm (see **Figure 7-3**). Lamella depths are taken over from the technical data sheet “X-Lam Rubner Holzbau”. To simplify the approach and avoid the insertion of another variable and thus the creation of many more possibilities with no apparent advantage, the concrete screed’s depth can be manually chosen by the user; the choice is between 40 mm, 60 mm, and 80 mm. The presence of the concrete layer atop of the CLT panel has no explicit positive effect on the resistance to fire because an eventual fire attacks the timber floor from below.

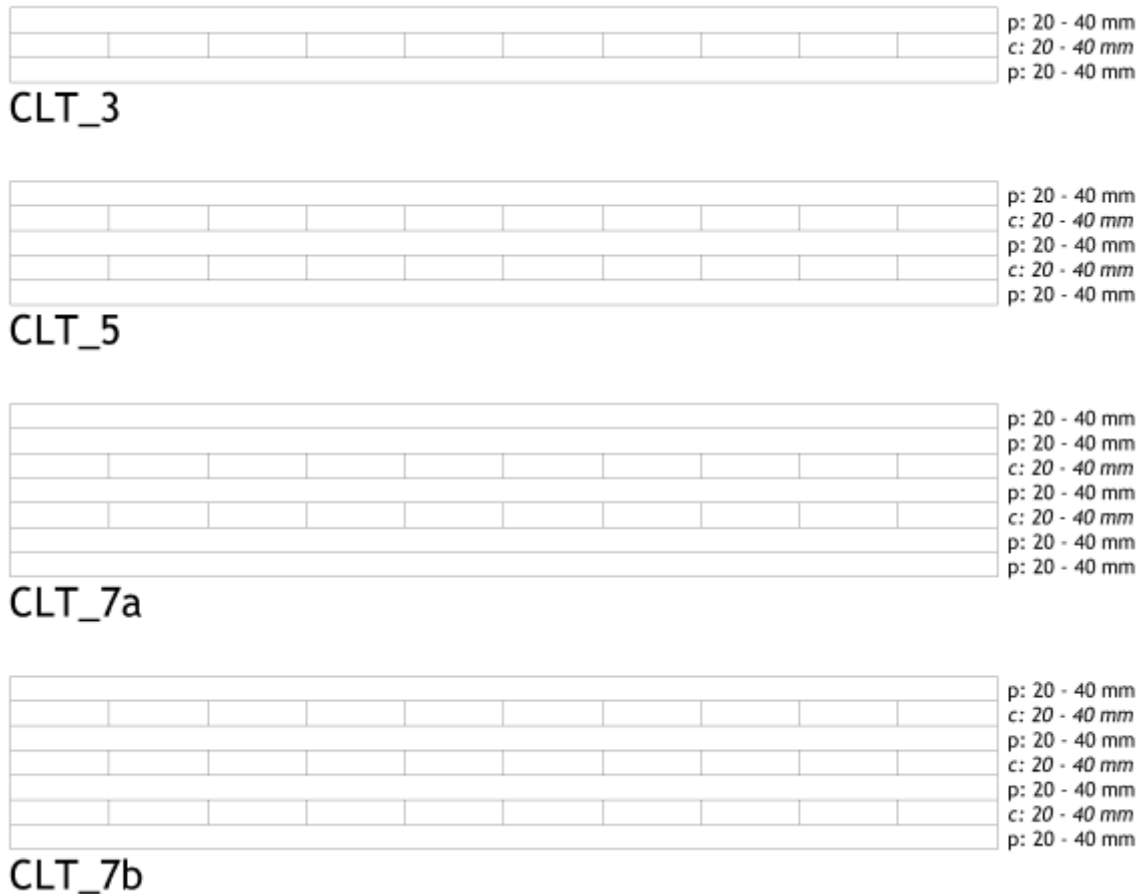


Figure 7-3: Draft of implemented CLT panels

7.1.1 Material strengths and safety factors

Material strength values in **Table 13** are taken over from the technical data sheet “X-Lam Rubner Holzbau”, which bases on their ETA document (European Technical Approval).

Material Strength for timber C24		Strength Value
[-]		[N/mm ²]
Flexural strength	$f_{m,k}$	26,4
Tensile strength parallel to fibre	$f_{t,0,k}$	14,5
Tensile strength perpendicular to fibre	$f_{t,90,k}$	0,12
Compressive strength parallel to fibre	$f_{c,0,k}$	21,0
Compressive strength perpendicular to fibre	$f_{c,90,k}$	2,50
Shear strength parallel to fibre	$f_{v,90,k}$	4,00
Shear strength perpendicular to fibre	$f_{v,9090,k}$	1,20
Mean E-Modulus parallel to fibre	$E_{0,mean}$	11550
Mean E-Modulus perpendicular to fibre	$E_{90,mean}$	370
Mean G-Modulus	$G_{090,mean}$	690

Density		Value
[-]		[kg/m ³]
Characteristic density	ρ_k	350
Mean density	ρ_{mean}	420

Table 13: Material strengths and density for timber

Table 14 visualizes the implemented material safety factors and load combination factors for the different analysed EU countries (Switzerland, Germany, Italy, and Austria); referenced values are obtained from respective national annexes to EN 1990-1-1 and EN 1995-1-1. The timber coefficients were picked based on service class 1, which means that the timber is placed in environments where the temperature is normally around 20 °C, and the relative humidity is higher than 65% for short periods of time. This assumption is quite realistic, as the subjects of this thesis are floor construction not in contact with the exterior environment. Additionally, the duration on which the imposed loads act on the structure (k_{mod}) is defined as middle, which means one week to six months over the whole structure's lifespan. Every single one of the analysed country norms defines that imposed loads of this class act over the aforementioned duration.

coefficient	Switzerland	Germany	Italy	Austria
k_{mod} permanent loads	0,60	0,60	0,60	0,60
k_{mod} imposed loads (middle duration)	0,80	0,80	0,80	0,80
k_{def}	0,60	0,60	0,60	0,60
γ_M	1,25	1,3	1,35	1,25
$\psi_{0, \text{office}}$	0,7	0,7	0,7	0,7
$\psi_{1, \text{office}}$	0,5	0,5	0,5	0,5
$\psi_{2, \text{office}}$	0,3	0,3	0,3	0,3
$\psi_{0, \text{residential}}$	0,7	0,7	0,7	0,7
$\psi_{1, \text{residential}}$	0,5	0,5	0,5	0,5
$\psi_{2, \text{residential}}$	0,3	0,3	0,3	0,3
$\gamma_{G,1}$	1,35	1,35	1,3	1,35
$\gamma_{Q,1}$	1,5	1,5	1,5	1,5

Table 14: Material safety factors and load combination factors in analysed EU countries

7.1.2 Determination of external loads

Because of the two different building's destinations, the loads are defined for these two distinct categories: residential and commercial. In both of these categories, dead loads and imposed loads are vectorized into ranges that are combined together to cover a larger amount of load combinations, i.e., a higher dead load value is combined with a low imposed load and the opposite

(see **Table 18**). The values of the self-weight loads are estimated from the “Data-Holz” database [90] and include nine different, but quite common, floor construction packages (named as the ones to be found in [90]), whereas the differences reside in the presence of wet or dry concrete screeds, loose fills above the CLT panel itself of various depths. Other differences are to be found in the presence of plasterboard panels below the timber layer and in the depth of the footfall sound insulation. As shown in **Table 15**, the calculation of these self-weight loads does not include the dead load of the CLT-panel, as it is already present in the pre-dimensioning tool itself.

gdmnxa01a			
Layer [-]	Depth [mm]	Density [kN/m ³]	Weight per m ² [kN/m ²]
Tiles including glue	15	20	0,3
Concrete Screed	50	24	1,2
Separation layer	0,2	14	0,0028
Footfall sound insulation	30	0,8	0,024
Fill elastic joint	60	15	0,9
Trickle protection	0	0	0
CLT panel			0
Rock wool	60	0,18	0,0108
Plasterboard panel	12,5	8	0,1
Plasterboard panel	12,5	10	0,125
Sum			2,663

gdmnxa02a			
Layer [-]	Depth [mm]	Density [kN/m ³]	Weight per m ² [kN/m ²]
Tiles including glue	15	20	0,3
Concrete Screed	60	24	1,44
Separation layer	0,2	14	0,0028
Footfall sound insulation	30	0,8	0,024
Fill elastic joint	60	15	0,9
Trickle protection	0	0	0
CLT Panel			0
Rock wool	60	0,18	0,0108
Plasterboard panel	12,5	8	0,1
Plasterboard panel	12,5	10	0,125
Sum			2,903

gdmnxn01a			
Layer [-]	Depth [mm]	Density [kN/m ³]	Weight per m ² [kN/m ²]
Tiles including glue	15	20	0,3
Concrete Screed	60	24	1,44
Separation layer	0,2	14	0,0028
Footfall sound insulation	30	0,8	0,024
Fill elastic joint	60	15	0,9
Trickle protection	0	0	0
CLT Panel			0
Rock wool	60	0,18	0,0108
Plasterboard panel	12,5	8	0,1
Plasterboard panel	12,5	10	0,125
Sum			2,903

gdmnxn02a			
Layer [-]	Depth [mm]	Density [kN/m ³]	Weight per m ² [kN/m ²]
Tiles including glue	15	20	0,3
Concrete Screed	60	24	1,44
Separation layer	0,2	14	0,0028
Footfall sound insulation	30	0,8	0,024
Fill non jointed	60	15	0,9
Trickle protection	0	0	0
CLT Panel			0
Sum			2,667

gdmnxn03a			
Layer [-]	Depth [mm]	Density [kN/m ³]	Weight per m ² [kN/m ²]
Tiles including glue	15	20	0,3
Concrete Screed	60	24	1,44
Separation layer	0,2	14	0,0028
Footfall sound insulation	30	0,8	0,024
Fill non jointed	120	15	1,8
Trickle protection	0	0	0
CLT Panel			0
Sum			3,567

gdmtxn01			
Layer [-]	Depth [mm]	Density [kN/m ³]	Weight per m ² [kN/m ²]
Tiles including glue	15	20	0,3
Dry Screed	25	9	0,225
Separation layer	0,2	14	0,0028
Footfall sound insulation	30	0,8	0,024
Fill non jointed	60	15	0,9
Trickle protection	0	0	0
CLT Panel			0
Sum			1,452

gdmtxa01a			
Layer [-]	Depth [mm]	Density [kN/m ³]	Weight per m ² [kN/m ²]
Tiles including glue	15	20	0,3
Rigidur screed	20	12	0,24
Footfall sound insulation	10	0,8	0,008
Fill non jointed	60	15	0,9
Trickle protection	0	0	0
CLT Panel			0
Rock wool	75	0,18	0,0135
Plasterboard panel	12,5	12	0,15
Plasterboard panel anti-fire	12,5	9	0,1125
Sum			1,724

tdmnxs01			
Layer [-]	Depth [mm]	Density [kN/m ³]	Weight per m ² [kN/m ²]
Tiles including glue	15	20	0,3
Concrete screed	50	24	1,2
Footfall sound insulation	40	0,8	0,032
Fill non jointed	120	15	1,8
Trickle protection	0	0	0
CLT Panel			0
Sum			3,332

gdmtda01a			
Layer [-]	Depth [mm]	Density [kN/m ³]	Weight per m ² [kN/m ²]
Tiles including glue	15	20	0,3
Rigidur screed	20	12	0,24
Footfall sound insulation	12	0,8	0,0096
Fill non jointed	60	15	0,9
Trickle protection	0	0	0
CLT Panel			0
Rock wool	75	0,18	0,0135
Plasterboard panel	30	12	0,36
Plasterboard panel anti-fire	30	9	0,27
Sum			2,093

Table 15: Research of common floor packages from dataholz.eu [90]

The determination of imposed loads refers to norms of different European countries (see **Table 16**), such as Austria [91, p. 18], Germany [92, pp. 16-17], Italy [93, p. 43] and Switzerland [94, p. 6]. The additional loads caused by divisor walls need to be considered as well; in every of the considered norms, the value of this additional imposed loads depends on the linear weight of the wall and usually varies between 0,8 – 1,2 kN/m² [93, p. 43]. Normally, in the highest load combination, the load caused by these walls needs to be reduced by psi factors, to take into account that full imposed loads due to building's destination and divisor walls do not really act simultaneously (see combination formulas in EN 1990-1-1). While developing this pre-dimensioning tool, the two imposed loads are added, consciously creating a slightly more conservative approach but with the main advantage that the number of variables at the pre-dimensioning stage is minimized. Also, the self-weight of divisor walls usually is unknown at these preliminary project stages.

Imposed loads depending on building's use in European Countries		
Country [-]	Residential [kN/m ²]	Commercial [kN/m ²]
Austria	2,00	3,00
Germany	2,00	2,00
Italy	2,00	3,00
Switzerland	2,00	3,00

Table 16: Imposed Loads for various EU countries

Table 17 shows contain the implemented loads (self-weight and imposed loads), resulting from what explained above (see **Table 15** and **Table 16**).

Load type	Load combination
Dead loads	1.8 – 2.8 kN/m ²
Steps	0.5 kN/m ²
Imposed loads	3.0 – 5.0 kN/m ²
Steps	1 kN/m ²

Table 17: Applied loads

In the following steps, load range vectors (shown in **Table 18**) are combined together using the so-called *combvec* function in MathWorks MATLAB (combination of values stored in vectors), so that every value of the imposed load vector and self-weight range (which contain 3 values each) is connected to one another, thus creating nine different load conditions. These are afterwards multiplied with the related safety coefficient. **Table 18** contains load combinations for residential and commercial building usage, respectively.

load combination	g_k	γ_G	q_k	γ_G	p_n
[-]	[kN/m ²]	[-]	[kN/m ²]	[-]	[kN/m ²]
p_1	1,8	1,35	3,0	1,5	6,93
p_2	2,3	1,35	3,0	1,5	7,61
p_3	2,8	1,35	3,0	1,5	8,28
p_4	1,8	1,35	4,0	1,5	8,43
p_5	2,3	1,35	4,0	1,5	9,11
p_6	2,8	1,35	4,0	1,5	9,78
p_7	1,8	1,35	5,0	1,5	9,93
p_8	2,3	1,35	5,0	1,5	10,61
p_9	2,8	1,35	5,0	1,5	11,28

Table 18: Combination of loads into different loading scenarios for residential building destination

As mentioned at the beginning of this chapter, this pre-dimensioning tool has seven implemented system spans, varying from 3,00 m – 6,00 m in 0,5 m steps. Since any load condition is to be applied regardless of the system span (so that the approach is as realistic as possible), 9x7=63 combinations of load and span conditions are once again created. Since the panel self-weight is calculated as well and depends on the section depths of **Table 19**, the load matrix and thus moments and shear forces matrices have 9 rows and 175 columns for CLT_3 [9x81], 27 rows and 175 columns for CLT_5 [27x81] and 81 rows and 175 columns for CLT_7a [81x81] as well as CLT_7b [81x81]. Because the load vector supposedly does not vary in regard to the panel, the column number doesn't change.

7.1.3 Creation of sections

The most performant way to create a simultaneous calculation approach is with matrices and vectors, whereas every single lamella combination that results in a panel is a row vector. Combined together and put one below the other, the result is a matrix; to access rows or columns, logical indexing is used. In order to reduce the number of possible combinations, which are created by the program itself, each and every created section is symmetric. Such a simplification is implemented because, except for rare cases, every CLT panel has symmetric disposition of lamellas. Besides that, the calculation is more efficient because of the lower number of created sections. All created CLT_5 panels have symmetric upper and lower exterior lamellas as well as symmetric upper and lower interior lamellas. Hereby the number of possible combinations diminishes from 243 to 27 (see **Table 20**). In the case of both seven-layered CLT panels, the possible combinations are reduced from 2187 to 81 (the created configurations for both CLT_7a and CLT_7b are shown together for graphic reasons). After reduction of possibilities for symmetric reasons, the CLT_3 panel goes from 27 to 9 different configurations (see **Table 19**).

Panel CLT_3				
Panel Nr.	1 st lamella	2 nd lamella	3 rd lamella	Total depth
[-]	[mm]	[mm]	[mm]	[mm]
1	20	20	20	60
2	20	30	20	70
3	20	40	20	80
4	30	20	30	80
5	30	30	30	90
6	30	40	30	100
7	40	20	40	100
8	40	30	40	110
9	40	40	40	120

Table 19: 9 different lamella configurations for CLT_3

Panel CLT_5						
Panel Nr.	1st lamella	2nd lamella	3rd lamella	4th lamella	5th lamella	Total depth
[-]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
1	20	20	20	20	20	100
2	20	20	30	20	20	110
3	20	20	40	20	20	120
4	20	30	20	30	20	120
5	20	30	30	30	20	130
6	20	30	40	30	20	140
7	20	40	20	40	20	140
8	20	40	30	40	20	150
9	20	40	40	40	20	160

10	30	20	20	20	30	120
11	30	20	30	20	30	130
12	30	20	40	20	30	140
13	30	30	20	30	30	140
14	30	30	30	30	30	150
15	30	30	40	30	30	160
16	30	40	20	40	30	160
17	30	40	30	40	30	170
18	30	40	40	40	30	180
19	40	20	20	20	40	140
20	40	20	30	20	40	150
21	40	20	40	20	40	160
22	40	30	20	30	40	160
23	40	30	30	30	40	170
24	40	30	40	30	40	180
25	40	40	20	40	40	180
26	40	40	30	40	40	190
27	40	40	40	40	40	200

Table 20: 27 different lamella configurations for CLT_5

Panel CLT_7a / CLT_7b								
Panel Nr.	1 st lamella	2 nd lamella	3 rd lamella	4 th lamella	5 th lamella	6 th lamella	7 th lamella	Total depth
[-]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
1	20	20	20	20	20	20	20	140
2	20	20	20	30	20	20	20	150
3	20	20	20	40	20	20	20	160
4	20	20	30	20	30	20	20	160
5	20	20	30	30	30	20	20	170
6	20	20	30	40	30	20	20	180
7	20	20	40	20	40	20	20	180
8	20	20	40	30	40	20	20	190
9	20	20	40	40	40	20	20	200
10	20	30	20	20	20	30	20	160
11	20	30	20	30	20	30	20	170
12	20	30	20	40	20	30	20	180
13	20	30	30	20	30	30	20	180
14	20	30	30	30	30	30	20	190
15	20	30	30	40	30	30	20	200
16	20	30	40	20	40	30	20	200
17	20	30	40	30	40	30	20	210
18	20	30	40	40	40	30	20	220
19	20	40	20	20	20	40	20	180
20	20	40	20	30	20	40	20	190
21	20	40	20	40	20	40	20	200
22	20	40	30	20	30	40	20	200
23	20	40	30	30	30	40	20	210
24	20	40	30	40	30	40	20	220

25	20	40	40	20	40	40	20	220
26	20	40	40	30	40	40	20	230
27	20	40	40	40	40	40	20	240
28	30	20	20	20	20	20	30	160
29	30	20	20	30	20	20	30	170
30	30	20	20	40	20	20	30	180
31	30	20	30	20	30	20	30	180
32	30	20	30	30	30	20	30	190
33	30	20	30	40	30	20	30	200
34	30	20	40	20	40	20	30	200
35	30	20	40	30	40	20	30	210
36	30	20	40	40	40	20	30	220
37	30	30	20	20	20	30	30	180
38	30	30	20	30	20	30	30	190
39	30	30	20	40	20	30	30	200
40	30	30	30	20	30	30	30	200
41	30	30	30	30	30	30	30	210
42	30	30	30	40	30	30	30	220
43	30	30	40	20	40	30	30	220
44	30	30	40	30	40	30	30	230
45	30	30	40	40	40	30	30	240
46	30	40	20	20	20	40	30	200
47	30	40	20	30	20	40	30	210
48	30	40	20	40	20	40	30	220
49	30	40	30	20	30	40	30	220
50	30	40	30	30	30	40	30	230
51	30	40	30	40	30	40	30	240
52	30	40	40	20	40	40	30	240
53	30	40	40	30	40	40	30	250
54	30	40	40	40	40	40	30	260
55	40	20	20	20	20	20	40	180
56	40	20	20	30	20	20	40	190
57	40	20	20	40	20	20	40	200
58	40	20	30	20	30	20	40	200
59	40	20	30	30	30	20	40	210
60	40	20	30	40	30	20	40	220
61	40	20	40	20	40	20	40	220
62	40	20	40	30	40	20	40	230
63	40	20	40	40	40	20	40	240
64	40	30	20	20	20	30	40	200
65	40	30	20	30	20	30	40	210
66	40	30	20	40	20	30	40	220
67	40	30	30	20	30	30	40	220
68	40	30	30	30	30	30	40	230

69	40	30	30	40	30	30	40	240
70	40	30	40	20	40	30	40	240
71	40	30	40	30	40	30	40	250
72	40	30	40	40	40	30	40	260
73	40	40	20	20	20	40	40	220
74	40	40	20	30	20	40	40	230
75	40	40	20	40	20	40	40	240
76	40	40	30	20	30	40	40	240
77	40	40	30	30	30	40	40	250
78	40	40	30	40	30	40	40	260
79	40	40	40	20	40	40	40	260
80	40	40	40	30	40	40	40	270
81	40	40	40	40	40	40	40	280

Table 21: 81 different lamella configurations for CLT_7a and CLT_7b

7.1.4 Calculation of gamma factors and resulting bending stiffness

The next steps contain the gamma-factor calculation with the simplified method, which is valid just for two and three lamellas parallel to span, as well as the “expanded” gamma method valid for more than three lamellas parallel to span [95, p. 181]. The simplified γ -method is contained in the Annex B of Eurocode EN 1995-1-1 [82, p. 164] and in plenty of approval documents of CLT documents. The actual purpose of this method is to calculate shear compliance of lamellas cross to span that are in close proximity and thus reducing the lamellas parallel to span bending stiffness by a gamma factor [95, p. 14].

The procedure to calculate the gamma factors for seven-layered panels (here CLT_7a and CLT_7b) is more complicated because the number of lamellas parallel to the span is higher than three. The calculation foots on the so-called „expanded” γ -method that was originally developed by Schelling Wolfgang; this method is valid for a finite amount m of subsequently connected layers [96, p. 167]. The calculation of the gamma factors bases on the solution of a linear system of equations; the amount of these equations depends on the number of lamellas parallel to the span present in the panel (see **Equation (7-1)**).

$$\begin{bmatrix} v_{1,1} & v_{1,2} & 0 & 0 & 0 & 0 & 0 \\ v_{2,1} & v_{2,2} & v_{2,3} & 0 & 0 & 0 & 0 \\ 0 & \dots & \dots & \dots & 0 & 0 & 0 \\ 0 & 0 & v_{i,i-1} & v_{i,i} & v_{i,i+1} & 0 & 0 \\ 0 & 0 & 0 & \dots & \dots & \dots & 0 \\ 0 & 0 & 0 & 0 & v_{m-1,m-2} & v_{m-1,m-1} & v_{m-1,m} \\ 0 & 0 & 0 & 0 & 0 & v_{m-1,m} & v_{m,m} \end{bmatrix} \cdot \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \dots \\ \gamma_i \\ \dots \\ \gamma_{m-1} \\ \gamma_m \end{bmatrix} = \begin{bmatrix} s_1 \\ s_2 \\ \dots \\ s_i \\ \dots \\ s_{m-1} \\ s_m \end{bmatrix} \quad (7-1)$$

Equation (7-2) to **Equation (7-5)** shows the application of the expanded gamma method for a 4 layered (parallel to span) CLT panel. [95, p. 183] The resulting bending stiffness of the CLT panel is afterwards calculated using **Equation (6-1)**.

$$[V] \cdot \gamma = s \quad \rightarrow \quad \gamma = [V]^{-1} \cdot s \quad (7-2)$$

$$C_{j,k} = \frac{b \cdot G_{R,jk}}{\Delta h_i} \quad (7-3)$$

$$D_i = \frac{\pi^2 \cdot E_i \cdot b \cdot d_i}{l_{ref}^2} \quad (7-4)$$

$$\begin{bmatrix} (C_{1,2} + D_1) \cdot a_1 & -C_{1,2} \cdot a_2 & 0 & 0 \\ -C_{1,2} \cdot a_1 & (C_{1,2} + C_{2,3} + D_2) \cdot a_2 & -C_{2,3} \cdot a_3 & 0 \\ 0 & -C_{2,3} \cdot a_2 & (C_{2,3} + C_{3,4} + D_3) \cdot a_3 & -C_{3,4} \cdot a_4 \\ 0 & 0 & -C_{3,4} \cdot a_3 & (C_{3,4} + D_4) \cdot a_4 \end{bmatrix} \cdot \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \\ \gamma_4 \end{bmatrix} =$$

$$= \begin{bmatrix} -C_{1,2} \cdot (a_2 - a_1) \\ -C_{2,3} \cdot (a_3 - a_2) + C_{1,2} \cdot (a_2 - a_1) \\ -C_{3,4} \cdot (a_4 - a_3) + C_{2,3} \cdot (a_3 - a_2) \\ C_{3,4} \cdot (a_4 - a_3) \end{bmatrix} \quad (7-5)$$

7.1.5 ULS verification

The now calculated panel bending stiffness is then used for the ULS verification of lamella stress and shear stress. Both these stresses are just carried by lamellas parallel to the span (see **Figure 7-3**). The following formulas, obtained from [85, p. 13] and [82, pp. 164-165], were used to calculate normal stress and shear stress, respectively. In a one-way spanned floor construction, the highest normal stress because of moments causes compression in the upper lamellas and causes tension in the lower lamellas. **Equation (7-6)** is to be intended as the sum of normal stress due to moment (σ_m) and normal force (σ_n).

$$\sigma_i = \sigma_{m,i} + \sigma_{n,i} = \frac{M \cdot E_i}{E_{I_{eff.CLT}}} \cdot \frac{\Delta h_i}{2} + \frac{M \cdot E_i}{E_{I_{eff.CLT}}} \cdot a_i \cdot \gamma_i \quad (7-6)$$

Equation (7-7) is for shear stress calculation in the most strained lamella, which in the case of a one-way spanned floor construction happens to be the closest one to the centre of gravity of the CLT panel itself. Therefore, the first part of the equation calculates the shear stress in other lamellas before the centre of gravity (i.e., top of CLT panel).

$$\tau_{xz,i} = V \cdot \frac{\sum_{i=1}^n \gamma_i \cdot E_i \cdot A_i \cdot a_i}{E_{I_{eff.CLT}} \cdot b_2} + V \cdot \frac{E_2 \cdot b_2 \cdot \frac{h_2^2}{8}}{E_{I_{eff.CLT}} \cdot b_2} \quad (7-7)$$

To compare the obtained stresses of **Equation (7-6)** and **Equation (7-7)** to the stress limits imposed by the material itself, a logical statement is used: if the normal/shear stress is lower than the maximum stress, the value one is associated, if it is higher the value 0 is associated. CLT panels that are too weak to withstand resulting stresses higher (be it normal or shear stress) than stress limits are directly eliminated because of their associated value of 0. Applied material strengths are listed in **Table 14**.

7.1.6 SLS verification

In regard to SLS, the necessary verifications according to [85, pp. 19-22] are the following:

- a) Instant deflection depending on load and span conditions. In order to verify if this deflection is not too high, the limit recommended by [82, p. 72] of $\frac{l}{300}$ is used.

$$u_{inst} = \frac{5 \cdot (g_{k1} + g_{k2} + q_k) \cdot l^4}{384 \cdot EI_{eff.CLT}} \quad (7-8)$$

- b) Final deflection limits depending on load and span conditions. In order to verify if this deflection is not too high, the limit recommended by [82, p. 72] of $\frac{l}{250}$ is used.

$$u_{fin} = \frac{5 \cdot (g_{k1} + g_{k2}) \cdot l^4}{384 \cdot EI_{eff.CLT}} \cdot (1 + k_{def}) + \frac{5 \cdot (q_k) \cdot l^4}{384 \cdot EI_{eff.CLT}} \cdot (1 + \psi_2 \cdot k_{def}) \quad (7-9)$$

- c) Frequency criterium depending on load and span conditions. If the obtained frequency is higher than 6 Hz, the frequency verification is fulfilled.

For $\frac{EI_{eff.CLT}}{EI_{eff.cross}} \geq 0.05$:

$$m = g_{k1} + g_{k2} \quad (7-10)$$

$$f_1 = \frac{\pi}{2 \cdot l^2} \cdot \sqrt{\frac{EI_{eff.CLT}}{m}} \cdot \sqrt{1 + \left(\frac{l}{b}\right)^4 \cdot \frac{EI_{eff.CLT}}{EI_{eff.cross}}} \quad (7-11)$$

For $\frac{EI_{eff.par}}{EI_{eff.cross}} < 0.05$:

$$f_1 = \frac{\pi}{2 \cdot l^2} \cdot \sqrt{\frac{EI_{eff.CLT}}{m}} \quad (7-12)$$

If $f_1 < f_{lim}$ but higher than $f_{1,min} = 4.5 \text{ Hz}$ it is possible to substitute the frequency criterium verification with the so-called “verification of vibration acceleration”.

$$a_{rms} = \frac{0.4 \cdot e^{-0.4 \cdot f_1} \cdot 700N}{2 \cdot \zeta \cdot m \cdot \frac{l}{2} \cdot b_f} \cdot \sqrt{\frac{EI_{eff.CLT}}{m}} \quad (7-13)$$

$$b_f = \min \left\{ \frac{l}{1,1} \cdot \sqrt[4]{\frac{EI_{eff,CLT}}{EI_{eff,cross}}}, b \right. \quad (7-14)$$

- d) Stiffness criterium depending on span conditions. This criterium shows that a deflection under a load of 1000 N at the worst location is less than 0,50 mm. In our case, the worst possible location is in the middle of the span.

$$w_{stat} = \frac{1000N \cdot l^3}{48 \cdot EI_{eff,CLT} \cdot b_f} \quad (7-15)$$

The very interesting thing achieved in the background calculations is the possible superposition between ULS and SLS results; CLT panels for which ULS and SLS requirements are fulfilled separately are extracted and superposed to in a matrix where both are fulfilled simultaneously. This means that all sections for which one verification is not satisfied are automatically eliminated while valid results are filtered and kept for further calculations.

7.1.7 Dimensioning under fire conditions

The dimensioning under fire conditions (“method of the reduced section”) works similarly to a ULS verification. The main difference resides in the fact that a reduced load combination (see **Equation (7-16)**) acts on a reduced section, where some depth has been burnt and thus is not able to contribute to the load-carrying mechanism. The factor $\psi_{2,i}$, according to EN 1991-1-1, depends on the building’s usage destination; for both residential and commercial destination corresponds to 0,3.

$$E_{fi,d} = \sum_{i=1}^n G_{k,i} + \sum_{i=1}^n \psi_{2,i} \cdot Q_{k,i} \quad (7-16)$$

Additionally, the characteristic material strengths used in **Table 13** can be increased by 15% as well. If the section is dimensioned according to the “method of the reduced sections” (see **Equation (7-17)**), both parameters $k_{mod,fi}$ and $\gamma_{M,fi}$ are equal to 1.

$$\sigma_{fi,d} \leq k_{fi} \cdot k_{mod,fi} \cdot \frac{f_k}{\gamma_{M,fi}} = 1.15 \cdot f_k \quad (7-17)$$

With this method, a smaller section remains as a part has been incinerated; the burnt depth depends on the length of exposition under fire, namely 30, 60, or 90 min. This burnt depth is eliminated column-wise from the existing sections, so reducing the section’s bending stiffness. It is assumed that the fire attacks the CLT panel from below, so just a one-sided fire exposition has to be taken into account because the upper side is protected by the flooring layer placed above the

CLT panel itself. If a timber beam is to be dimensioned under fire conditions, the fire would be attacking the side edges as well as the lower edge. In this case, the burnt depth needs to be subtracted from all three sides; the verification then is undertaken on the reduced section. The burning rates of timber are well known from plenty of laboratory tests: the following **Table 22** shows which burning rates were used while determining the remaining section depth. They can also be obtained from EN 1995-1-2.

Position	burning rate
[-]	[mm/min]
1 st lamella	0,65
2 nd lamella (first 25 mm)	1,30
2 nd lamella (rest of lamella)	0,65
3 rd lamella (first 25 mm)	1,30
3 rd lamella (rest of lamella)	0,65
n th lamella (first 25 mm)	1,30
n th lamella (rest of lamella)	0,65
k0*d0	7 mm

Table 22: Burning rates for CLT ([95, p. 91])

Again, stresses parallel to span and cross to it (shear stress) are verified and compared to strength limits under fire conditions (see **Equation (7-18)** and **Equation (7-19)**).

$$\sigma_{i,fi} = \frac{M_{fi} \cdot E_i}{EI_{eff,CLT,fi}} \cdot \left(\frac{1}{2} \cdot \Delta h_i + a_{i,fi} \cdot \gamma_{i,fi} \right) \quad (7-18)$$

$$\tau_{xz,i,fi} = V_{fi} \cdot \frac{\sum_{i=1}^n \gamma_{i,fi} \cdot E_i \cdot A_i \cdot a_{i,fi}}{EI_{eff,CLT,fi} \cdot b_2} + V_{fi} \cdot \frac{E_2 \cdot b_2 \cdot \frac{h_2^2}{8}}{EI_{eff,CLT,fi} \cdot b_2} \quad (7-19)$$

7.1.8 Estimation of sound insulation properties

The evaluation of sound insulation properties of CLT panels, namely the footfall sound insulation and the airborne sound insulation, is pretty complicated. If the achievement of precise results is needed, laboratory tests are mandatory to determine these qualities. They are usually performed on already complete floor construction packages (also including screeds, footfall insulation, etc.). Because this thesis revolves around establishing what the structural core of a CLT panel floor construction can do on its own, no complex calculations were performed. Instead, an empiric approach to determine both the footfall and airborne sound insulation values of the bare CLT panel is used. This gives us very rough, imprecise information, which allows a quick evaluation of this given panel's sound insulation capabilities. These approaches all base on the CLT panel weight per

square meter (m'). The following **Equation (7-20)** describes an empiric approach for determining the equivalent footfall sound insulation, which basically is the starting point for the total footfall sound insulation determination. According to [97, p. 13] and [98, p. 6], this approach is valid for panels of 140 mm – 275 mm thickness (for further details see [98]) or panels with mass per unit area between 35 kg/m² – 130 kg/m² (see [97]). Given the density of timber sitting at 350 kg/m³, the ranges are more or less coincident.

$$L_{n,w,eq,CLT} = 128 - 22 \cdot \log_{10}(m'_{CLT}) \quad [dB] \quad (7-20)$$

Another similar approach that defines the airborne sound insulation of CLT panels is present in [97, p. 13] (see **Equation (7-21)**); this formula has the same range of validity as stated in the paragraph before. Another empiric approach for CLT panels as floor construction is provided by *Stora Enso* [99, p. 8] and listed in **Equation (7-22)**.

$$R_{w,eq,CLT} = 20,3 \cdot \log_{10}(m'_{CLT}) \quad [dB] \quad (7-21)$$

$$R_{w,eq,CLT} = 12,2 \cdot \log_{10}(m'_{CLT}) + 15 \quad [dB] \quad (7-22)$$

Since these formulas are approximative, their results should be taken as estimated values and treated accordingly. Therefore, to obtain the equivalent impact sound insulation $L_{n,w,eq}$ of the CLT panels as structural core **Equation (7-20)** is applied. If a concrete screed, which obviously positively contributes to insulation qualities, the results are expanded by adding the additional mass of the concrete screed in the logarithms part of **Equation (7-20)**. The minimal value of **Equation (7-21) and Equation (7-22)** is implemented in the approach.

7.1.9 Obtaining valid results

At the end of the calculation process, plenty of matrices are obtained, every one of them characterised by its underlying parameters: loading conditions for each span, implemented duration of fire exposure (either R30, R60 or R90) as well as the loosely connected concrete screed placed on top of the CLT panel. The table solely contains combinations between span, loading conditions and panel dimensions that fulfil the verifications explained in **chapter 7.1.5, chapter 7.1.6 and chapter 7.1.7**, respectively. If other combinations do not satisfy any of the verifications contained in the just mentioned chapters, they are automatically eliminated from the table and thus do not appear in the pre-dimensioning table itself; no matter if it is a ULS, SLS or dimensioning under fire conditions.

7.2 TCC floor with screws as shear connectors

Composite floors exploit the combined action of steel and concrete while using both materials to their strengths. Thus, obtaining more capable and economic structures has been used for several years. Since floor construction consisting of regular CLT panels are limited in span (usually due to serviceability limit state requirements), the idea of a material combination with concrete arose some years back. In steel-concrete-composite (STC) floors, the composite action is achieved by connecting both materials via shear connectors; in timber-concrete-floors, the same happens. The result is a floor able to carry significant loads on longer spans while also being less sensitive to vibrations due to its increased sectional stiffness while also having a reduced section depth. This floor type is more performant than its counterpart analysed in **chapter 7.1**. Compared to reinforced concrete slabs, TCC slabs also have several advantages: reduced self-weight due to lesser concrete volume needed, building time reductions due to the usage of prefabricated elements and no need of formworks [84, p. 17]. This means that a TCC floor or beam is a successful mix between timber and concrete, as it uses both materials to their relative strength and beyond. **Figure 7-4** shows a section through a typical TCC floor, consisting of a CLT panel and a concrete slab placed on top. Commonly, this construction type is applied to one-way spanned floors because it allows optimal utilization of the concrete topping under compression while the timber is under tension. Now, the so crucial total bending stiffness is achieved by screws placed in an angle of 45°; they normally are placed into predrilled holes in the CLT panel and ensure composite action as soon as the concrete layer on top has reached its full strength. The shear connectors are subject to shear forces along the “gap” between timber and concrete because, under load-deformation, both materials would have different deformational behaviour (see **Figure 6-1**). They also prevent the concrete slab from uplifting under the same deformation.

The author used two main documents to develop the pre-dimensioning tool for timber concrete floor constructions: the first is a report of state of the art in terms of construction practice and research by Dias et al. and named “Design of timber-concrete composite structures” [84]. The second document is the future European normative for TCC structures titled “Eurocode 5: Design of Timber Structures – Structural design of timber-concrete composite structures – Common rules and rules for buildings” [89] by the European Committee for Standardization (CEN). The elaborating team responsible for the Eurocode 5 is named CEN/TC 250/SC 5/WG 2, which is part of the “Structural Eurocodes” department of the CEN. Since the 17th of February 2020, this document is in the approval phase, which will last until the 1st of April 2021 [100].

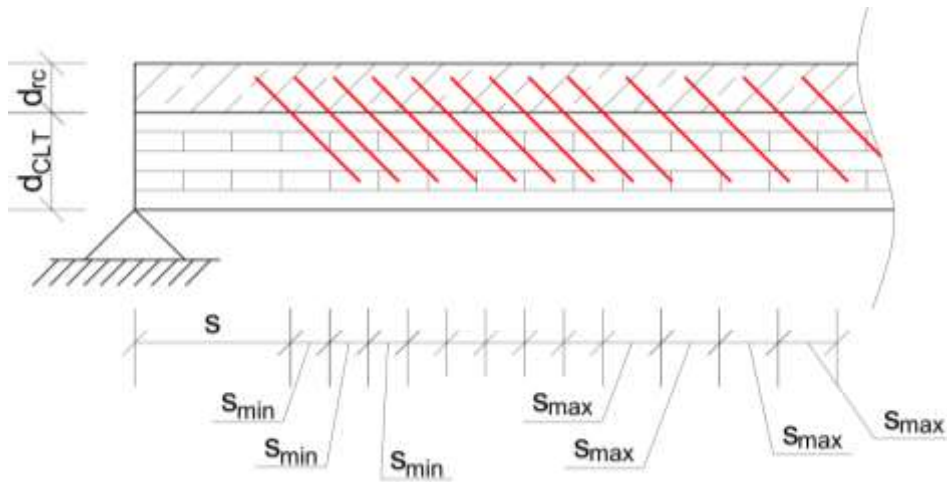


Figure 7-4: Schematic drawing for TCC floors with screws ($\alpha = 45^\circ$) as shear connectors

Because of the time-dependant behaviour of the materials timber and concrete, [84, pp. 108-110] states that the following three periods of time have to be considered during the design process of TCC beams or floor (see **Figure 7-5**):

- 1) “ $t=0$ ” is the moment at which the concrete has reached its strength (or most of it), but no shrinkage and creep have taken place yet because the concrete is “young”.
- 2) “ $t=\infty$ ” which is the moment the creep and shrinkage in concrete have reached a plateau.
- 3) “ $t=3-7$ years” is a sort of mid-period, which needs to be considered because between years 3 and 7, the concrete section creeps faster than the timber section. After that period of time, concrete doesn’t creep as much while timber keeps creeping (around 40% of its total strain).

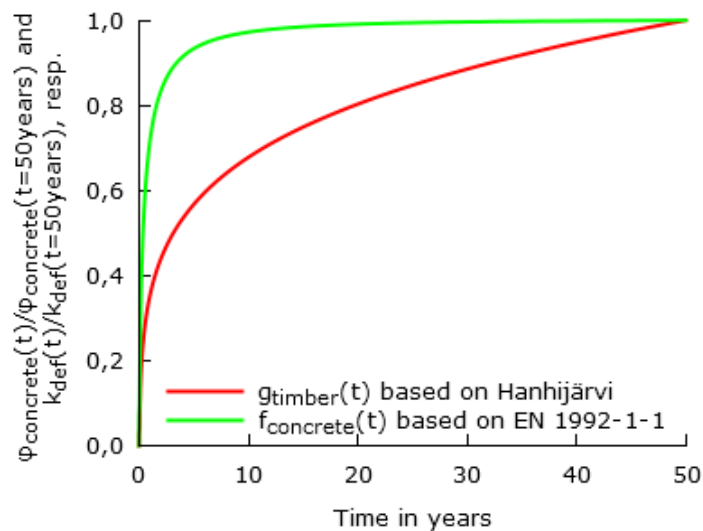


Figure 7-5: Creep strain development over time [84, p. 109]

Because of the time-dependent behaviour shown in Figure 7-5, the ratio between timber stiffness and concrete stiffness reaches a maximum at the time “ $t=3-7$ years” (see **Figure 7-6**). This has an influence on the bending moment as well as on the internal section forces [84, p. 109].

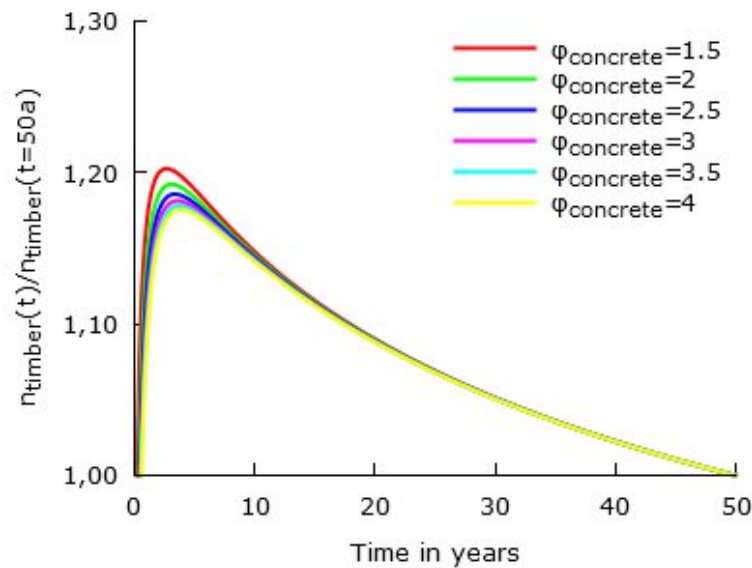


Figure 7-6: Ratio timber and concrete stiffness development over time [84, p. 109]

Therefore, it is difficult to establish which point in time is the most relevant for the TCC section. The pre-dimensioning tool implements the verification of all of them. Dias et al. performed a case study to establish whether the verification of this additional time was necessary or not; the answer is negative because no existing building had a failure during this time. Typically, the SLS requirements are the decisive ones. This does not apply to situations where deformations can be neglected, i.e., for agricultural buildings [84, pp. 110-111]. In this regard, the draft normative [89] establishes that further design stages should be considered except when the higher stress in timber at “t=0” or “t=∞” due to the quasi-permanent load combination is increased by 25%, but ULS is still fulfilled in the timber section (see 7.1.2 (4) in [89, p. 27]). The pre-dimensioning tool contains all three of the periods mentioned above since the additional effort is considered manageable by the author.

The long-term behaviour of concrete and its implication for the load-carrying capacity of the TCC section need to be considered; because of drying over time, concrete creeps and shrinks, resulting in additional eigenstresses in the section. Creeping and shrinking is evaluated according to formulas provided in **chapter 3.1.2** and Annex B of EN 1992-1-1 [101]. The detailed calculation is not reported in the form of equations but is visible in the attached design of a TCC floor construction. Also, the timber elements are subject to shrinking or swellings because of humidity variations. [25, p. 28] Since the floor constructions for which this pre-dimensioning tool is conceived are in the building itself, moisture levels were considered constant over time, thus purposely not considering eigenstress resulting from changes in the relative humidity. These facts need to find a place during the design process, making it more demanding for the projecting engineer.

7.2.1 Material strengths and safety factors

In regard to the material strength of timber, the same material is used as described in **Table 13**. Concerning concrete, the following strength parameters are used (see **Table 23**).

Material Strength for Concrete C 50/60		Strength Value
[-]		[N/mm ²]
Compressive strength (cubic specimen)	$f_{c,k}$	50,0
Compressive strength (cylindrical specimen)	$f_{c,k}$	60,0
Mean value of compressive strength (cubic specimen)	$f_{c,m}$	58,0
Tensional strength	f_{ctm}	5,3
Creep coefficient	φ	2,5
E-Modulus	$E_{tim,t0}$	37000
Density		Value
[-]		[kg/m ³]
Characteristic density	ρ_k	2400

Table 23: Concrete strength parameters at “t=0”

As previously mentioned in **chapter 7.2**, timber and concrete's time-dependent behaviour and strength over time have to be considered. In this regard, [89, p. 27] contains “modification of creep coefficients for composite action in-slab systems and beam systems” (Table 7.1 in [89]). A similar evaluation to **Table 24** is elaborated by Dias et al. (see Table 13 in [84, p. 122]).

	for “t=inf”	for “t=3-7 years”
Concrete, $\varphi=3,5$:		
and $k_{def} = 0,6$	$\psi_{conc.fin} = 2,6 - 0,8 \cdot \gamma_1^{1,2}$	$\psi_{conc.mid} = 2,5 - \gamma_1^{1,1}$
and $k_{def} = 0,8$	$\psi_{conc.fin} = 2,3 - 0,5 \cdot \gamma_1^{2,6}$	$\psi_{conc.mid} = 2,2 - 0,8 \cdot \gamma_1^{1,2}$
Concrete, $\varphi=2,5$:		
and $k_{def} = 0,6$	$\psi_{conc.fin} = 2,0 - 0,5 \cdot \gamma_1^{1,9}$	$\psi_{conc.mid} = 2,5 - 0,6 \cdot \gamma_1^{1,1}$
and $k_{def} = 0,8$	$\psi_{conc.fin} = 1,8 - 0,3 \cdot \gamma_1^{2,5}$	$\psi_{conc.mid} = 1,7 - 0,5 \cdot \gamma_1^{1,1}$
Timber:		
all cases	$\psi_{tim.fin} = 1,0$	$\psi_{tim.mid} = 0,5$
Connection:		
all cases	$\psi_{conn.fin} = 1,0$	$\psi_{conn.mid} = 0,65$

Table 24: Modification of creep coefficients [89, p. 27]

The gamma factor contained in **Table 24** is calculated using **Equation (6-2)**; generally speaking, the TCC section is calculated using the gamma method, which is illustrated in **Equation (6-1)** to **Equation (6-3)** for a t-shaped section with two materials. Other methods such as the differential equation method or the shear analogy method may as well be used to calculate the resulting bending stiffness for the required time points. These modified creep coefficients of **Table 24** are then used to reduce the strength parameters according to the following formulas (see [89, p. 21]):

$$E_{rc.fin} = \frac{E_{rc}}{1 + \psi_{conc.fin} \cdot \varphi(\infty, t_0)} \quad E_{rc.mid} = \frac{E_{rc}}{1 + \psi_{conc.mid} \cdot \varphi(\infty, t_0)} \quad (7-23)$$

$$E_{tim.fin} = \frac{E_{CLT}}{1 + \psi_{tim.fin} \cdot k_{def}} \quad E_{tim.mid} = \frac{E_{CLT}}{1 + \psi_{tim.mid} \cdot k_{def}} \quad (7-24)$$

$$K_{ser.fin} = \frac{K_{ser}}{1 + \psi_{conn.fin} \cdot k_{def}'} \quad K_{ser.mid} = \frac{K_{ser}}{1 + \psi_{conn.mid} \cdot k_{def}'} \quad (7-25)$$

$$K_{u.fin} = \frac{K_u}{1 + \psi_{conn.fin} \cdot k_{def}'} \quad K_{u.mid} = \frac{K_u}{1 + \psi_{conn.mid} \cdot k_{def}'} \quad (7-26)$$

The modification factors k_{mod}' and k_{def}' are calculated using the following Equations:

$$k_{mod}' = \sqrt{k_{tc} \cdot k_{mod}} \quad (7-27)$$

$$k_{def}' = 2 \cdot k_{def} \quad (7-28)$$

7.2.2 Shear connectors

As the title of this chapter suggests, screws are used as shear connectors. In order to produce a realistic approach, the pre-dimensioning tool has an implemented real set of screws, namely ASSY plus VG screws by WÜRTH. The position and angle of the screws that act as a connection between timber and concrete are sketched in **Figure 7-4**. Details regarding the screw strength, as well as the slip modulus for serviceability (for K_{ser} see **Equation (7-29)**) contained in the relative ETA approval document [102]. The slip modulus depends on the screw diameter and the thread length in timber which the author defines as 200 mm [102, p. 10].

$$K_{ser} = 100 \cdot l_{ef} \text{ (per shear connector)} \quad (7-29)$$

ASSY plus VG screw orientation	FRk in N	
	With interlayer	Direct contact between timber and concrete
$\alpha = 90^\circ$	$f_{h,2,k} \cdot d \cdot t \left[\sqrt{1 + \frac{4 \cdot M_{y,k}}{f_{h,2,k} \cdot d \cdot t^2} + \frac{f_{h,1,k}}{2 \cdot f_{h,2,k}}} - 1 \right]$	$\sqrt{4 \cdot M_{y,k} \cdot f_{h,2,k} \cdot d}$
$\alpha = 30^\circ$ or $\alpha = 45^\circ$	$(\cos \alpha + \mu \cdot \sin \alpha) \cdot \min \left\{ \begin{array}{l} F_{ax,\alpha,Rk} \\ f_{tens,k} \end{array} \right.$	
where:		
FRk	is the characteristic load-carrying capacity per ASSY plus VG screw in N;	
t	is the interlayer thickness in mm;	
t _b	is the interlayer batten thickness in mm; the interlayer batten consists of timber or wood-based panels with a maximum width of 40 mm and a maximum thickness of 50 mm (only for prefabricated concrete members in combination with the FT-Connector and setting the screws after hardening of the concrete);	
f _{h,1,k}	is the characteristic embedment strength in the interlayer in MPa;	
f _{h,2,k}	is the characteristic embedment strength in the timber member in MPa;	
d	is the ASSY plus VG screw diameter in mm;	
M _{y,k}	is the characteristic fastener yield moment in Nmm;	
F _{ax,α,Rk}	is the characteristic withdrawal capacity in N; $F_{ax,\alpha,Rk} = \frac{f_{ax,k} \cdot d \cdot \ell_{ef}}{1,2 \cdot \cos^2 \alpha + \sin^2 \alpha} \cdot \left(\frac{\rho_k}{350} \right)^{0,8}$	
ℓ _{ef}	is the penetration depth of the ASSY plus VG screw in the timber member in mm; for concrete flanges loaded in tension, the value taken into account for ℓ _{ef} shall be limited to 110 mm for 8 mm screws and to 170 mm for 10 mm screws	
ρ _k	is the characteristic timber member density in kg/m ³ ;	
μ	Friction coefficient; for direct contact between timber and concrete μ = 0,25; otherwise μ = 0.	

Table 2.4 – Properties of ASSY plus VG screws

ASSY plus VG screw	d = 8 mm	d = 10 mm
Yield moment M _{y,k} [Nm]	20	36
Tensile capacity f _{tens,k} [kN]	17	32
Withdrawal parameter f _{ax,k} [N/mm ²]	11	10

Figure 7-7: Values of FRk for timber-concrete-joints with ASSY plus VG screws [102, p. 11]

Thanks to the empirical formulas provided by ETA 13/0029 and visualized in Figure 7-7, the load-carrying capacity F_{Rk} of screws as shear connectors has been calculated. If another screw type or brand would have been used, other empirical formulas needed to be applied. In the absence of strengths and slip moduli provided by the producing company, Table 7.1 in EN 1995-1-1 [82, p. 71] supplies designing engineers with the following equations:

Slip modulus for dowels, bolts, screws, and nails (with predrilling):

$$K_{ser} = 2 \cdot \frac{\rho_m^{1,5} \cdot d}{23} \text{ (per shear connector)} \quad (7-30)$$

Slip modulus for nails (without predrilling):

$$K_{ser} = 2 \cdot \frac{\rho_m^{1.5} \cdot d^{0.8}}{30} \text{ (per shear connector)} \quad (7-31)$$

Equation (2.1) in EN 1995-1-1 [82, p. 28] defines that the slip modulus for the ultimate limit state (ULS) is calculated as follows:

$$K_u = \frac{2}{3} \cdot K_{ser} \text{ (per shear connector)} \quad (7-32)$$

The load-carrying capacity F_{Rk} calculated with **Equation (7-33)** is based on the Johansen models for timber-to-timber connections in single shear also contained in Equation (8.6) of EN 1995-1-1.

$$f_{c,h.2.k} = 3 \cdot f_{ck} \text{ (per shear connector)} \quad (7-33)$$

7.2.3 Determination of external loads

Because a comparative approach is critical for the elaboration of this pre-dimensioning tool, the applied external loads (dead loads and imposed loads) are the same as described and calculated in **chapter 7.1.2**. In addition to the CLT panel dead load, the concrete topping self-weight is considered in the dead loads. For more details, see **Table 16**, **Table 17** and **Table 18**.

7.2.4 Determination of internal loads

In **chapter 7.2**, the time-dependent behaviour of concrete is discussed. Concrete shrinkage happens because water is bound in the material matrix, reducing the total concrete volume during the hardening process. This causes a shortening of the concrete slab, which in statically determined systems results in deformations, while in statically undetermined systems, this shortening causes deformations and stresses [84, p. 74]. Generally speaking, forces acting on the materials composing the section are distributed according to their bending stiffness. This force distribution is visible in the following formulas. **Figure 7-8** illustrates how concrete shrinking restrain results in an additional vertical deformation (very similar to the one caused by a vertical distributed load) while timber shrinkage has the opposite effect as it causes a negative deflection.

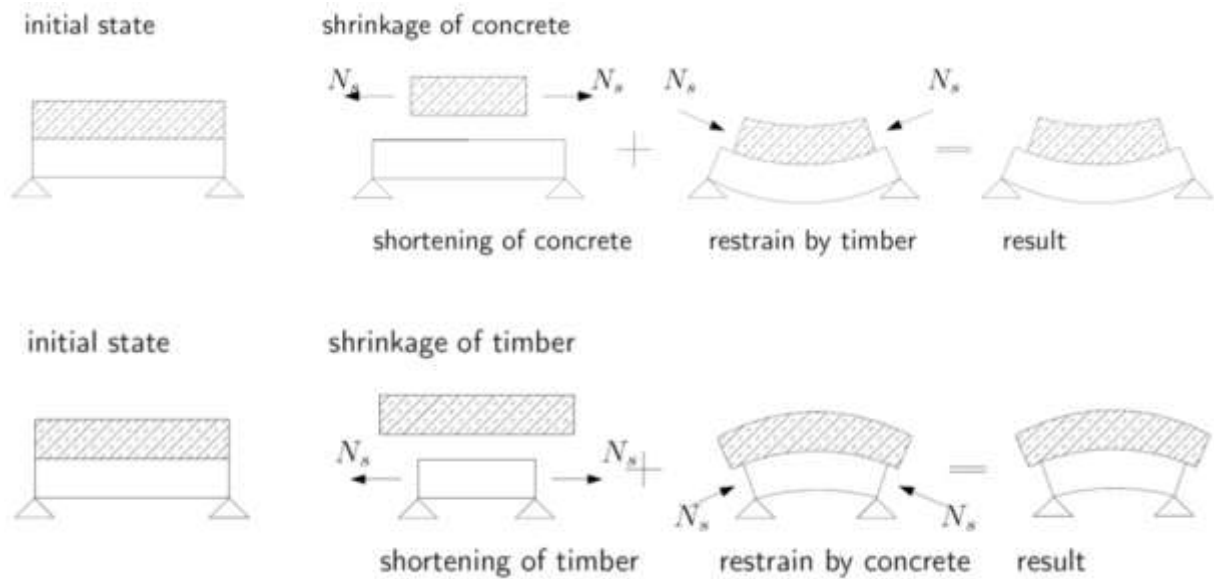


Figure 7-8: Repercussions of concrete and timber shrinkage on a TCC floor or beam [84, p. 75]

The future normative concerning TCC beams and floors [84, p. 49] contains approaches to calculate fictitious vertical loads caused by concrete shrinkage or timber shrinkage.

$$p_{SLS.t0} = C_{p.SLS} \cdot \Delta\varepsilon \quad (7-34)$$

$$C_{p.SLS.t0} = \pi^2 \cdot \frac{E_{rc} \cdot A_{rc} \cdot E_{tim} \cdot A_{CLT} \cdot Z \cdot \gamma_1}{(E_{rc} \cdot A_{rc} \cdot E_{tim} \cdot A_{CLT}) \cdot L^2} \quad (7-35)$$

$$\Delta\varepsilon_{ef.conc} = \varepsilon_2 - \varepsilon_1 \quad (7-36)$$

Equation (7-36) describes the different inelastic strain between material one and material two. A high $\Delta\varepsilon$ -value causes a high fictitious load, which needs to be added to the external loads determined in **chapter 7.2.3**. The TCC normative [89, p. 50] provides the projecting engineer with a set of formulas for calculating the inelastic strain caused by different situations, namely concrete shrinkage (see **Equation (7-39)** to **Equation (7-41)**), timber swelling or shrinkage (see **Equation (7-38)**) as well as temperature differential (see **Equation (7-37)**). These formulas are listed as follows:

$$\Delta\varepsilon = \alpha_{i.T} \cdot \Delta T_{U.i.calc} \quad (7-37)$$

$$\varepsilon_2 = \alpha_{T.U} \cdot \Delta m_{calc} \quad (7-38)$$

$$\varepsilon_{ef.conc}(t = t_0) = 0 \quad (7-39)$$

$$\varepsilon_{ef.conc}(t = 3 \text{ to } 7 \text{ years}) = 0.6 \cdot \varepsilon_{conc} \quad (7-40)$$

$$\varepsilon_{ef.conc}(t = \infty) = 0.9 \cdot \varepsilon_{conc} \quad (7-41)$$

The required equations, parameters, and coefficients necessary to determine the value of ε_{conc} , which corresponds to the end-value of concrete shrinkage, are contained in EN 1992-1-1 (Annex B as well as Equations (3.8) to (3.13)). The detailed calculation is listed in the coming up figure.

$$f_{cm} = 53 \frac{N}{mm^2} \quad (C 45/55)$$

$$\alpha_{ds1} = 3 \quad \alpha_{ds2} = 0.13 \quad (\text{Cement Class S})$$

$$\beta_{RH} := 1.55 \cdot \left(1 - \left(\frac{RH}{100}\right)^3\right) = 1.356 \quad (\text{Formula B.12})$$

$$\varepsilon_{ct,0} := 0.85 \cdot \left((220 + 110 \cdot \alpha_{ds1}) \cdot \exp\left(\frac{f_{cm}}{f_{cm,0}} \cdot -\alpha_{ds2}\right) \right) \cdot 10^{-6} \cdot \beta_{RH} = 3.183 \cdot 10^{-4} \quad (\text{Formula B.11})$$

$$k_h = 0.85 \quad (\text{Tab 3.3 in EN 1992-1-1})$$

$$\beta_{ds,fin} := \frac{t_{fin} - t_s}{(t_{fin} - t_s) + 0.04 \cdot \sqrt{\left(\frac{h_0}{mm}\right)^2}} = 0.994 \quad (\text{Formula 3.10 in EN 1992-1-1})$$

$$\varepsilon_{ct,fin} := \beta_{ds,fin} \cdot k_h \cdot \varepsilon_{ct,0} = 2.689 \cdot 10^{-4} \quad (\text{Formula 3.9 in EN 1992-1-1})$$

$$\beta_{as,fin} := 1 - \exp(-0.2 \cdot t_{fin}^{0.5}) = 1 \quad (\text{Formula 3.13 in EN 1992-1-1})$$

$$\varepsilon_{ca} := 2.5 \cdot \left(\frac{f_{ck}}{N/mm^2} - 10\right) \cdot 10^{-6} = 8.75 \cdot 10^{-5} \quad (\text{Formula 3.12 in EN 1992-1-1})$$

$$\varepsilon_{ca,fin} := \beta_{as,fin} \cdot \varepsilon_{ca} = 8.75 \cdot 10^{-5} \quad (\text{Formula 3.11 in EN 1992-1-1})$$

$$\varepsilon_{cs,fin} := \varepsilon_{ca,fin} + \varepsilon_{ct,fin} = 3.564 \cdot 10^{-4} \quad (\text{Formula 3.8 in EN 1992-1-1})$$

End value of shrinkage of concrete according to EN 1992-1-1

Figure 7-9: Determination of shrinkage of concrete C45/55 for "t=∞"

$$h_0 := \frac{2 \cdot A_{rc}}{\text{width}} = 200 \text{ mm} \quad (\text{Formula B.6})$$

$$\beta_{f_{cm}} := \frac{16.8}{\sqrt{f_{cm}}} \cdot \sqrt{\frac{N}{\text{mm}^2}} = 2.308 \quad (\text{Formula B.4})$$

$$\beta_{t_0} := \frac{1}{(0.1 + t_0^{0.2})} = 0.635 \quad (\text{Formula B.5})$$

$$\alpha_1 := \left(\frac{35 \frac{N}{\text{mm}^2}}{f_{cm}} \right)^{0.7} = 0.748 \quad \alpha_2 := \left(\frac{35 \frac{N}{\text{mm}^2}}{f_{cm}} \right)^{0.2} = 0.92 \quad \alpha_3 := \left(\frac{35 \frac{N}{\text{mm}^2}}{f_{cm}} \right)^{0.5} = 0.813$$

(Formula B.8c)

$$\varphi_{RH} := \begin{cases} \text{if } f_{cm} \leq 35 \frac{N}{\text{mm}^2} \\ \left| 1 + \frac{1 - \frac{RH}{100}}{0.1 \cdot \sqrt[3]{\frac{h_0}{\text{mm}}}} \right| \end{cases} = 1.509 \quad (\text{Formula B.3a})$$

$$\left| \begin{cases} \text{else} \\ \left(1 + \frac{1 - \frac{RH}{100}}{0.1 \cdot \sqrt[3]{\frac{h_0}{\text{mm}}}} \right) \cdot \alpha_2 \end{cases} \right| \quad (\text{Formula B.3b})$$

$$\varphi_0 := \varphi_{RH} \cdot \beta_{f_{cm}} \cdot \beta_{t_0} = 2.21 \quad (\text{Formula B.2})$$

$$\beta_H := \begin{cases} \text{if } f_{cm} \leq 35 \frac{N}{\text{mm}^2} \\ \left| \min \left(1.5 \left(1 + (0.012 \cdot RH)^{18} \right) \cdot \frac{h_0}{\text{mm}} + 250, 1500 \right) \right| \end{cases} = 503.189 \quad (\text{Formula B.8a})$$

$$\left| \begin{cases} \text{else} \\ \left| \min \left(1.5 \left(1 + (0.012 \cdot RH)^{18} \right) \cdot \frac{h_0}{\text{mm}} + 250 \cdot \alpha_3, 1500 \cdot \alpha_3 \right) \right| \end{cases} \right| \quad (\text{Formula B.8b})$$

$$\beta_{c,t,t_0} := \left(\frac{t_{fin} - t_0}{(\beta_H + t_{fin} - t_0)} \right)^{0.3} = 0.992 \quad (\text{Formula B.7})$$

$$\varphi_{t,t_0} := \varphi_0 \cdot \beta_{c,t,t_0} = 2.192 \quad (\text{Formula B.1})$$

Figure 7-10: Determination of creep coefficient of C45/55 for “t=∞”

Figure 7-10 demonstrates how the creep coefficient is determined for C45/55. Since **Table 24** just contains two possible creep coefficients, the formulas related to the closest one ($\varphi = 2.5$) are used for calculating the time dependant behaviour of concrete. According to Table 7.1 in [89, p. 27], linear interpolation can be used for different creep coefficients of timber, but it is not explained how this interpolation shall work, since based on the creep coefficient, other equations are used to determine $\psi_{conc.fin}$ and $\psi_{conc.mid}$. Therefore, no interpolation is undertaken, and the next closest creep coefficient is used.

7.2.5 Creation of sections

Since one of the scopes of this thesis is to create a consistent analysis and pre-dimensioning tool for massive floor construction and compare the obtained results, the CLT panels that were implemented in the analysis of bare CLT panels floors (see **chapter 7.1**) are again used here. The difference lies in the concrete layer's presence placed on top of the CLT panel, which helps in the load-carrying mechanism (composite action). The author handpicked three different screed depths to produce a more variegated and thus realistic approach: 8 cm, 10 cm, and 12 cm. The idea behind this choice is the following: realistically, a CLT panel producer may offer panels in his catalogue and cast concrete on top of them when a TCC floor solution is required. See **chapter 7.1.4** for a more in-depth explanation of which section types are implemented and how they were computed.

7.2.6 Calculation of gamma factors and resulting bending stiffness

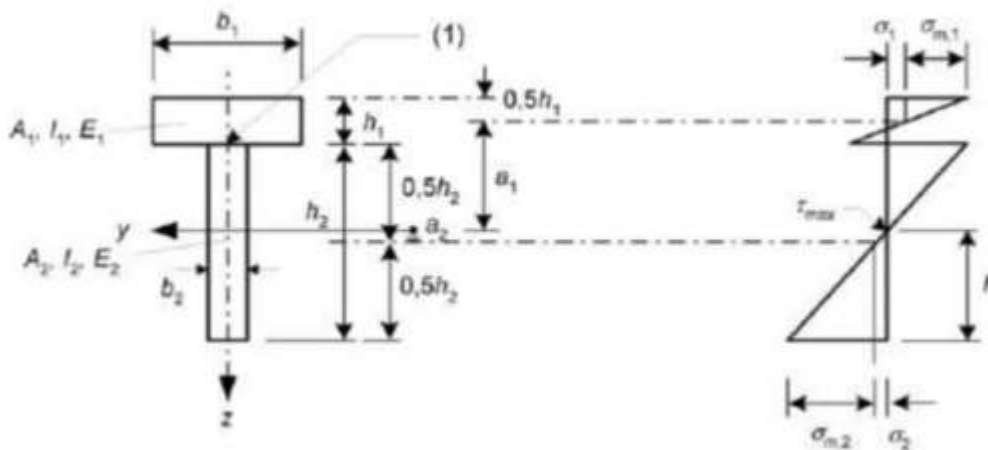


Figure 7-11: Composite section and related stress distribution in a bi-area section [82, p. 163]

After taking over the panels from **chapter 7.1**, their effective stiffness ($EI_{eff,CLT}$) is automatically taken over as well. These properties, along with the panel area (just the lamellas parallel to span), are attributed to section 2 in **Figure 7-11**, while section 1 in the same figure represents the concrete screed. In our case, both sections have the same width of one meter because we are designing TCC floors. The gamma factor differs depending on the analysed limit state (ULS or SLS); it represents the composite action between section one and two, namely between concrete and timber and in the case of screws as shear connectors is calculated with **Equation (7-42)** and **Equation (7-43)** also present in [82, p. 164].

$$\gamma_{1,t0,ser} = \frac{1}{1 + \pi^2 \cdot \frac{E_{rc} \cdot A_{rc} \cdot s_{i,eff}}{n_{vbm} \cdot K_{ser} \cdot l^2}} \quad (7-42)$$

$$\gamma_{1,t0,u} = \frac{1}{1 + \pi^2 \cdot \frac{E_{rc} \cdot A_{rc} \cdot s_{i,eff}}{n_{vbm} \cdot K_u \cdot l^2}} \quad (7-43)$$

In the formulas above, n_{vbm} is the number of shear connectors per meter width (until the symmetry axis located at mid-span) while $s_{i,eff}$ represents the effective spacing between shear connectors that are distanced according to the shear force distribution along the floor (densifying distancing closer to the support, where the shear force is the highest). This effective spacing is defined by the now following **Equation (7-44)**, also present in EN 1995-1-1 [82, p. 136]. Obviously s_{min} represents the minimum spacing while s_{max} the maximum spacing.

$$s_{i,eff} = 0.75 \cdot s_{min} + 0.25 \cdot s_{max} \quad (7-44)$$

In a bi-area section such as the one we tractate here, the composite factor for section two (γ_2) will always be equal to one at any point in time. The distances a_1 and a_2 between partial sections one and two to the section centroid (see **Figure 7-11**) are calculated according to Equation (6-3), with the principal difference that section three is non-existent and therefore equal to zero. After all these considerations concerning composite TCC floors with screws as shear connectors, the total sectional bending stiffnesses for ULS, SLS and “t=0” conditions can be determined as follows:

$$EI_{eff.t0.u} = E_{rc} \cdot I_{rc} + EI_{eff.CLT} + E_{rc} \cdot A_{rc} \cdot \gamma_{1.u} \cdot a_{1.t0.u}^2 + E_0 \cdot A_{CLT} \cdot \gamma_{2.u} \cdot a_{2.t0.u}^2 \quad (7-45)$$

$$EI_{eff.t0.ser} = E_{rc} \cdot I_{rc} + EI_{eff.CLT} + E_{rc} \cdot A_{rc} \cdot \gamma_{1.ser} \cdot a_{1.t0.ser}^2 + E_0 \cdot A_{CLT} \cdot \gamma_{2.ser} \cdot a_{2.t0.ser}^2 \quad (7-46)$$

Since the future TCC Eurocode [89] requires designing engineers to analyse the time dependant behaviour of the floor construction, the total sectional bending stiffness needs to be determined for the other necessary moments, namely “t=∞” and “t=3-7 years”. Therefore, the whole procedure displayed in **Equation (7-42)** to **Equation (7-46)** as well as **Equation (6-3)** need to be repeated for these two points in time. To avoid unnecessary repetitions, solely the formulas to calculate the bending stiffness for these additional points in time are here cited.

$$EI_{eff.fin.u} = E_{rc.fin} \cdot I_{rc} + EI_{eff.CLT.fin} + E_{rc.fin} \cdot A_{rc} \cdot \gamma_{1.u.fin} \cdot a_{1.fin.u}^2 + E_{CLT.fin} \cdot A_{CLT} \cdot \gamma_{2.u.fin} \cdot a_{2.fin.u}^2 \quad (7-47)$$

$$EI_{eff.fin.ser} = E_{rc.fin} \cdot I_{rc} + EI_{eff.CLT.fin} + E_{rc.fin} \cdot A_{rc} \cdot \gamma_{1.ser.fin} \cdot a_{1.fin.ser}^2 + E_{CLT.fin} \cdot A_{CLT} \cdot \gamma_{2.ser.fin} \cdot a_{2.fin.ser}^2 \quad (7-48)$$

$$EI_{eff.mid.u} = E_{rc.mid} \cdot I_{rc} + EI_{eff.CLT.mid} + E_{rc.mid} \cdot A_{rc} \cdot \gamma_{1.u.mid} \cdot a_{1.mid.u}^2 + E_{CLT.mid} \cdot A_{CLT} \cdot \gamma_{2.u.mid} \cdot a_{2.mid.u}^2 \quad (7-49)$$

$$EI_{eff.mid.ser} = E_{rc.mid} \cdot I_{rc} + EI_{eff.CLT.mid} + E_{rc.mid} \cdot A_{rc} \cdot \gamma_{1.ser.mid} \cdot a_{1.mid.ser}^2 + E_{CLT.mid} \cdot A_{CLT} \cdot \gamma_{2.ser.mid} \cdot a_{2.mid.ser}^2 \quad (7-50)$$

Six different bending stiffnesses are to be used for verifications, depending on the point in time and the necessary verification. Quite some effort goes into the determination of resulting bending stiffnesses and attribution to the right situation. The future TCC Eurocode [89, p. 50] requires multiplying the resulting bending stiffness with a coefficient $C_{J,sls}$ that expresses the interaction between vertical load and inelastic strain. This factor is determined with **Equation (7-51)**.

$$C_{J,sls} = \frac{p_{sls} + q_d}{\frac{E_{rc} \cdot A_{rc} + E_{tim} \cdot A_{CLT}}{\gamma_1 \cdot E_{rc} \cdot A_{rc} \cdot E_{tim} \cdot A_{CLT}} \cdot p_{sls} + q_d} \quad (7-51)$$

The expression q_d refers to the external load in either a ULS or SLS configuration. As mentioned in the previous paragraph, this coefficient $C_{J,sls}$ needs to be separately determined for all three points in time (“t=0”, “t=∞” and “t=3-7 years”) and multiplied with the related bending stiffness (see **Equation (7-52)** and **Equation (7-53)**). Again, the quoting of these formulas for “t=∞” and “t=3-7 years” is seen as unnecessary but shall not be forgotten during the design process.

$$(EI)_{ef.sls.t0.u} = C_{J,sls.t0.u} \cdot EI_{eff.t0.u} \quad (7-52)$$

$$(EI)_{ef.sls.t0.ser} = C_{J,sls.t0.ser} \cdot EI_{eff.t0.ser} \quad (7-53)$$

7.2.7 ULS verification

The now calculated resulting panel bending stiffnesses are then used for the ULS verification of lamella normal stresses and shear stresses. The future TCC Eurocode [89, p. 52] provides an equation to determine the following loads:

- 1) Bending moments in the concrete slab
- 2) Bending moments in the timber slab
- 3) Normal force in the concrete slab
- 4) Normal force in the timber slab
- 5) Shear force in the concrete slab
- 6) Shear force in the timber slab
- 7) Shear force in the connection due to shrinkage

The resulting moment (caused by the external forces and 80% of the fictitious load caused by inelastic restraint) is subdivided on the concrete and timber section basing on the proportion between the sections own bending stiffness and the total bending stiffness (see **Equation (7-54)** and **Equation (7-55)**). These resulting moments have again to be worked out for “t=∞” and “t=3-7 years” but are not quoted here.

$$M_{1.t0.u} = \frac{E_{rc} \cdot I_{rc}}{EI_{eff.t0.u}} \cdot M(q_d + 0,8 \cdot p_{sls}) \quad (7-54)$$

$$M_{2.t0.u} = \frac{E_{CLT} \cdot I_{CLT}}{EI_{eff.t0.u}} \cdot M(q_d + 0,8 \cdot p_{sls}) \quad (7-55)$$

The resulting axial force (caused by the difference of external moment and attributed moment to the section) is again subdivided based on the proportion between the sections own bending stiffness and the total bending stiffness (see **Equation (7-56)** and **Equation (7-57)**). These resulting normal forces have again to be worked out for “t=∞” and “t=3-7 years” but are not quoted here, as it is seen as unnecessary.

$$N_{1.t0.u} = \frac{M(q_d) - \sum_{i=1}^2 M_{1.t0.u}}{z} \quad (7-56)$$

$$N_{2.t0.u} = \frac{M(q_d) - \sum_{i=1}^2 M_{2.t0.u}}{z} \quad (7-57)$$

Both these stresses are carried by lamellas parallel to the span or the concrete section. The following formula, obtained from [84, p. 150], were used to calculate normal stresses. In a one-way spanned floor construction, the highest normal stress because of moments causes compression in the upper lamellas. It causes tension in the lower lamellas and tension on the lower edge of the concrete and compression at the top edge of the concrete slab (see **Figure 7-11**). **Equation (7-58)** is to be intended as the sum of normal stress due to moment ($\sigma_{m.1.t0.u}$ and $\sigma_{m.2.t0.u}$) and normal force ($\sigma_{n.1.t0.u}$ and $\sigma_{n.2.t0.u}$).

$$\sigma_{1.t0.u} = \sigma_{m.1.t0.u} + \sigma_{n.1.t0.u} = \pm \frac{M_{1.t0.u}}{W_{rc}} + \frac{N_{1.t0.u}}{A_{rc}} \quad (7-58)$$

$$\sigma_{2.t0.u} = \sigma_{m.2.t0.u} + \sigma_{n.2.t0.u} = \pm \frac{M_{2.t0.u}}{W_{CLT}} + \frac{N_{2.t0.u}}{A_{CLT}} \quad (7-59)$$

The resulting stresses determined thanks to the previous equations are compared to the relative material strengths, namely timbers tensile and compressive strength (see **Table 13**) and the compressive and tensile strength of concrete (see **Table 23**). Thanks to the stress distribution visible in **Figure 7-11**, there are tensional stresses on the lower edge of the concrete screed that may be higher than the material concrete's tensional strength. If this shall be the case, a reinforcement composed of steel bars is placed on the bottom of the reinforced concrete screed. This reinforcement's dimensioning been carried out using the equations featured in [101] and [103]. The interesting thing that happens is that these positive stresses are not to be found in any

system configuration. It is noticeable that with increasing stiffness of the panel, these tensional stresses become compressional stresses. In addition to that, by reducing the concrete stiffness over time (due to shrinking) and the comparatively lower reduction of timber stiffness, all these tensional stresses become negative. This is probably explainable because the bending stiffness of concrete and timber is not equally reduced over time.

Equation (7-61), obtained from formula (B.9) for $\gamma_3 = 0$ in EN 1995-1-1 [82, p. 165] is for shear stress calculation in the most strained point of the section, which in this case is defined by the distance from the lower edge to the centre of gravity of the composite section (see **Equation (7-61)**) and is located in the CLT element. The resulting shear stress is then directly compared to the shear strength of timber.

$$h_{t0.u} = a_{2,t0.u} + \frac{h_{CLT}}{2} \quad (7-60)$$

$$\tau_{2,t0.u} = 0.5 \cdot h_{t0.u}^2 \cdot \frac{E_{rc}}{EI_{eff,t0.u}} \cdot V(q_d + p_{sls}) \quad (7-61)$$

In addition to the shear verification of timber, the TCC normative [89] in paragraph 8.2.4 requires designing engineers to verify shear stress in concrete (for in-plane shear). Shear stress in two distinct shear planes (namely *a-a* and *b-b* shown in **Figure 7-12**) needs to be determined using the following equations, respectively.

$$\tau_{Ed} = \frac{\Delta F_d}{h_f \cdot \Delta x} \quad (7-62)$$

$$\tau_{Ed} = \frac{2 \cdot \Delta F_d}{l_{shear} \cdot \Delta x} \quad (7-63)$$

ΔF_d is defined as shear force over a certain length of the beam; for dimensioning purposes, the highest shear force (located in support proximity) is used. The parameter Δx corresponds to the length on which the shear force acts. This length can be 1000 mm or half of the linear distance between where the beam moment is 0 and the maximum moment value. In a simply supported and one-way spanned beam, this would correspond to 25% of the span length. The parameter h_f corresponds to the thickness of the concrete flange and l_{shear} is defined as the shear surface length around the shear connector. It basically is the enveloping length of the single shear connector in contact with concrete.

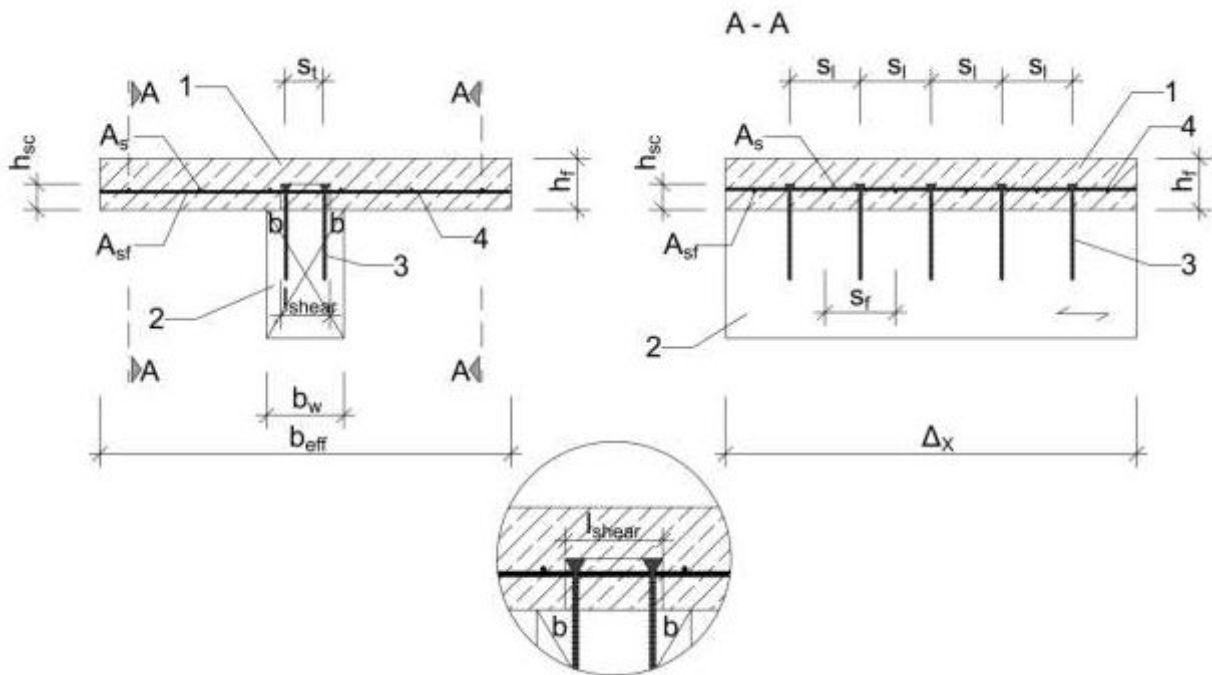


Figure 7-12: Visualization of shear planes a-a and b-b in a TCC beam [89, p. 32]

With the stresses worked out in **Equation (7-62)** and **Equation (7-63)**, the concrete crushing in the compression struts of the concrete slab needs to be verified, which implies that the condition in **Equation (7-64)** needs to be met. The angle θ is defined as concrete strut angle and is assumed to be 45° . If the shear surface passes around shear connectors, the condition in **Equation (7-65)** needs to be satisfied. The strength reduction factor ν is defined in paragraph 6.5.2 of [101, p. 117] and determined as follows: $\nu = 1 - f_{ck}/250$.

$$\sigma_{cd} = \tau_{Ed} \cdot (\cot(\theta) + \tan(\theta)) < \nu \cdot f_{cd} \quad (7-64)$$

$$\sigma_{cd} = \tau_{Ed} < \nu \cdot f_{cd} \quad (7-65)$$

$$\nu = 0.6 \cdot \left(1 - \frac{f_{c,k}}{250}\right) \quad (7-66)$$

The TCC Eurocode [89, p. 32] contains an equation to determine transverse reinforcement for the section in regard to shear strength per unit length A_{sf}/s_f , which is taken over as follows:

$$\frac{A_{sf}}{s_f} = \frac{\Delta F_d}{\Delta x \cdot f_{yd} \cdot \cot(\theta)} \quad (7-67)$$

The last verification that needs to be undertaken is the proof of the shear connectors. As explained beforehand, they are under shear stress because of the shear stress coming from the composite

action. This shear stress is the highest in correspondence of floor supports. EN 1995-1-1 [82, p. 165] contains an equation to calculate the acting forces on shear connectors (see **Equation (7-69)**). Because of the time-dependant behaviour of a TCC floor construction, the shear force has to be calculated for “t=0”, “t=∞” and “t_3-7 years”. Since the creep causes reduction of bending stiffness over time, the shear force on the connectors is diminished as well.

$$F_{1,t0} = \frac{\gamma_1 \cdot E_1 \cdot A_1 \cdot a_{1,t0} \cdot s_{eff}}{EI_{eff,t0,u}} \cdot V_{max} \quad (7-68)$$

$$V_{max} = -\pi \cdot E_2 \cdot A_2 \cdot \frac{E_1 \cdot I_1 + E_2 \cdot I_2}{(\gamma_1 \cdot E_1 \cdot A_1 + E_2 \cdot A_2) \cdot L \cdot a_{1,c}} \cdot \Delta\varepsilon + V(q_d) \quad (7-69)$$

7.2.8 SLS verification

The serviceability limit state is verified using the same equations shown in **chapter 7.1.6** but with the difference that the resulting bending stiffness for “t=0”, “t=∞” and “t_3-7 years” has to be distinctively used depending on which moment in time is currently analysed. This means that SLS checks (**Equation (7-8)** to **Equation (7-15)**) need to be performed for all three points in time.

7.2.9 Dimensioning under fire conditions

As mentioned in chapter 7.1.7, the dimensioning under fire conditions is carried out with the “method of the reduced section” under the same presumption that fire attacks the floor from below. The burnt away depth depends on the length of exposure to fire (hereby R 30, R 60, or R 90). The incinerated layer is subtracted from the original panel, and the panels own bending stiffness (reduced section) has to be calculated again. Since the CLT panel conformation has changed, the γ -factor for the bi-area section (CLT panel + concrete screed) has to be evaluated again. Consequently, the total bending stiffnesses have to be determined again as well as all the results connected to that bending stiffness. All calculations have to be performed again, because essentially the CLT section is another and thus, everything changes. The ultimate goal is to prove that the remaining composite section can withstand the loads under fire conditions, determined in **Equation (7-16)**. This means that a maximum moment and shear force needs to be determined under fire conditions. The resulting stresses are determined thanks to the formulas contained in **chapter 7.2.4**, **chapter 7.2.6**, and **chapter 7.2.7**. These stresses are compared to the material stresses modified for the fire conditions according to **Equation (7-17)**.

7.2.10 Estimation of sound insulation properties

Sound insulation for TCC floors is estimated using the following equations formulas that cover impact sound insulation and airborne sound insulation properties of TCC panels. The equivalent footfall sound insulation of a timber-concrete floor may approximately be obtained applying the following **Equation (7-70)** and **Equation (7-71)**, obtained from [104, p. 45]:

$$L_{n,w,eq.rc} = 153 - 35 \cdot \log_{10}(m') \text{ [dB] for } m' \geq 100 \frac{kg}{m^2} \quad (7-70)$$

$$L_{n,w,eq.rc} = 98,5 - 7,78 \cdot \log_{10}(m') \text{ [dB] for } m' \leq 100 \frac{kg}{m^2} \quad (7-71)$$

Kraler [104, p. 12] provides readers with two formulas to determine the airborne sound insulation of heavy and stiff building elements. This formula is listed from an Austrian norm, namely ÖNORM B 8115-4 and is valid for weights per square meter between $100 \text{ kg/m}^2 - 700 \text{ kg/m}^2$.

$$R_{w,eq.rc} = 32,4 \cdot \log_{10}(m'_{rc}) - 26 \text{ [dB]} \quad (7-72)$$

Since these formulas are approximative, their results should be taken as estimated values and treated accordingly.

7.2.11 Obtaining valid results

As explained in **chapter 7.1.8**, all sections that cannot fulfil one or of the requirements of ULS, SLS or dimensioning under fire conditions are automatically eliminated from the matrix with all possible combinations of panel conformations on the vertical axis and load and span combinations on the horizontal axis. By eliminating non-valid results, the relative entry in the matrix is empty.

7.3 TCC floor with notches as shear connectors

The 3rd type of analysed massive floor constructions is also a timber concrete floor, which is very similar to the one explained and designed in **chapter 7.2**. The main difference resides in the manner on how the composite action is achieved. These notches are cut in the panel beforehand and are afterwards filled with concrete when poured in. According to Dias et al., notches are capable shear connection types, well balanced between executional simplicity and mechanical effectiveness, as they present high stiffnesses. On the downside, the timber's failure mode is brittle and, the axial load carrying capacity is low. To prevent the concrete slab from uplifting under compression stress, dowels are placed in the notch (see **Figure 7-13**). These steel dowels also add ductility to the connection, but they increase the axial load carrying capacity too. [84, p. 35]

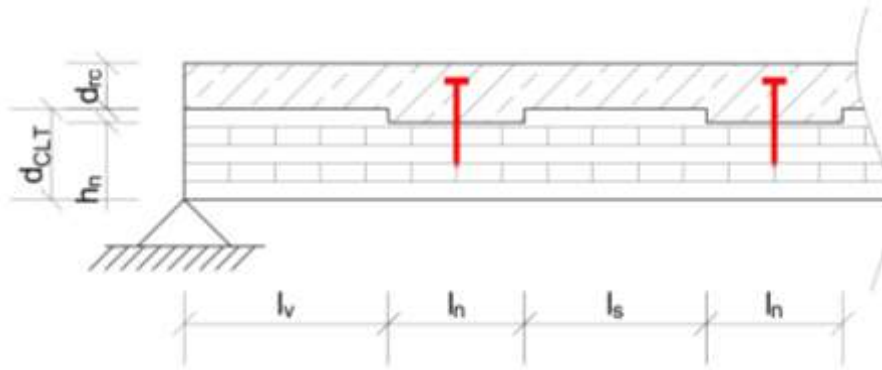


Figure 7-13: Schematic drawing for TCC floors with notches as shear connectors

There are not many changes from a design point of view since this is also a timber-concrete composite floor construction. In that regard, the future Eurocode for TCC floors [89, pp. 40-41] makes plenty of specifications regarding the notch dimensions. The author decides to fix the notch depth on 30 mm for all load configurations and to vary the notch dimensions and inter distances to see how these changes would affect the load-carrying behaviour and number of possible panel configurations. The normative fixes the minimal notch depth accordingly to **Equation (7-73)**.

$$h_n \geq \begin{cases} 20 \text{ mm for normal loads} \\ 30 \text{ mm for heavy loads} \end{cases} \quad (7-73)$$

Other dimensional requirements stated in [89] are listed in **Table 25**.

	Minimum dimension
Notch length	$l_n \geq 150 \text{ mm}$
Length of timber in front of the notch	$l_v \geq 12,5 \cdot h_n$
Distance between notches	$l_s \geq 12,5 \cdot h_n$
Notch width	b_n (no specifications made)
Minimum steel fastener diameter	$d \geq 6 \text{ mm}$
Angle of the notch	$80^\circ \leq \alpha \leq \min \{115^\circ; 90^\circ + \theta\}$

Table 25: Dimensional requirements for notches according to [89, p. 41]

7.3.1 Material strengths and safety factors

Since this is also a TCC floor, the time dependant behaviour has to be considered. Refer to **chapter 7.2.1** as nothing changes regardless of the type of shear connection.

7.3.2 Shear connectors

There is no distinction between the slip modulus for the ultimate limit state and the serviceability limit state as they are the same, unlike when screws or dowels are used as shear connectors. This analogy is the case because, during the performance of push-out test and beam tests, the load-

displacement curves exhibit constant stiffness until shortly before the load-carrying capacity is reached [84, p. 62]. The slip modulus is determined thanks to the following **Equation (7-74)**. For notch depths between 20-30 mm, linear interpolation may be used.

$$K_{ser} \geq \begin{cases} 1000 \frac{N/mm}{mm} & \text{for } h_n = 20 \text{ mm} \\ 1500 \frac{N/mm}{mm} & \text{for } h_n \geq 30 \text{ mm} \end{cases} \quad (7-74)$$

7.3.3 Determination of external loads

Because a similar approach is critical in the elaboration of this pre-dimensioning tool, the applied external loads (dead loads and imposed loads) are the same as described and calculated in **chapter 7.1.2**. In addition to the CLT panel dead load, the concrete topping self-weight is considered in the dead loads. For more details, see **Table 16**, **Table 17** and **Table 18**.

7.3.4 Determination of internal loads

Refer to **chapter 7.2.4** as nothing changes regardless of the type of shear connection and the value of the γ factor itself.

7.3.5 Creation of sections

Since one of the scopes of this thesis is to create a consistent analysis and pre-dimensioning tool for massive floor construction and compare the obtained results, the CLT panels that were implemented in the analysis of bare CLT panels floors (see **chapter 7.1**) are implemented here. The difference lies in the concrete layer's presence placed on top of the CLT panel, which helps in the load-carrying mechanism (composite action). The author has handpicked three different screed depths to produce a more variegated and realistic approach: 8 cm, 10 cm, and 12 cm. The idea behind this choice is the following: realistically, a CLT panel producer may offer panels in his catalogue and cast concrete on top of them when a TCC floor solution is required. See **chapter 7.1.4** for a more in-depth explanation of which section types are used and how they were computed.

7.3.6 Calculation of gamma factors and resulting bending stiffnesses

To apply the gamma method to determine internal loads, Dias et al. propose the following empirical approach to calculate the effective distance between notches. The following formula fulfils a similar purpose as **Equation (7-44)** to determine the effective distance between screws and is also somehow reminiscent of it. Since any approach to determine the effective distance between notches is absent from [89], it was decided to replace it. Otherwise, it would not have been possible to use the gamma method to determine the resulting bending stiffness (for more information, see [84, pp. 86-87]).

$$s_{eff.notch} = 1.14 \cdot s_{min} + 3.14 \cdot \frac{s_{max}}{span\ length} \cdot (s_{max} - s_{min}) \quad (7-75)$$

To obtain more cost-effective TCC constructions, it makes sense to place the notches along the panel so that they all can take on the same shear force; this means that all notches would fail simultaneously when this maximum shear force is reached (see **Figure 7-14**). If the notches are disposed following other criteria, the closest to the support takes up the most shear force and would be decisive in the notch design, while all the other notches would not be fully utilized. This exactly what has been performed during the design process this thesis bases upon. The number of notches depends on the span and is defined as follows:

Span [m]	Number of notches
5; 5,5; 6,0	3
6,5; 7,0; 7,5	4
8,0; 8,5; 9,0	5

Table 26: Number of notches depending on the span

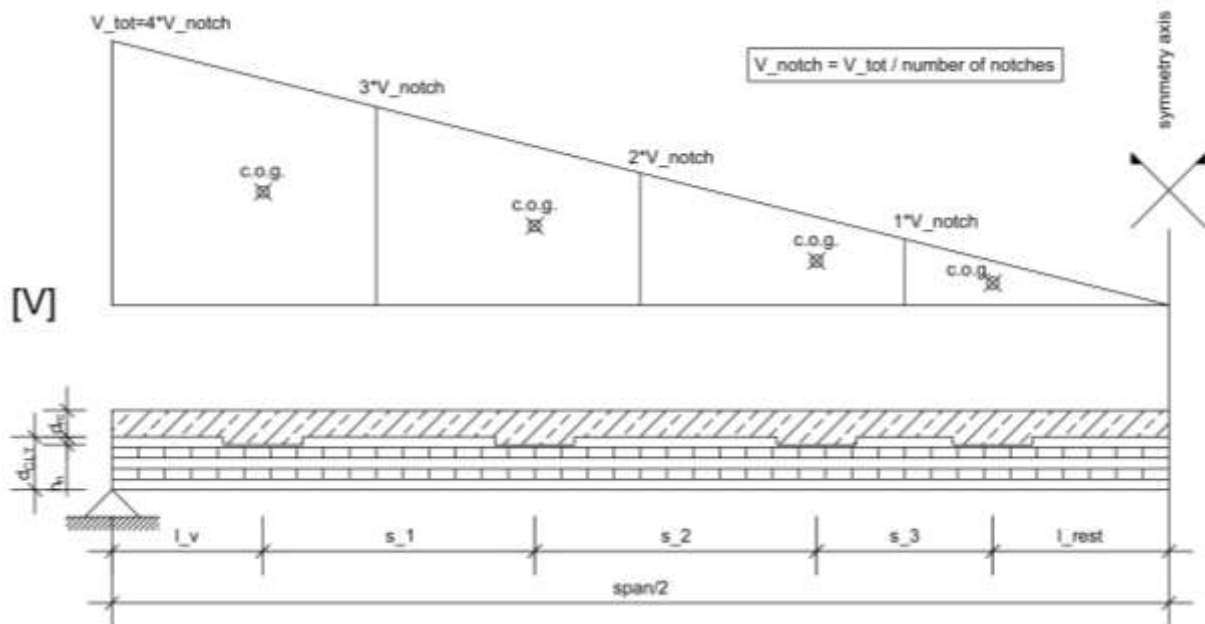


Figure 7-14: Determination of notch spacing with equal subdivision of shear force

Besides the different calculation of the effective notch distance, there aren't any changes. Refer to **chapter 7.2.6** as nothing changes regardless of the type of shear connection.

7.3.7 ULS Verification

Figure 7-14 and **Figure 7-15** visualize which proportion of the total shear force has to be taken on by each notch depending on distance and dimension from panel start. During the dimensioning process, just the shear force for the 1st notch was calculated as it had the highest shear force acting on it. The other notches were not verified since they have the exact dimensions as the first notch but reduced shear forces acting on them.

Figure 7-15: Shear forces taken on by notches Figure 7-15

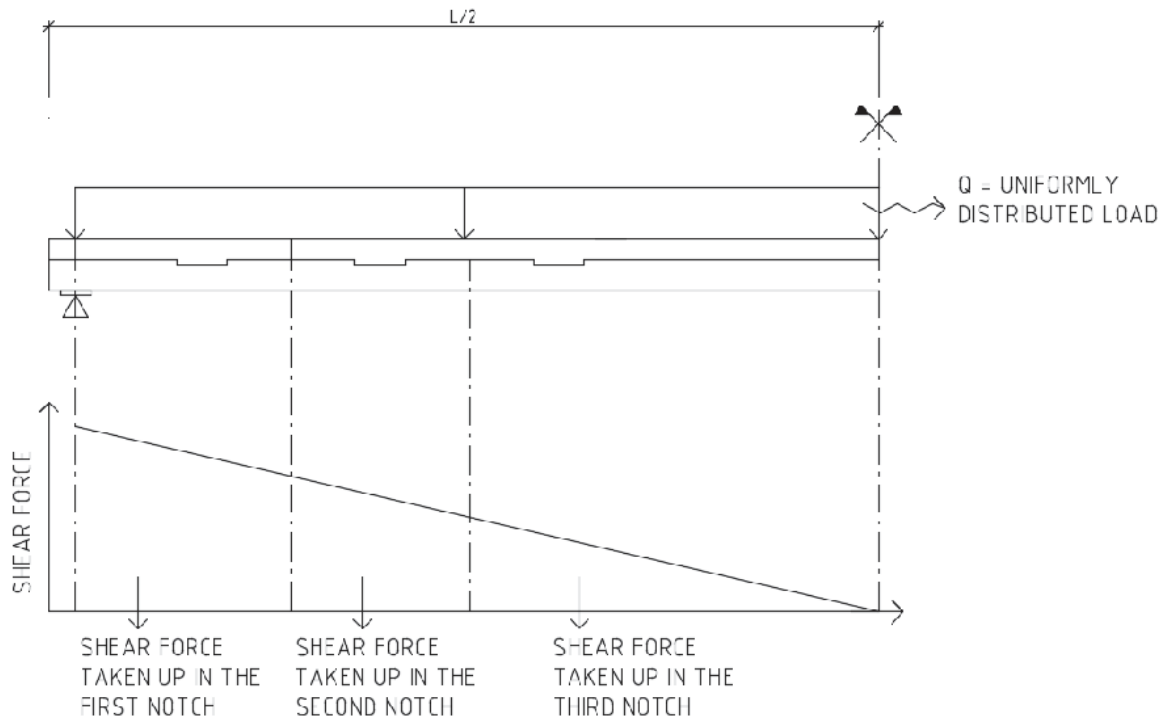


Figure 7-15: Shear forces taken on by notches [105, p. 74]

Refer to **chapter 7.2.7** as almost nothing changes regardless of the type of shear connection. The only difference regards the determination of the load-carrying capacity of the shear connection, which is to be calculated accordingly to the now following formula:

$$F_{Rd} = \min \begin{cases} f_{v.c.d} \cdot b_n \cdot l_n & \text{a) shear of concrete} \\ f_{c.d} \cdot b_n \cdot h_n & \text{b) crushing of concrete} \\ k_{cr} \cdot f_{v.t.d} \cdot b_n \cdot 8 \cdot h_n & \text{c) shear of timber} \\ f_{c.o.d} \cdot b_n \cdot h_n & \text{d) crushing of timber} \end{cases} \quad (7-76)$$

$$f_{v.c.d} = \frac{v \cdot f_{c.d}}{(\cot(\theta) + \tan(\theta))} \quad (7-77)$$

$$\theta = \max \left\{ \arctan \left(\frac{0.5 \cdot (h_c + h_n)}{l_n + l_s} \right); \arctan \left(\frac{h_n}{l_n} \right) \right\} \quad (7-78)$$

The load-carrying capacity F_{Rd} is worked out as the minimum resisting force considering the shear strength of both materials and their “crushing” strength. The concrete strut angle θ calculated with **Equation (7-78)** and is visualized in **Figure 7-16**. The acting force $F_{v.Ed}$ is the acting shear force in the connection and to be determined according to **Equation (7-69)**, which is to be calculated for all three different points in time: “ $t=0$ ”, “ $t=\infty$ ” and “ $t=3-7$ years”.

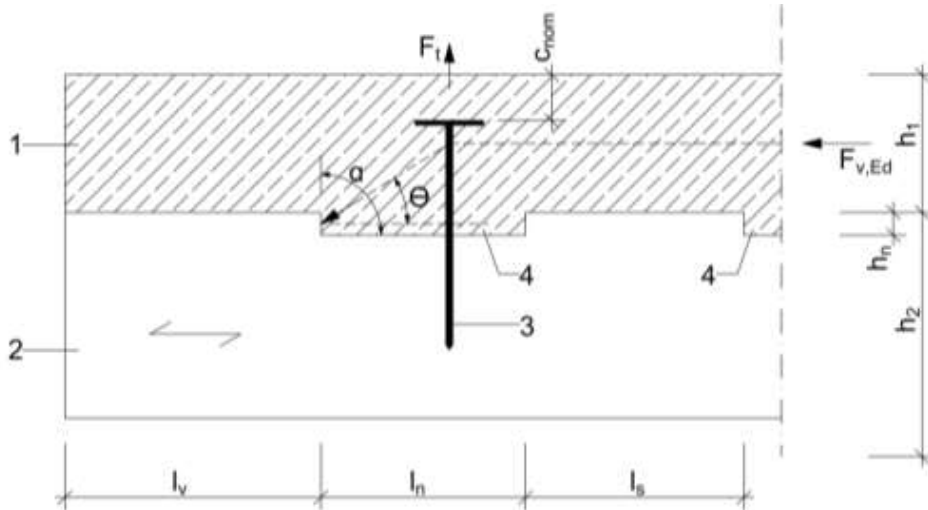


Figure 7-16: Schematic drawing for TCC floors with notches as shear connectors [89, p. 43]

Since the dowel connection prevents the concrete slab from uplifting when compressed, these dowels shall be designed accordingly. The future TCC [89, p. 43] provides engineers with the following approach to determine this tensional force:

$$F_{t.Ed} = \max\{F_{v.Ed} \cdot \tan(\theta); 0.1 \cdot F_{v.Ed}\} \quad (7-79)$$

The dowel's resisting tensional force is defined as the dowel area (depending on its diameter) multiplied by steels yielding strength.

7.3.8 SLS Verification

The serviceability limit state is verified using the same equations shown in **chapter 7.1.6**, with the difference that the resulting bending stiffness for “ $t=0$ ”, “ $t=\infty$ ” and “ t_3-7 years” have to be used depending on which moment in time is currently analysed. This means that SLS checks (**Equation (7-8)** to **Equation (7-15)**) need to be performed for all three points in time.

7.3.9 Dimensioning under fire conditions

Refer to **chapter 7.2.9** as nothing changes regardless of the type of shear connection, except of the differences outlined in **chapter 7.3.2**, **chapter 7.3.6** and **chapter 7.3.7**. The thing that has to be kept in mind is that a different section is worked out because the lower part is incinerated and unable to carry loads.

7.3.10 Estimation of sound insulation properties

Sound insulation properties are estimated using formulas provided in **chapter 7.2.10**. They cover the impact sound insulation and airborne sound insulation properties of CLT panels and reinforced concrete layers. Minimum values are used when two formulas obtained from different sources are present.

7.3.11 Obtaining valid results

As explained in a more detailed manner in **chapter 7.1.8**, all the sections that are not able to fulfil one or of the requirements of ULS, SLS or dimensioning under fire conditions are automatically eliminated from the matrix with all possible combinations of panel conformations on the vertical axis and load and span combinations on the horizontal axis. By eliminating non-valid results, the entry in the results matrix is empty.

8 Visualization and discussion of obtained results

The results, which are visualized in the following multiple pages, are in the form of tables. Both types of floor constructions (CLT panel or TCC floor construction) have their tables characterized by relative parameters. On the vertical axis, the table shows the panel number and overall depth, while the horizontal axis shows the load combinations (see **chapter 7.1.2**, **chapter 7.2.3** and **chapter 7.3.3**) applied to every analysed span. The data visualized in the tables show the maximum degree of utilization reached by every single combination between load, span, and panel dimensions. Thanks to colours used in the data visualization, the reader quickly sees which verification is crucial for the load-span-panel combination. Therefore, statements about which type of verifications dominate the design of massive timber floor constructions can be made. Every combination between load-span-panel that doesn't fulfil one of the requirements is not visualized in the table. So, after a quick look, the user can obtain an overview of the possibilities and limitations that this type of massive timber construction offers about quite real dimensioning situations.

8.1 Simple CLT floor constructions

8.1.1 Characterizing Parameters

Two main parameters distinguish the tables one from another, namely the resistance to fire and the presence of a concrete screed placed above the CLT panel itself. This screed does contribute to the floor panel's total stiffness but is not attached to the CLT panels using any shear connectors. This concrete screed's overall depth is 60 mm; this dimension is determined thanks to the research of standard CLT floor constructions (as a comprehensive package with footfall sound insulation, floor, etc.) performed in **chapter 7.1.2**. Concerning the fire resistance as a requirement for timber floors, two different fire durations have been implemented in the tool: 30 and 60 minutes. This means that four different tables per CLT panel types are the output and sixteen tables overall for the CLT panel solution.

In order to understand which type of verification is the leading one during the dimensioning process for each combination, colours have been awarded and are visible in every single table (see **Figure 8-1**). This allows the reader to recognize if the ULS, SLS or ULS under fire conditions verifications are crucial. The ULS group contains all the verifications undertaken in **chapter 7.1.5**. The SLS group all formulas applied in **chapter 7.1.6**, and the ULS under fire conditions contains all material verifications present in **chapter 7.1.7**.

Legend: CRUCIAL CRITERIUMS		
SLS-t0	ULS _{fi} -t0	ULS-t0

Figure 8-1: Legend of crucial criteriums

8.1.2 Three-layer CLT panel (CLT_3)

Table 27 contains an overview of the different combinations between load and built-in situation (namely, presence of concrete screed or not) and the fire's implemented duration. The three observed imposed loads (see chapter 7.1.2) are contained in each table. The following figures only show the g_{k2} combination tables. Otherwise, the displayed data would rapidly become difficult to overlook.

Variations of CLT_3		Self-weight		
		g _{k1}	g _{k2}	g _{k3}
Variant	R 60, no screed	CLT_3_r1_c1	CLT_3_r1_c2	CLT_3_r1_c3
	R 30, no screed	CLT_3_r2_c1	CLT_3_r2_c2	CLT_3_r2_c3
	R 60, screed 60 mm	CLT_3_r3_c1	CLT_3_r3_c2	CLT_3_r3_c3
	R 30, screed 60 mm	CLT_3_r4_c1	CLT_3_r4_c2	CLT_3_r4_c3

Table 27: Variation overview for CLT_3

No results have been obtained for the CLT_3_r1_c2 and CLT_3_r2_c2 option.

CLT_3 panel configuration: CLT_3_r3_c2																														
Resistance to fire: R 60, self-weight including 60 mm concrete screed g _{k2} : 3,74 kN/m ²																														
Panel Nr.	depth_tot	SPAN 1 = 2,5 m			SPAN 2 = 3,0m			SPAN 3 = 3,5 m			SPAN 4 = 4,0 m			SPAN 5 = 4,5 m			SPAN 6 = 5,0 m			SPAN 7 = 5,5m			SPAN 8 = 6,0 m			SPAN 9 = 6,5 m			acoustic	
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	R _w	L _{w,eq}			
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]							
1	60	0,85	0,85	0,87																						28,6	97			
2	70	0,78	0,78	0,79																							30,0	95,5		
3	80	0,70	0,70	0,70																							31,2	94,2		
4	80	0,69	0,69	0,69	0,99																						31,2	94,2		
5	90	0,61	0,61	0,61	0,88	0,91																					32,2	93,1		
6	100	0,54	0,54	0,54	0,78	0,79	0,87																				33,1	92,1		
7	100	0,54	0,54	0,54	0,78	0,78	0,84																				33,1	92,1		
8	110	0,47	0,47	0,47	0,68	0,68	0,72	0,92																			34,0	91,2		
9	120	0,41	0,41	0,41	0,60	0,60	0,61	0,81	0,88	0,97																	34,7	90,4		

Figure 8-2: Maximum utilization ratios of the CLT_3_r3_c2 configuration

CLT_3 panel configuration: CLT_3_r4_c2																														
Resistance to fire: R 30, self-weight including 60 mm concrete screed g _{k2} : 3,74 kN/m ²																														
Panel Nr.	depth_tot	SPAN 1 = 2,5 m			SPAN 2 = 3,0m			SPAN 3 = 3,5 m			SPAN 4 = 4,0 m			SPAN 5 = 4,5 m			SPAN 6 = 5,0 m			SPAN 7 = 5,5m			SPAN 8 = 6,0 m			SPAN 9 = 6,5 m			acoustic	
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	R _w	L _{w,eq}			
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	60	0,85	0,85	0,87																							42,3	78,8		
2	70	0,78	0,78	0,79																							42,4	78,6		
3	80	0,70	0,70	0,70																							42,5	78,3		
4	80	0,69	0,69	0,69	0,99																						42,5	78,3		
5	90	0,61	0,61	0,61	0,88	0,91																					42,7	78,1		
6	100	0,54	0,54	0,54	0,78	0,79	0,87																				42,8	77,9		
7	100	0,54	0,54	0,54	0,78	0,78	0,84																				42,8	77,9		
8	110	0,47	0,47	0,47	0,68	0,68	0,72	0,92																			42,9	77,7		
9	120	0,41	0,41	0,41	0,60	0,60	0,61	0,81	0,88	0,97																	43,0	77,5		

Figure 8-3: Maximum utilization ratios of the CLT_3_r4_c2 configuration

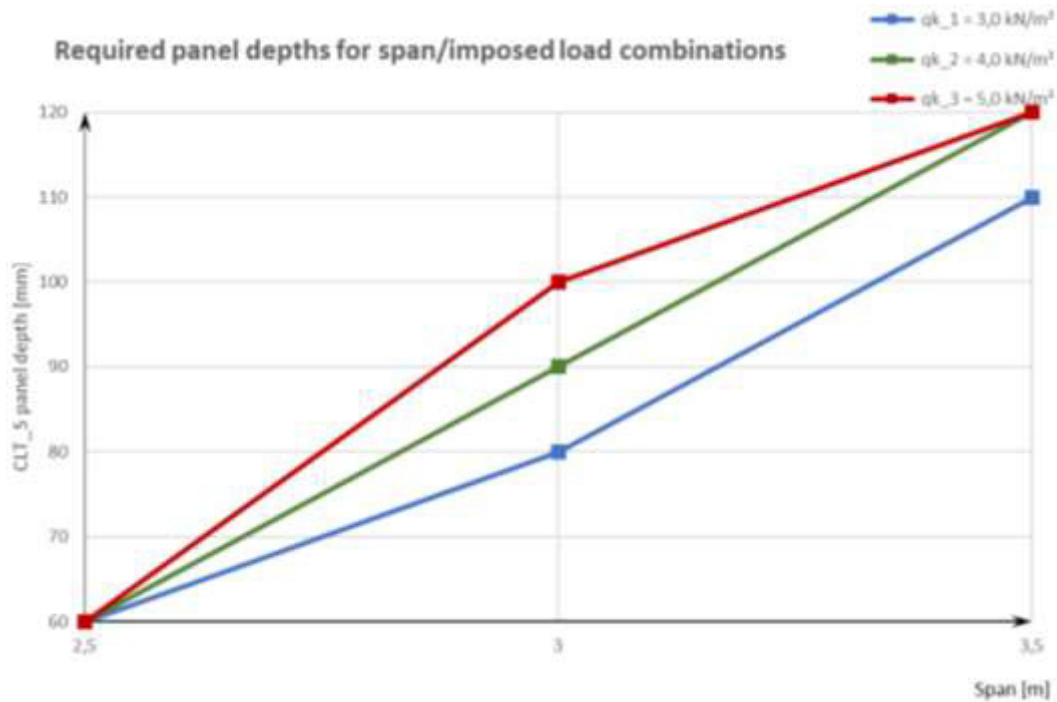


Figure 8-4: Minimum panel depths in regard to span for CLT_3_r3_c2 and CLT_3_r4_c2

The graph in **Figure 8-4** shows the minimum necessary panel depth on the vertical axis (ergo, the one that corresponds to the highest degree of utilization in **Figure 8-2** and **Figure 8-3**) and the attributed span length on the horizontal axis. The three lines in the diagram correspond to different imposed load levels. As explained previously, all span-load-panel depth combinations that cannot fulfil all requirements (namely ULS, SLS and ULS under fire conditions) are automatically eliminated and thus not shown in the tables.

A three-layered CLT panel of any analysed depth cannot fulfil all requirements, no matter the wanted resistance to fire. This table underlines the fact that this solution is not suitable for floor constructions. Matters improve when a loosely applied concrete screed of 60 mm is present; the concrete stiffness is added to the panel bending stiffness, creating a stiffer solution. Still, the maximum reachable span length amounts to 3,5 m, which means that this solution would only be interesting for residential buildings with small spans, even though a characteristic imposed load of 5,0 kN/m² may be applied. Usually, CLT panels consisting of three layers are used for walls, as they're subject to lower loads than floors. In **Figure 8-2** and **Figure 8-3**, there are no differences in the results: this means that the most stringent criterium is certainly the SLS dimensioning (probably due to the stiffness criterium). Also, the cell colouring underlines the same fact. When the minimum required panel depth is the same independently from the imposed load level, the stiffness criterium is the leading verification. In all the other cases, deflection limits are the ones influencing the required panel dimensions. The situation doesn't change radically from what just explained when the dead load changes its value (g_{k1} and g_{k3}).

8.1.3 Five-layer CLT panel (CLT_5)

Table 28 contains an overview of the different combinations between load and built-in situation (namely, presence of concrete screed or not) and the fire's implemented duration. The three observed imposed loads (see chapter 7.1.2) are contained in each table. The following figures only show the g_k2 combination tables. Otherwise, the illustrated data would rapidly become difficult to overlook.

Variations of CLT_5		Self-weight		
		g_k1	g_k2	g_k3
Variant	R 60, no screed	CLT_5_r1_c1	CLT_5_r1_c2	CLT_5_r1_c3
	R 30, no screed	CLT_5_r2_c1	CLT_5_r2_c2	CLT_5_r2_c3
	R 60, screed 60 mm	CLT_5_r3_c1	CLT_5_r3_c2	CLT_5_r3_c3
	R 30, screed 60 mm	CLT_5_r4_c1	CLT_5_r4_c2	CLT_5_r4_c3

Table 28: Variation overview for CLT_5

CLT_5 panel configuration: CLT_5_r1_c2																														
Resistance to fire: R 60, self-weight g_k2: 2,30 kN/m ²																														
Panel Nr.	depth_tot	SPAN 1 = 2,5 m			SPAN 2 = 3,0m			SPAN 3 = 3,5 m			SPAN 4 = 4,0 m			SPAN 5 = 4,5 m			SPAN 6 = 5,0 m			SPAN 7 = 5,5m			SPAN 8 = 6,0 m			SPAN 9 = 6,5 m			R_w	L_w_eq
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0		
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	100																											33,1	92,1	
2	110	0,99	0,99	0,99																								34,0	91,2	
3	120	0,76	0,76	0,76																								34,7	90,4	
4	120	0,77	0,77	0,77																								34,7	90,4	
5	130	0,61	0,61	0,61	0,87	0,87	0,87																					35,4	89,6	
6	140	0,49	0,49	0,49	0,70	0,70	0,70	0,96	0,96																			36,1	88,9	
7	140	0,49	0,49	0,49	0,71	0,71	0,71	0,96	0,97																			36,1	88,9	
8	150	0,41	0,41	0,41	0,58	0,58	0,59	0,79	0,83	0,93																		36,7	88,2	
9	160	0,34	0,34	0,34	0,49	0,49	0,50	0,66	0,71	0,80	0,93																	37,3	87,6	
10	120	0,81	0,81	0,81																								34,7	90,4	
11	130	0,62	0,62	0,62	0,90	0,90	0,90																					35,4	89,6	
12	140	0,49	0,49	0,49	0,71	0,71	0,71	0,96	0,96	0,96																		36,1	88,9	
13	140	0,49	0,49	0,49	0,70	0,70	0,70	0,95	0,95	0,95																		36,1	88,9	
14	150	0,39	0,39	0,39	0,56	0,56	0,56	0,77	0,77	0,77																		36,7	88,2	
15	160	0,32	0,32	0,32	0,46	0,46	0,46	0,63	0,63	0,63	0,82	0,82	0,92															37,3	87,6	
16	160	0,32	0,32	0,32	0,46	0,46	0,46	0,63	0,63	0,63	0,82	0,83	0,93															37,3	87,6	
17	170	0,27	0,27	0,27	0,39	0,39	0,39	0,52	0,52	0,54	0,68	0,72	0,81	0,90														37,7	87,0	
18	180	0,23	0,23	0,23	0,33	0,33	0,33	0,44	0,44	0,47	0,58	0,63	0,70	0,78	0,89													38,0	86,5	
19	140	0,56	0,56	0,56	0,80	0,80	0,80																					36,1	88,9	
20	150	0,44	0,44	0,44	0,62	0,62	0,62	0,85	0,85	0,85																		36,7	88,2	
21	160	0,35	0,35	0,35	0,50	0,50	0,50	0,68	0,68	0,68	0,89	0,89	0,89															37,3	87,6	
22	160	0,34	0,34	0,34	0,49	0,49	0,49	0,67	0,67	0,67	0,87	0,87	0,87															37,3	87,6	
23	170	0,28	0,28	0,28	0,40	0,40	0,40	0,55	0,55	0,55	0,71	0,71	0,71	0,90	0,90	0,99												37,7	87,0	
24	180	0,23	0,23	0,23	0,33	0,33	0,33	0,45	0,45	0,45	0,59	0,59	0,60	0,75	0,76	0,85	0,92											38,0	86,5	
25	180	0,23	0,23	0,23	0,33	0,33	0,33	0,45	0,45	0,45	0,59	0,59	0,61	0,74	0,77	0,86	0,92											38,0	86,5	
26	190	0,20	0,20	0,20	0,28	0,28	0,28	0,38	0,38	0,38	0,50	0,50	0,53	0,63	0,67	0,76	0,81	0,92										38,3	86,0	
27	200	0,17	0,17	0,17	0,24	0,24	0,24	0,32	0,32	0,32	0,42	0,42	0,47	0,53	0,60	0,67	0,72	0,82	0,91	0,95								38,6	85,5	

Figure 8-5: Maximum degrees of utilization of CLT_5_r1_c2 configuration

8 Visualization and discussion of obtained results

CLT_5 panel configuration: CLT_5_r3_c2																														
Resistance to fire: R 60, loose concrete screed depth: 60 mm, self-weight including concrete g_{k2} : 3,74 kN/m ²																														
Panel Nr.	depth_tot	SPAN 1 = 2,5 m			SPAN 2 = 3,0m			SPAN 3 = 3,5 m			SPAN 4 = 4,0 m			SPAN 5 = 4,5 m			SPAN 6 = 5,0 m			SPAN 7 = 5,5m			SPAN 8 = 6,0 m			SPAN 9 = 6,5 m			acoustic	
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	R_w	L_w_eq
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	100	0,56	0,56	0,56	0,80	0,86	0,95																					42,8	77,9	
2	110	0,49	0,49	0,49	0,70	0,75	0,83																					42,9	77,7	
3	120	0,43	0,43	0,43	0,61	0,66	0,73	0,94																				43,0	77,5	
4	120	0,43	0,43	0,43	0,62	0,68	0,75	0,96																				43,0	77,5	
5	130	0,38	0,38	0,38	0,54	0,60	0,66	0,85	0,95																			43,1	77,3	
6	140	0,33	0,33	0,34	0,47	0,53	0,58	0,75	0,84	0,92																		43,2	77,1	
7	140	0,33	0,33	0,34	0,48	0,54	0,59	0,77	0,85	0,94																		43,2	77,1	
8	150	0,29	0,29	0,31	0,43	0,48	0,53	0,68	0,76	0,84																		43,4	76,9	
9	160	0,25	0,25	0,27	0,38	0,43	0,47	0,61	0,68	0,75	0,91																	43,5	76,7	
10	120	0,42	0,42	0,42	0,60	0,60	0,65	0,84	0,93																			43,0	77,5	
11	130	0,36	0,36	0,36	0,52	0,52	0,56	0,73	0,81	0,89																		43,1	77,3	
12	140	0,31	0,31	0,31	0,45	0,45	0,49	0,63	0,70	0,77	0,94																	43,2	77,1	
13	140	0,32	0,32	0,32	0,45	0,45	0,50	0,64	0,72	0,79	0,96																	43,2	77,1	
14	150	0,27	0,27	0,27	0,39	0,40	0,44	0,56	0,63	0,69	0,84	0,94																43,4	76,9	
15	160	0,24	0,24	0,24	0,34	0,35	0,38	0,50	0,55	0,61	0,74	0,82	0,91															43,5	76,7	
16	160	0,24	0,24	0,24	0,34	0,35	0,39	0,50	0,56	0,62	0,75	0,84	0,92															43,5	76,7	
17	170	0,21	0,21	0,21	0,30	0,31	0,35	0,45	0,50	0,55	0,67	0,74	0,82	0,95														43,6	76,5	
18	180	0,18	0,18	0,18	0,26	0,28	0,31	0,40	0,44	0,49	0,60	0,66	0,73	0,85	0,94													43,7	76,3	
19	140	0,32	0,32	0,32	0,45	0,45	0,45	0,61	0,65	0,72	0,87	0,97																43,2	77,1	
20	150	0,27	0,27	0,27	0,39	0,39	0,39	0,54	0,56	0,62	0,76	0,84	0,93															43,4	76,9	
21	160	0,24	0,24	0,24	0,34	0,34	0,34	0,47	0,49	0,54	0,66	0,73	0,81	0,94														43,5	76,7	
22	160	0,24	0,24	0,24	0,34	0,34	0,35	0,47	0,50	0,55	0,67	0,74	0,82	0,95														43,5	76,7	
23	170	0,21	0,21	0,21	0,30	0,30	0,30	0,41	0,44	0,48	0,59	0,65	0,72	0,84	0,93													43,6	76,5	
24	180	0,18	0,18	0,18	0,26	0,26	0,27	0,35	0,39	0,43	0,52	0,58	0,63	0,74	0,82	0,90												43,7	76,3	
25	180	0,18	0,18	0,18	0,26	0,26	0,27	0,35	0,39	0,43	0,52	0,58	0,64	0,75	0,83	0,91												43,7	76,3	
26	190	0,16	0,16	0,16	0,23	0,23	0,24	0,31	0,35	0,38	0,47	0,52	0,57	0,67	0,74	0,81	0,91											43,8	76,1	
27	200	0,14	0,14	0,14	0,20	0,20	0,22	0,28	0,31	0,34	0,42	0,46	0,51	0,60	0,66	0,73	0,82	0,91	0,99									43,9	75,9	

Figure 8-6: Maximum degrees of utilization of CLT_5_r3_c2 configuration

The following two graphic representations show the minimum necessary panel depth (ergo, the one corresponding to the highest degree of utilization) that fulfils all static requirements depending on the imposed load for the g_{k2} loading situation and every possible span.

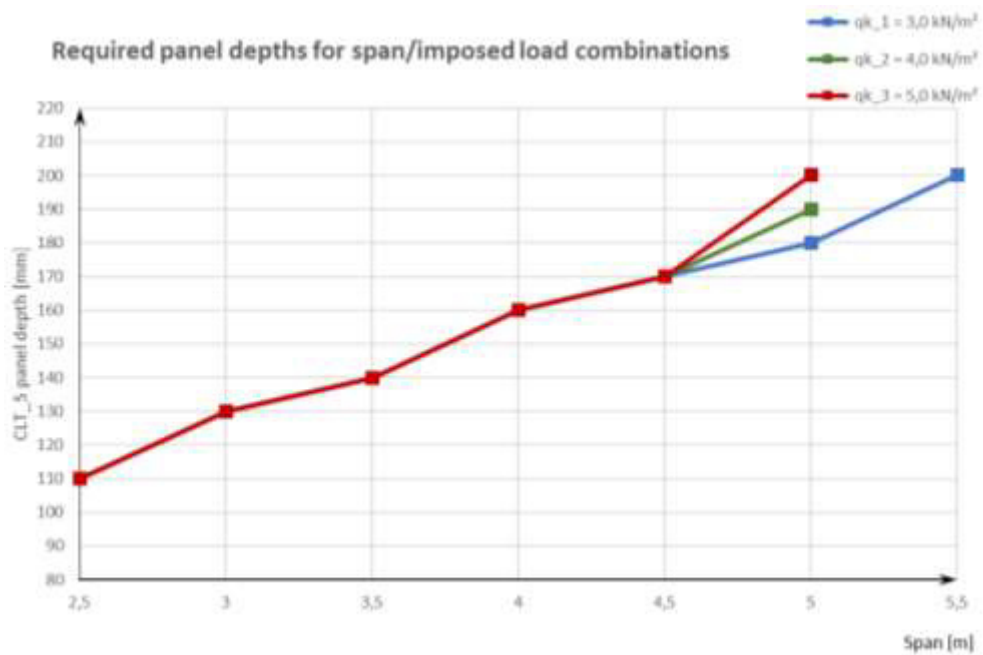


Figure 8-7: Minimum panel depths in regard to span for CLT_5_r1_c2 and CLT_5_r2_c2

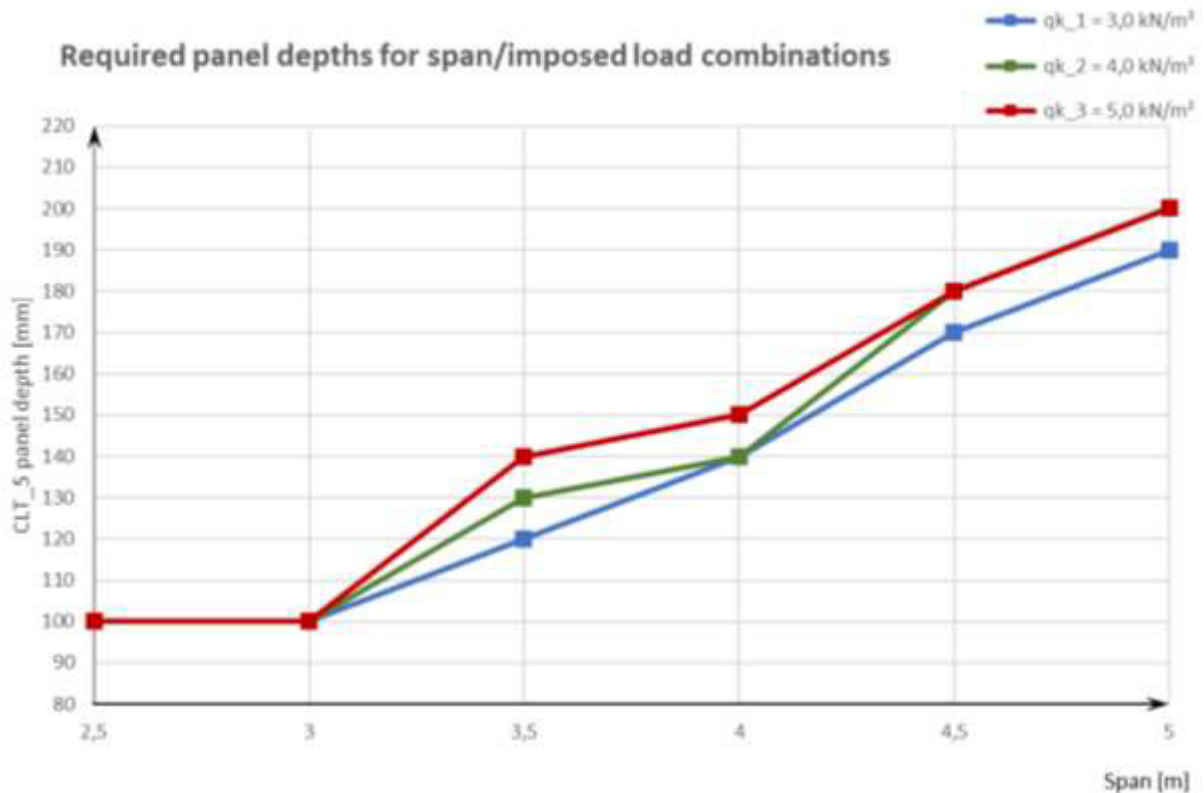


Figure 8-8: Minimum panel depths in regard to span for CLT_5_r3_c2 and CLT_5_r4_c2

The graphs in **Figure 8-7** and **Figure 8-8** show the minimum necessary panel depths on the vertical axis (ergo the one that corresponds to the highest degree of utilization in **Figure 8-5** to **Figure 8-6** and the attributed span length on the horizontal axis. The three lines in the diagram correspond to different imposed load levels. As explained previously, all span-load-panel depth combinations that cannot fulfil all requirements (namely ULS, SLS and ULS under fire conditions) are automatically eliminated and thus not shown in the table.

As we know from the practical experiences and built examples, five-layered CLT panels are commonly used for floor constructions. The representations in **Figure 8-5** and **Figure 8-6** underline that fact, as they can reach spans of 5,0 m with panel depths of 200 mm given our three imposed levels and dead load $g_{k,2}$. This span length more or less corresponds to the length at which CLT panels are most cost-effective and competitive when compared to other floor types. Five meters is also a more realistic and quite used span length in residential and smaller commercial buildings. Interestingly enough, the presence of the concrete screed doesn't turn the tide in favour of a more capable solution since the increase of bending stiffness capabilities on the one hand. Still, the addition of dead load, on the other hand, seem to nullify each other. The graphs of **Figure 8-7** and **Figure 8-8** show that a concrete screed allows the usage of small CLT panels for the lower span range; this aspect shall be strongly considered during the design process as the concrete screed is necessary to fulfil acoustic requirements. This fact is underlined by the better footfall and airborne sound properties of the solution with screed rather than those without it. In these cases, the needed

sound insulation requirements may be reached by adding sand or bounded fills above the CLT panel itself; this results in a dead load that doesn't contribute to the overall load carrying behaviour, unlike a loosely connected concrete screed. As the colours in the previous graphic representations underline, the SLS requirement again governs the design process; the deformation limits depending on the span are probably the most restricting criterium in this case. Since required panel depths do not change depending on the load level, the leading parameter is the stiffness criterium (see **Figure 8-7**). When the self-weight rises due to the presence of the loosely connected concrete screed, the leading verification become deflection limits, as we see different results depending on the imposed load level (**Figure 8-8**). The resistance to different fire durations (30 and 60 minutes doesn't provoke any different results). The situation doesn't change radically from what just explained when the dead load changes its value (g_k1 and g_k3).

8.1.4 Seven-layer CLT panel (CLT_7a)

Table 29 contains an overview of the different combinations between load and built-in situation (namely, presence of concrete screed or not) and the implemented duration of the fire. The three observed imposed loads (see **chapter 7.1.2**) are contained in each table. The following figures only show the gk_2 combination tables; the other two combinations are in the annexe. Otherwise, the shown data would rapidly become difficult to overlook.

Variations of CLT_7a		Self-weight		
		g_k1	g_k2	g_k3
Variant	R 60, no screed	CLT_7a_r1_c1	CLT_7a_r1_c2	CLT_7a_r1_c3
	R 30, no screed	CLT_7a_r2_c1	CLT_7a_r2_c2	CLT_7a_r2_c3
	R 60, screed 60 mm	CLT_7a_r3_c1	CLT_7a_r3_c2	CLT_7a_r3_c3
	R 30, screed 60 mm	CLT_7a_r4_c1	CLT_7a_r4_c2	CLT_7a_r4_c3

Table 29: Variation overview for CLT_7a

The following graphic representations will only show the CLT_7a_r1_c2 and CLT_7a_r3_c2 combinations because the different fire duration requirements don't impact the floor dimensioning or at least on the possible configurations. This fact has been highlighted in **chapter 8.1.2** and **chapter 8.1.3**.

8 Visualization and discussion of obtained results

CLT_7a panel configuration: CLT_7a_r1_c2																														
Resistance to fire: R 60, self-weight g_k2: 2,30 kN/m²																														
Panel Nr.	depth_tot	SPAN 1 = 2,5 m			SPAN 2 = 3,0 m			SPAN 3 = 3,5 m			SPAN 4 = 4,0 m			SPAN 5 = 4,5 m			SPAN 6 = 5,0 m			SPAN 7 = 5,5 m			SPAN 8 = 6,0 m			SPAN 9 = 6,5 m			R_w	L_w_eq
		qk = 3.0	qk = 4.0	qk = 5.0	qk = 3.0	qk = 4.0	qk = 5.0	qk = 3.0	qk = 4.0	qk = 5.0	qk = 3.0	qk = 4.0	qk = 5.0	qk = 3.0	qk = 4.0	qk = 5.0	qk = 3.0	qk = 4.0	qk = 5.0	qk = 3.0	qk = 4.0	qk = 5.0	qk = 3.0	qk = 4.0	qk = 5.0	qk = 3.0	qk = 4.0	qk = 5.0		
[]	[mm]	[kN/m²]			[kN/m²]			[kN/m²]			[kN/m²]			[kN/m²]			[kN/m²]			[kN/m²]			[kN/m²]			[dB]				
1	140	0,57	0,57	0,57	0,82	0,82	0,82																					36,1	88,9	
2	150	0,45	0,45	0,45	0,65	0,65	0,65	0,88	0,88	0,88																		36,7	88,2	
3	160	0,36	0,36	0,36	0,52	0,52	0,52	0,70	0,70	0,70	0,92	0,92	0,92															37,3	87,6	
4	160	0,35	0,35	0,35	0,51	0,51	0,51	0,69	0,69	0,69	0,90	0,90	0,90															37,3	87,6	
5	170	0,29	0,29	0,29	0,42	0,42	0,42	0,57	0,57	0,57	0,74	0,74	0,74	0,93	0,93													37,7	87,0	
6	180	0,24	0,24	0,24	0,35	0,35	0,35	0,47	0,47	0,47	0,61	0,61	0,62	0,78	0,79	0,88	0,96											38,0	86,5	
7	180	0,24	0,24	0,24	0,34	0,34	0,34	0,47	0,47	0,47	0,61	0,61	0,63	0,77	0,80	0,89	0,96											38,0	86,5	
8	190	0,20	0,20	0,20	0,29	0,29	0,29	0,39	0,39	0,39	0,51	0,51	0,55	0,65	0,70	0,78	0,84	0,96										38,3	86,0	
9	200	0,17	0,17	0,17	0,25	0,25	0,25	0,34	0,34	0,34	0,44	0,44	0,49	0,55	0,62	0,69	0,74	0,85	0,95	0,99								38,6	85,5	
10	160	0,42	0,42	0,42	0,60	0,60	0,60	0,81	0,81	0,81																		37,3	87,6	
11	170	0,33	0,33	0,33	0,48	0,48	0,48	0,65	0,65	0,65	0,84	0,84	0,84															37,7	87,0	
12	180	0,27	0,27	0,27	0,39	0,39	0,39	0,53	0,53	0,53	0,69	0,69	0,69	0,87	0,87	0,87												38,0	86,5	
13	180	0,26	0,26	0,26	0,38	0,38	0,38	0,52	0,52	0,52	0,67	0,67	0,67	0,85	0,85	0,85												38,0	86,5	
14	190	0,22	0,22	0,22	0,31	0,31	0,31	0,43	0,43	0,43	0,56	0,56	0,56	0,70	0,70	0,71	0,87	0,87	0,97									38,3	86,0	
15	200	0,18	0,18	0,18	0,26	0,26	0,26	0,36	0,36	0,36	0,47	0,47	0,47	0,59	0,59	0,62	0,73	0,76	0,85	0,89								38,6	85,5	
16	200	0,18	0,18	0,18	0,26	0,26	0,26	0,35	0,35	0,35	0,46	0,46	0,46	0,59	0,59	0,63	0,72	0,77	0,86	0,89								38,6	85,5	
17	210	0,15	0,15	0,15	0,22	0,22	0,22	0,30	0,30	0,30	0,39	0,39	0,39	0,50	0,50	0,55	0,61	0,68	0,76	0,79	0,90							38,8	85,0	
18	220	0,13	0,13	0,13	0,19	0,19	0,19	0,26	0,26	0,26	0,34	0,34	0,35	0,43	0,44	0,49	0,53	0,61	0,68	0,71	0,81	0,90	0,92					39,1	84,6	
19	180	0,32	0,32	0,32	0,45	0,45	0,45	0,62	0,62	0,62	0,81	0,81	0,81															38,0	86,5	
20	190	0,25	0,25	0,25	0,37	0,37	0,37	0,50	0,50	0,50	0,65	0,65	0,65	0,82	0,82	0,82												38,3	86,0	
21	200	0,21	0,21	0,21	0,30	0,30	0,30	0,41	0,41	0,41	0,53	0,53	0,53	0,67	0,67	0,67	0,83	0,83	0,83									38,6	85,5	
22	200	0,20	0,20	0,20	0,29	0,29	0,29	0,40	0,40	0,40	0,52	0,52	0,52	0,66	0,66	0,66	0,81	0,81	0,81	0,98	0,98							38,6	85,5	
23	210	0,17	0,17	0,17	0,25	0,25	0,25	0,33	0,33	0,33	0,43	0,43	0,43	0,55	0,55	0,55	0,68	0,68	0,71	0,82	0,84	0,94	0,97					38,8	85,0	
24	220	0,14	0,14	0,14	0,21	0,21	0,21	0,28	0,28	0,28	0,37	0,37	0,37	0,46	0,46	0,46	0,57	0,57	0,63	0,69	0,75	0,83	0,85	0,97				39,1	84,6	
25	220	0,14	0,14	0,14	0,21	0,21	0,21	0,28	0,28	0,28	0,36	0,36	0,36	0,46	0,46	0,46	0,57	0,57	0,63	0,69	0,75	0,84	0,86	0,97				39,1	84,6	
26	230	0,12	0,12	0,12	0,18	0,18	0,18	0,24	0,24	0,24	0,31	0,31	0,31	0,39	0,39	0,41	0,49	0,50	0,56	0,59	0,67	0,75	0,77	0,87	0,97	0,98		39,3	84,1	
27	240	0,11	0,11	0,11	0,15	0,15	0,15	0,21	0,21	0,21	0,27	0,27	0,27	0,34	0,34	0,37	0,42	0,45	0,51	0,53	0,60	0,67	0,69	0,78	0,88	0,88	1,00	39,5	83,7	
28	160	0,42	0,42	0,42	0,60	0,60	0,60	0,81	0,81	0,81																		37,3	87,6	
29	170	0,33	0,33	0,33	0,48	0,48	0,48	0,65	0,65	0,65	0,84	0,84	0,84															37,7	87,0	
30	180	0,27	0,27	0,27	0,39	0,39	0,39	0,53	0,53	0,53	0,69	0,69	0,69	0,87	0,87	0,87												38,0	86,5	
31	180	0,26	0,26	0,26	0,38	0,38	0,38	0,52	0,52	0,52	0,67	0,67	0,67	0,85	0,85	0,85												38,0	86,5	
32	190	0,22	0,22	0,22	0,31	0,31	0,31	0,43	0,43	0,43	0,56	0,56	0,56	0,70	0,70	0,71	0,87	0,87	0,97									38,3	86,0	
33	200	0,18	0,18	0,18	0,26	0,26	0,26	0,36	0,36	0,36	0,47	0,47	0,47	0,59	0,59	0,62	0,73	0,76	0,85	0,89								38,6	85,5	
34	200	0,18	0,18	0,18	0,26	0,26	0,26	0,36	0,36	0,36	0,46	0,46	0,46	0,59	0,59	0,63	0,72	0,77	0,86	0,90								38,6	85,5	
35	210	0,16	0,16	0,16	0,22	0,22	0,22	0,30	0,30	0,30	0,39	0,39	0,39	0,50	0,50	0,56	0,61	0,68	0,76	0,80	0,90							38,8	85,0	
36	220	0,13	0,13	0,13	0,19	0,19	0,19	0,26	0,26	0,26	0,34	0,34	0,35	0,43	0,44	0,49	0,53	0,61	0,68	0,71	0,81	0,90	0,92					39,1	84,6	
37	180	0,32	0,32	0,32	0,45	0,45	0,45	0,62	0,62	0,62	0,81	0,81	0,81															38,0	86,5	
38	190	0,25	0,25	0,25	0,37	0,37	0,37	0,50	0,50	0,50	0,65	0,65	0,65	0,82	0,82	0,82												38,3	86,0	
39	200	0,21	0,21	0,21	0,30	0,30	0,30	0,41	0,41	0,41	0,53	0,53	0,53	0,68	0,68	0,68	0,83	0,83	0,83									38,6	85,5	
40	200	0,21	0,21	0,21	0,29	0,29	0,29	0,40	0,40	0,40	0,52	0,52	0,52	0,66	0,66	0,66	0,81	0,81	0,81	0,98	0,98							38,6	85,5	
41	210	0,17	0,17	0,17	0,25	0,25	0,25	0,33	0,33	0,33	0,43	0,43	0,43	0,55	0,55	0,55	0,68	0,68	0,71	0,82	0,84	0,94	0,98					38,8	85,0	
42	220	0,14	0,14	0,14	0,21	0,21	0,21	0,28	0,28	0,28	0,37	0,37	0,37	0,47	0,47	0,47	0,57	0,57	0,63	0,69	0,75	0,84	0,85	0,97				39,1	84,6	
43	220	0,14	0,14	0,14	0,21	0,21	0,21	0,28	0,28	0,28	0,36	0,36	0,36	0,46	0,46	0,46	0,57	0,57	0,63	0,69	0,75	0,84	0,86	0,97				39,1	84,6	
44	230	0,12	0,12	0,12	0,18	0,18	0,18	0,24	0,24	0,24	0,31	0,31	0,31	0,39	0,39	0,41	0,49	0,50	0,56	0,59	0,67	0,75	0,77	0,87	0,97	0,98		39,3	84,1	
45	240	0,11	0,11	0,11	0,15	0,15	0,15	0,21	0,21	0,21	0,27	0,27	0,27	0,34	0,34	0,37	0,42	0,45	0,51	0,53	0,60	0,67	0,69	0,78	0,88	0,88	1,00	39,5	83,7	
46	200	0,25	0,25	0,25	0,36	0,36	0,36	0,48	0,48	0,48	0,63	0,63	0,63	0,80	0,80	0,80	0,99	0,99	0,99									38,6	85,5	
47	210	0,20	0,20	0,20	0,29	0,29	0,29	0,39	0,39	0,39	0,51	0,51	0,51	0,65	0,65	0,65	0,80	0,80	0,80	0,97	0,97	0,97					38,8	85,0		
48	220	0,17	0,17	0,17	0,24	0,24	0,24	0,33	0,33	0,33	0,43	0,43	0,43	0,54	0,54	0,54	0,66	0,66	0,66	0,80	0,80	0,80	0,96	0,96				39,1	84,6	
49	220	0,16	0,16	0,16	0,23	0,23	0,23	0,32	0,32	0,32	0,42	0,42	0,42	0,53	0,53	0,53	0,65	0,65	0,65	0,78	0,78	0,80	0,93	0,93				39,1	84,6	
50	230	0,14	0,14	0,14	0,20	0,20	0,20	0,27	0,27	0,27	0,35	0,35	0,35	0,44	0,44	0,44	0,54	0,54	0,											

8 Visualization and discussion of obtained results

CLT_7a panel configuration: CLT_7a_r3_c2																														
Resistance to fire: R 60, loose concrete screed depth: 60 mm, self-weight including concrete g_k2: 3,74 kN/m ²																														
Panel Nr.	depth_tot	SPAN 1 = 2,5 m			SPAN 2 = 3,0m			SPAN 3 = 3,5 m			SPAN 4 = 4,0 m			SPAN 5 = 4,5 m			SPAN 6 = 5,0 m			SPAN 7 = 5,5m			SPAN 8 = 6,0 m			SPAN 9 = 6,5 m			R_w	L_w_eq
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0		
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	140	0,32	0,32	0,32	0,46	0,46	0,46	0,63	0,67	0,74	0,90	1,00																43,2	77,1	
2	150	0,28	0,28	0,28	0,40	0,40	0,40	0,55	0,58	0,64	0,78	0,87	0,95															43,4	76,9	
3	160	0,24	0,24	0,24	0,35	0,35	0,35	0,48	0,51	0,56	0,68	0,75	0,83	0,97														43,5	76,7	
4	160	0,24	0,24	0,24	0,35	0,35	0,35	0,48	0,51	0,56	0,69	0,76	0,84	0,98														43,5	76,7	
5	170	0,21	0,21	0,21	0,31	0,31	0,31	0,42	0,45	0,50	0,61	0,67	0,74	0,86	0,96													43,6	76,5	
6	180	0,19	0,19	0,19	0,27	0,27	0,28	0,36	0,40	0,44	0,54	0,59	0,65	0,76	0,85	0,93												43,7	76,3	
7	180	0,19	0,19	0,19	0,27	0,27	0,28	0,36	0,40	0,44	0,54	0,60	0,66	0,77	0,85	0,94												43,7	76,3	
8	190	0,16	0,16	0,16	0,24	0,24	0,25	0,32	0,36	0,39	0,48	0,54	0,59	0,69	0,76	0,84	0,94											43,8	76,1	
9	200	0,14	0,14	0,14	0,21	0,21	0,22	0,29	0,32	0,35	0,43	0,48	0,53	0,62	0,68	0,75	0,84	0,94										43,9	75,9	
10	160	0,25	0,25	0,25	0,36	0,36	0,36	0,49	0,49	0,53	0,64	0,72	0,79	0,92														43,5	76,7	
11	170	0,22	0,22	0,22	0,31	0,31	0,31	0,43	0,43	0,46	0,56	0,62	0,69	0,80	0,89	0,98												43,6	76,5	
12	180	0,19	0,19	0,19	0,27	0,27	0,27	0,37	0,37	0,40	0,49	0,55	0,60	0,70	0,78	0,86	0,96											43,7	76,3	
13	180	0,19	0,19	0,19	0,27	0,27	0,27	0,37	0,37	0,41	0,50	0,55	0,61	0,71	0,79	0,86	0,97											43,7	76,3	
14	190	0,17	0,17	0,17	0,24	0,24	0,24	0,33	0,33	0,36	0,44	0,49	0,54	0,63	0,70	0,76	0,86	0,95										43,8	76,1	
15	200	0,15	0,15	0,15	0,21	0,21	0,21	0,29	0,29	0,32	0,39	0,43	0,48	0,56	0,62	0,68	0,77	0,85	0,93									43,9	75,9	
16	200	0,15	0,15	0,15	0,21	0,21	0,21	0,28	0,29	0,32	0,39	0,44	0,48	0,56	0,62	0,68	0,77	0,85	0,94									43,9	75,9	
17	210	0,13	0,13	0,13	0,18	0,18	0,18	0,25	0,26	0,29	0,35	0,39	0,43	0,50	0,56	0,61	0,69	0,77	0,84	0,92								44,0	75,8	
18	220	0,11	0,11	0,11	0,16	0,16	0,16	0,22	0,24	0,26	0,32	0,35	0,39	0,45	0,50	0,55	0,62	0,69	0,76	0,83	0,92							44,1	75,6	
19	180	0,20	0,20	0,20	0,28	0,28	0,28	0,38	0,38	0,39	0,50	0,53	0,58	0,68	0,75	0,82	0,93											43,7	76,3	
20	190	0,17	0,17	0,17	0,25	0,25	0,25	0,34	0,34	0,34	0,44	0,46	0,51	0,59	0,66	0,72	0,82	0,90	0,99									43,8	76,1	
21	200	0,15	0,15	0,15	0,22	0,22	0,22	0,30	0,30	0,30	0,39	0,41	0,45	0,53	0,58	0,64	0,72	0,80	0,88	0,96								43,9	75,9	
22	200	0,15	0,15	0,15	0,22	0,22	0,22	0,30	0,30	0,30	0,39	0,41	0,45	0,53	0,59	0,64	0,73	0,80	0,88	0,96								43,9	75,9	
23	210	0,13	0,13	0,13	0,19	0,19	0,19	0,26	0,26	0,27	0,34	0,37	0,40	0,47	0,52	0,57	0,65	0,72	0,79	0,86	0,95							44,0	75,8	
24	220	0,12	0,12	0,12	0,17	0,17	0,17	0,23	0,23	0,24	0,30	0,33	0,36	0,42	0,47	0,51	0,58	0,64	0,70	0,77	0,85	0,94	1,00					44,1	75,6	
25	220	0,12	0,12	0,12	0,17	0,17	0,17	0,23	0,23	0,24	0,30	0,33	0,36	0,42	0,47	0,52	0,58	0,64	0,71	0,77	0,86	0,94						44,1	75,6	
26	230	0,10	0,10	0,10	0,15	0,15	0,15	0,20	0,20	0,22	0,27	0,30	0,33	0,38	0,42	0,46	0,52	0,58	0,64	0,70	0,77	0,85	0,91					44,2	75,4	
27	240	0,09	0,09	0,09	0,13	0,13	0,13	0,18	0,18	0,20	0,24	0,27	0,30	0,35	0,38	0,42	0,48	0,53	0,58	0,63	0,70	0,77	0,82	0,91	0,99			44,2	75,3	
28	160	0,25	0,25	0,25	0,36	0,36	0,36	0,49	0,49	0,53	0,64	0,72	0,79	0,92														43,5	76,7	
29	170	0,22	0,22	0,22	0,31	0,31	0,31	0,43	0,43	0,46	0,56	0,63	0,69	0,80	0,89	0,98												43,6	76,5	
30	180	0,19	0,19	0,19	0,27	0,27	0,27	0,37	0,37	0,40	0,49	0,55	0,60	0,70	0,78	0,86	0,96											43,7	76,3	
31	180	0,19	0,19	0,19	0,27	0,27	0,27	0,37	0,37	0,41	0,50	0,55	0,61	0,71	0,79	0,86	0,97											43,7	76,3	
32	190	0,17	0,17	0,17	0,24	0,24	0,24	0,33	0,33	0,36	0,44	0,49	0,54	0,63	0,70	0,77	0,86	0,95										43,8	76,1	
33	200	0,15	0,15	0,15	0,21	0,21	0,21	0,29	0,29	0,32	0,39	0,44	0,48	0,56	0,62	0,68	0,77	0,85	0,93									43,9	75,9	
34	200	0,15	0,15	0,15	0,21	0,21	0,21	0,29	0,29	0,32	0,40	0,44	0,48	0,56	0,62	0,68	0,77	0,85	0,94									43,9	75,9	
35	210	0,13	0,13	0,13	0,18	0,18	0,18	0,25	0,26	0,29	0,35	0,39	0,43	0,50	0,56	0,61	0,69	0,77	0,84	0,92								44,0	75,8	
36	220	0,11	0,11	0,11	0,16	0,16	0,16	0,22	0,24	0,26	0,32	0,35	0,39	0,45	0,50	0,55	0,62	0,69	0,76	0,83	0,92							44,1	75,6	
37	180	0,20	0,20	0,20	0,28	0,28	0,28	0,38	0,38	0,39	0,50	0,53	0,58	0,68	0,75	0,82	0,93											43,7	76,3	
38	190	0,17	0,17	0,17	0,25	0,25	0,25	0,34	0,34	0,34	0,44	0,46	0,51	0,59	0,66	0,72	0,82	0,90	0,99									43,8	76,1	
39	200	0,15	0,15	0,15	0,22	0,22	0,22	0,30	0,30	0,30	0,39	0,41	0,45	0,53	0,58	0,64	0,72	0,80	0,88	0,96								43,9	75,9	
40	200	0,15	0,15	0,15	0,22	0,22	0,22	0,30	0,30	0,30	0,39	0,41	0,45	0,53	0,59	0,64	0,73	0,80	0,88	0,97								43,9	75,9	
41	210	0,13	0,13	0,13	0,19	0,19	0,19	0,26	0,26	0,27	0,34	0,37	0,40	0,47	0,52	0,57	0,65	0,72	0,79	0,86	0,95							44,0	75,8	
42	220	0,12	0,12	0,12	0,17	0,17	0,17	0,23	0,23	0,24	0,30	0,33	0,36	0,42	0,47	0,51	0,58	0,64	0,70	0,77	0,85	0,94						44,1	75,6	
43	220	0,12	0,12	0,12	0,17	0,17	0,17	0,23	0,23	0,24	0,30	0,33	0,36	0,42	0,47	0,52	0,58	0,64	0,71	0,77	0,86	0,94						44,1	75,6	
44	230	0,10	0,10	0,10	0,15	0,15	0,15	0,20	0,20	0,22	0,27	0,30	0,33	0,38	0,42	0,46	0,53	0,58	0,64	0,70	0,77	0,85	0,91					44,2	75,4	
45	240	0,09	0,09	0,09	0,13	0,13	0,13	0,18	0,18	0,20	0,24	0,27	0,30	0,35	0,38	0,42	0,48	0,53	0,58	0,63	0,70	0,77	0,82	0,91	0,99			44,2	75,3	
46	200	0,16	0,16	0,16	0,23	0,23	0,23	0,31	0,31	0,31	0,40	0,40	0,44	0,51	0,57	0,62	0,70	0,78	0,85	0,93								43,9	75,9	
47	210	0,14	0,14	0,14	0,20	0,20	0,20	0,27	0,27	0,27	0,36	0,36	0,39	0,45	0,50	0,55	0,62	0,69	0,76	0,83	0,92							44,0	75,8	
48	220	0,12	0,12	0,12	0,18	0,18	0,18	0,24	0,24	0,24	0,32	0,32	0,35	0,40	0,45	0,49	0,55	0,61	0,67	0,74	0,82	0,89	0,96					44,1	75,6	
49	220	0,12	0,12	0,12	0,18	0,18	0,18	0,24	0,24	0,24	0,31	0,32	0,35	0,41	0,45	0,49	0,56	0,62	0,68	0,74	0,82	0,90	0,96					44,1	75,6	
50	230	0,11	0,11	0,11	0,16	0,16	0,16	0,21	0,21	0,21	0,28																			

8 Visualization and discussion of obtained results

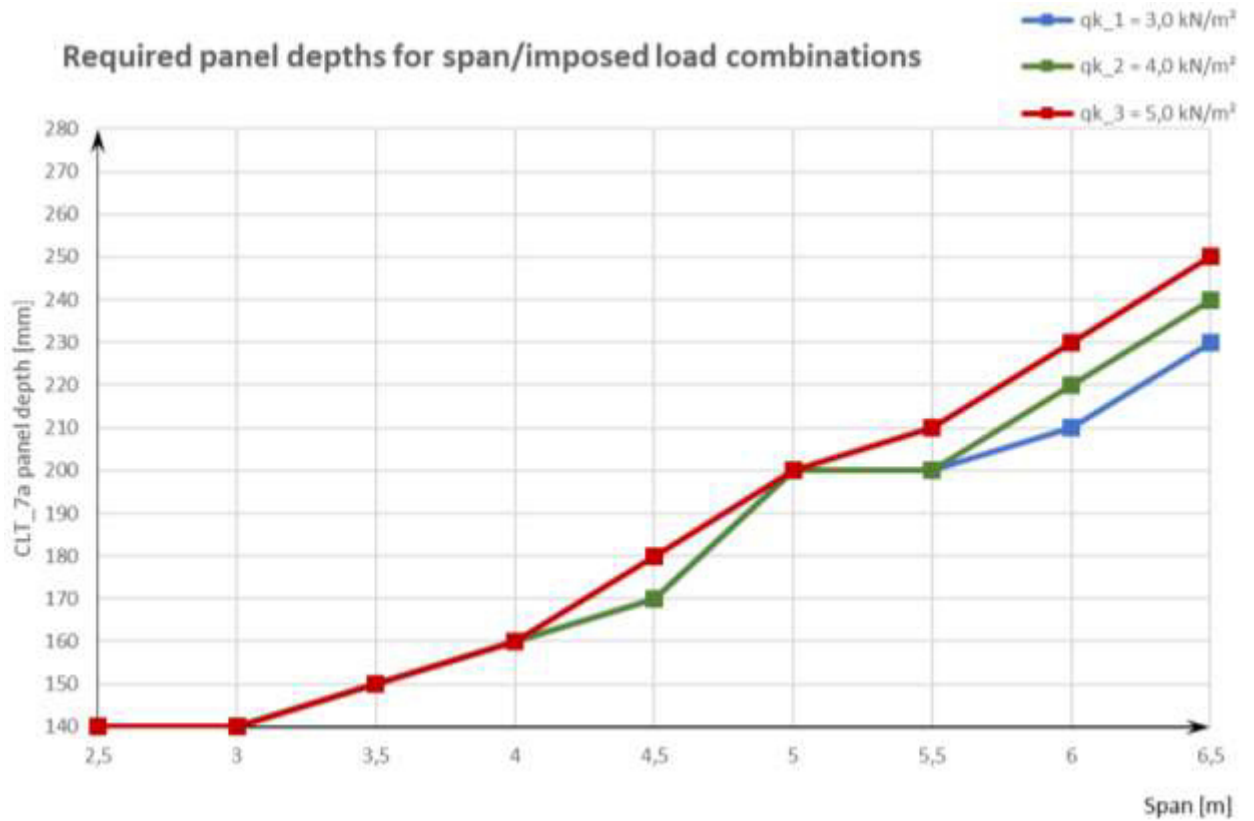


Figure 8-11: Minimum panel depths in regard to span for CLT_7a_r1_c2 and CLT_7a_r2_c2

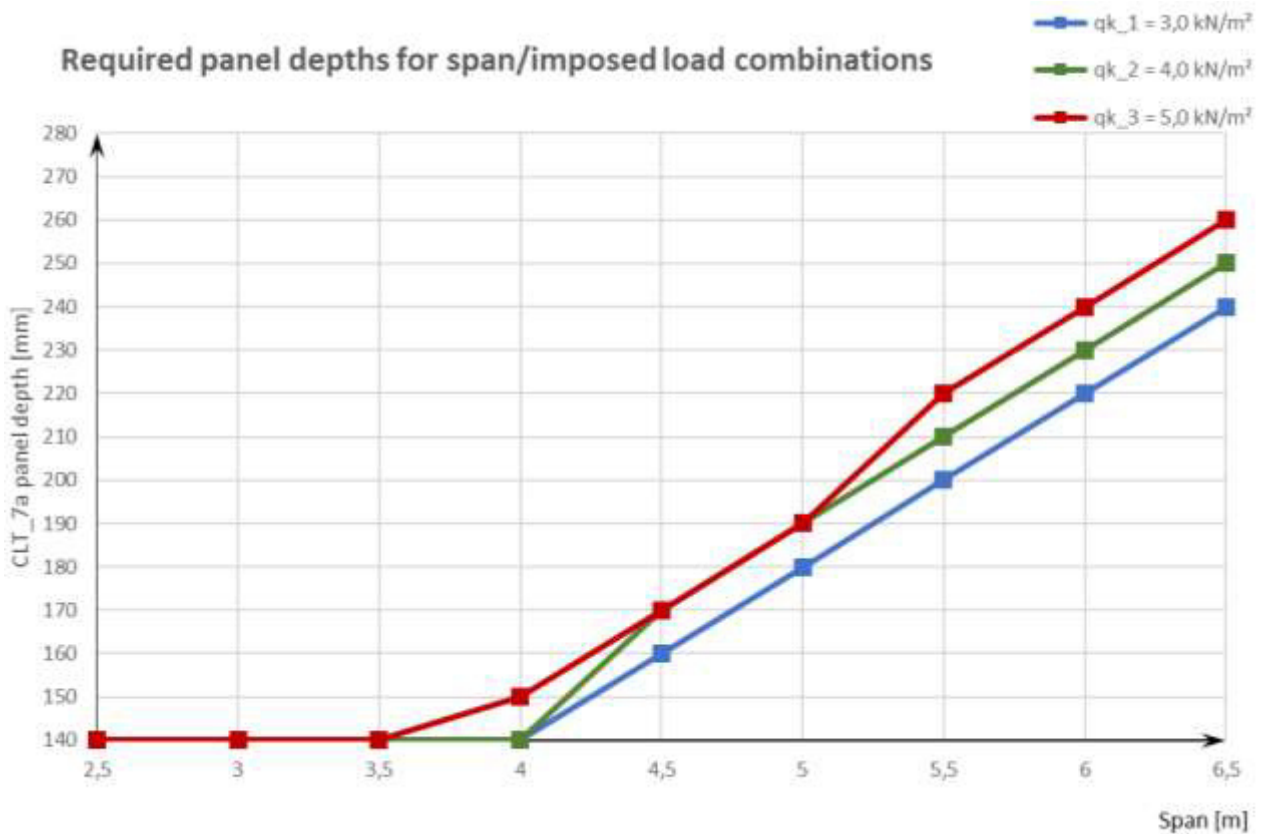


Figure 8-12: Minimum panel depths in regard to span for CLT_7a_r3_c2 and CLT_7a_r4_c2

Diagrams in **Figure 8-11** and **Figure 8-12** show minimum necessary panel depths on the vertical axis (corresponding to highest degree of utilization in **Figure 8-9** and **Figure 8-10**) and the attributed span on the horizontal axis. The three lines in the diagram correspond to different imposed load levels. Span-load-panel depth combinations that cannot fulfil all requirements (namely ULS, SLS and ULS under fire conditions) are eliminated and thus not shown in the table.

If seven-layered CLT (version A, see **Figure 7-3**) panel is used, it is possible to reach the maximum span of 6,5 m, which is considerable for a bare CLT panel. In such cases, the panel depths become significant as they start from 230 mm. These solutions would be especially interesting for standard commercial destinations, as generally speaking, the used spans are longer, and the higher total floor package depth is less of a concern since the interior height. Thus, the maximum building cubature is not as important as they are in residential buildings. Interestingly enough, the presence of the concrete screed doesn't move the needle since the increase of total bending stiffness on the one hand. Still, it adds more flexibility in the lower span range and for thinner panels, opening up more options. The concrete screed presence, on the other hand, is arguably counterproductive when it comes to longer spans due to the added weight. These solutions lead to lower utilization ratios in the upper span range. The graphs of **Figure 8-11** and **Figure 8-12** show that concrete screed allows the usage of small CLT panels for the lower span range; this aspect shall be strongly considered during the design process as the concrete screed is necessary to fulfil acoustic requirements. The stiffness criterium (see **chapter 7.3.8**), which is solely linked to the panel conformation and thus stiffness is the leading verification for the lower span range while deflection limits are leading in the higher span range of **Figure 8-11**. Contrarily to that, deflection limits are leading for lower spans already when a concrete screed is present (see **Figure 8-12**).

8.1.5 Seven-layer CLT panel (CLT_7b)

Table 29 contains an overview of the different combinations between load and built-in situation (namely, presence of concrete screed or not) and the fire's implemented duration. The three observed imposed loads (see **chapter 7.1.2**) are contained in each table. The following figures only show the gk₂ combination tables; the other two combinations are in the annexe. Otherwise, the displayed data would rapidly become difficult to overlook.

Variations of CLT_7b		Self-weight		
		g_k1	g_k2	g_k3
Variant	R 60, no screed	CLT_7b_r1_c1	CLT_7b_r1_c2	CLT_7b_r1_c3
	R 30, no screed	CLT_7b_r2_c1	CLT_7b_r2_c2	CLT_7b_r2_c3
	R 60, screed 60 mm	CLT_7b_r3_c1	CLT_7b_r3_c2	CLT_7b_r3_c3
	R 30, screed 60 mm	CLT_7b_r4_c1	CLT_7b_r4_c2	CLT_7b_r4_c3

Table 30: Variation overview for CLT_7b

The following graphic representations will only show the CLT_7b_r1_c2 and CLT_7b_r3_c2 combinations because the different fire duration requirements do not impact the floor dimensioning or at least on the possible configurations. This fact has been highlighted in **chapter 8.1.2** and **chapter 8.1.3**.

If a seven-layered CLT (version B, see **Figure 7-3**) panel is used, it is possible to reach the maximum span of 6,5 m for any imposed load level, which is considerable for a bare CLT panel. In such cases, the panel depths become significant as they start from 230 mm. Because of the different lamella disposition, CLT 7_b panels have slightly lower bending stiffness parallel to span than their CLT_7a counterpart but still show higher stiffness cross to span, which is of interest also for transmission of horizontal loads. Interestingly enough, the presence of the concrete screed doesn't move the needle since the increase of total bending stiffness on the one hand, but the addition of dead load, on the other hand, seem to nullify each other. The tables in Annex A – 7-layer CLT panel (CLT-7b) show that the presence of a concrete screed allows the usage of small CLT panels for the lower span range; this aspect shall be strongly considered during the design process as the concrete screed is necessary to fulfil acoustic requirements. For further aspects that also apply to the seven-layered panels, refer to **chapter 8.1.3** and **chapter 8.1.4**.

8.2 TCC floor with screws as shear connectors

8.2.1 Characterizing Parameters

Two main parameters distinguish the tables one from another, namely the resistance to fire and the concrete screed depth above the CLT panel itself. Since we are talking TCC floors, obviously, the screed and CLT panel are connected by screws. This screed consisting of two different overall depths (90 mm and 120 mm) contributes to the floor panel's total stiffness and thus to the load-carrying capabilities of the floor itself. Concerning the fire resistance as a requirement for timber floors, two different fire durations have been implemented in the tool: 30 and 60 minutes. This means that four different tables per CLT panel types are the output and sixteen tables overall for the CLT panel solution. To avoid a further varying parameter, the screw spacing ($s_{min} = 200\text{ mm}$; $s_{max} = 400\text{ mm}$) and the number of screws (8) per span is constant for all four pre-dimensioning tables.

In order to understand which type of verification is the leading one during the dimensioning process for each combination, colours have been awarded and are visible in every single table (see **Figure 8-1**). This allows the reader to recognize if the ULS, SLS or ULS under fire conditions verifications are crucial. Because the observation of different points is necessary, these three main groups are further divided into subgroups characterized by their related point in time: “ t_0 ”, “ t_{mid} ” and “ t_{fin} ”. The ULS group contains all the verifications undertaken in **chapter 7.2.7**, the SLS group

all formulas applied in **chapter 7.2.8**, and the ULS under fire conditions includes all material verifications present in **chapter 7.2.9**.

Legend: CRUCIAL CRITERIUMS		
SLS_fin	ULS_fi_fin	ULS_fin
SLS_mid	ULS_fi_mid	ULS_mid
SLS-t0	ULS_fi_t0	ULS_t0

Figure 8-13: Legend of crucial criteriums

8.2.2 3-layer CLT panel (CLT_3)

No CLT panel configuration can fulfil the needed requirements for any of the analysed spans, be it with a 90 mm or 120 mm screed. Therefore, no results are shown.

8.2.3 5-layer CLT panel (CLT_5)

8.2.4 Variations of CLT_5		Self-weight		
		g_k1	g_k2	g_k3
Variant	R 60, 90 mm screed	TCC_5_s_r1_c1	TCC_5_s_r1_c2	TCC_5_s_r1_c3
	R 60, 120 mm screed	TCC_5_s_r2_c1	TCC_5_s_r2_c2	TCC_5_s_r2_c3
	R 30, 90 mm screed	TCC_5_s_r3_c1	TCC_5_s_r3_c2	TCC_5_s_r3_c3
	R 30, 120 mm screed	TCC_5_s_r4_c1	TCC_5_s_r4_c2	TCC_5_s_r4_c3

Table 31 contains an overview of the different combinations between load and built-in situation (namely, presence of concrete screed or not) and the fire's implemented duration. The three observed imposed loads (see **chapter 7.1.2**) are contained in each table. The following figures only show the g_k2 combination tables because otherwise, the illustrated data would rapidly become difficult to overlook.

Variations of CLT_5		Self-weight		
		g_k1	g_k2	g_k3
Variant	R 60, 90 mm screed	TCC_5_s_r1_c1	TCC_5_s_r1_c2	TCC_5_s_r1_c3
	R 60, 120 mm screed	TCC_5_s_r2_c1	TCC_5_s_r2_c2	TCC_5_s_r2_c3
	R 30, 90 mm screed	TCC_5_s_r3_c1	TCC_5_s_r3_c2	TCC_5_s_r3_c3
	R 30, 120 mm screed	TCC_5_s_r4_c1	TCC_5_s_r4_c2	TCC_5_s_r4_c3

Table 31: Variation overview for TCC_5_screws

8 Visualization and discussion of obtained results

CLT_5 panel configuration: TCC_5_S_r1_c2																														
Resistance to fire: R 60, concrete screed depth: 90 mm, self-weight including concrete $g_k2: 4,46 \text{ kN/m}^2$, screws as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			acoustic	
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	R_w	L_w_eq
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	100																											52,4	68,3	
2	110																											52,6	68,1	
3	120	0,96	0,98																									52,9	67,8	
4	120	0,97																										52,9	67,8	
5	130	0,85	0,89	0,97																								53,1	67,6	
6	140	0,75	0,81	0,88	0,92																							53,3	67,3	
7	140	0,75	0,81	0,88	0,92																							53,3	67,3	
8	150	0,68	0,74	0,81	0,84	0,92																						53,5	67,1	
9	160	0,62	0,68	0,74	0,77	0,84	0,92	0,94																				53,7	66,9	
10	120	0,99	0,99																									52,9	67,8	
11	130	0,88	0,88	0,93																								53,1	67,6	
12	140	0,78	0,78	0,84	0,92	0,97																						53,3	67,3	
13	140	0,78	0,78	0,84	0,91	0,97																						53,3	67,3	
14	150	0,69	0,71	0,77	0,81	0,88	0,96	0,98																				53,5	67,1	
15	160	0,61	0,64	0,70	0,73	0,80	0,87	0,90	0,98																			53,7	66,9	
16	160	0,61	0,65	0,70	0,73	0,80	0,87	0,90	0,99																			53,7	66,9	
17	170	0,55	0,59	0,64	0,67	0,74	0,80	0,82	0,90	0,98	1,00																53,9	66,7		
18	180	0,50	0,55	0,59	0,62	0,68	0,73	0,76	0,83	0,90	0,92																54,1	66,4		
19	140	0,81	0,81	0,82	0,95	0,95																						53,3	67,3	
20	150	0,72	0,72	0,74	0,85	0,85	0,93	0,99																				53,5	67,1	
21	160	0,65	0,65	0,67	0,76	0,77	0,84	0,88	0,95																			53,7	66,9	
22	160	0,64	0,64	0,68	0,75	0,78	0,84	0,88	0,95																			53,7	66,9	
23	170	0,57	0,57	0,62	0,67	0,71	0,77	0,79	0,87	0,95	0,96																53,9	66,7		
24	180	0,51	0,52	0,56	0,60	0,65	0,70	0,73	0,80	0,87	0,88	0,96															54,1	66,4		
25	180	0,51	0,52	0,57	0,60	0,65	0,71	0,73	0,80	0,87	0,88	0,97															54,1	66,4		
26	190	0,46	0,48	0,52	0,55	0,60	0,65	0,67	0,73	0,80	0,81	0,89	0,97	0,97													54,3	66,2		
27	200	0,41	0,45	0,48	0,51	0,55	0,60	0,62	0,68	0,74	0,75	0,82	0,89	0,89	0,98												54,5	66,0		

Figure 8-14: CLT_5_r1_c2 configuration

CLT_5 panel configuration: TCC_5_S_r2_c2																														
Resistance to fire: R 60, concrete screed depth: 120 mm, self-weight including concrete $g_k2: 4,46 \text{ kN/m}^2$, screws as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			acoustic	
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	R_w	L_w_eq
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	100																											55,9	64,6	
2	110																											56,0	64,4	
3	120	0,69	0,75	0,81	0,85	0,93																						56,2	64,2	
4	120																											56,2	64,2	
5	130	0,66	0,69	0,74	0,79	0,86	0,93	0,96																				56,4	64,0	
6	140	0,59	0,64	0,69	0,72	0,79	0,85	0,88	0,96																			56,6	63,8	
7	140	0,60	0,64	0,69	0,73	0,79	0,85	0,89	0,97																			56,6	63,8	
8	150	0,54	0,59	0,64	0,67	0,73	0,79	0,82	0,89	0,96	0,98																	56,7	63,6	
9	160	0,51	0,55	0,59	0,62	0,68	0,73	0,76	0,82	0,89	0,91	0,99															56,9	63,4		
10	120	0,69	0,73	0,79	0,84	0,91	0,99																					56,2	64,2	
11	130	0,62	0,67	0,72	0,76	0,83	0,90	0,94																				56,4	64,0	
12	140	0,57	0,62	0,66	0,70	0,76	0,82	0,86	0,93																			56,6	63,8	
13	140	0,57	0,62	0,67	0,70	0,77	0,83	0,86	0,94																			56,6	63,8	
14	150	0,53	0,57	0,61	0,65	0,70	0,76	0,79	0,86	0,93	0,95																56,7	63,6		
15	160	0,49	0,53	0,57	0,60	0,65	0,70	0,73	0,79	0,86	0,88	0,96															56,9	63,4		
16	160	0,52	0,54	0,57	0,60	0,65	0,70	0,73	0,80	0,86	0,88	0,96															56,9	63,4		
17	170	0,47	0,49	0,53	0,56	0,60	0,65	0,68	0,74	0,80	0,82	0,89	0,96	0,97													57,1	63,3		
18	180	0,42	0,46	0,49	0,52	0,56	0,61	0,63	0,68	0,74	0,76	0,82	0,89	0,90	0,98												57,2	63,1		
19	140	0,56	0,61	0,65	0,69	0,75	0,81	0,84	0,92	1,00																		56,6	63,8	
20	150	0,51	0,56	0,60	0,63	0,69	0,74	0,77	0,84	0,91	0,93																56,7	63,6		
21	160	0,47	0,51	0,55	0,58	0,63	0,68	0,71	0,77	0,84	0,86	0,93															56,9	63,4		
22	160	0,49	0,51	0,55	0,59	0,64	0,69	0,71	0,78	0,84	0,86	0,94															56,9	63,4		
23	170	0,44	0,48	0,51	0,54	0,59	0,63	0,66	0,72	0,77	0,79	0,86	0,93	0,95													57,1	63,3		
24	180	0,41	0,44	0,47	0,50	0,55	0,59	0,61	0,66	0,72	0,74	0,80	0,86	0,87	0,95												57,2	63,1		
25	180	0,45	0,46	0,48	0,51	0,55	0,59	0,61	0,67	0,72	0,74	0,80	0,86	0,88	0,95												57,2	63,1		
26	190	0,41	0,42	0,44	0,47	0,51	0,55	0,57	0,62	0,67	0,68	0,74	0,80	0,81	0,89	0,96	0,96										57,4	62,9		
27	200	0,37	0,39	0,41	0,44	0,47	0,51	0,53	0,58	0,62	0,64	0,69	0,75	0,76	0,82	0,89	0,89	0,97									57,6	62,7		

Figure 8-15: CLT_5_r2_c2 configuration

8 Visualization and discussion of obtained results

CLT_5 panel configuration: TCC_5_S_r3_c2																														
Resistance to fire: R 30, concrete screed depth: 90 mm, self-weight including concrete g_{k2} : 4,46 kN/m ² , screws as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			acoustic	
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	R_w	L_w_eq
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	100																											52,4	68,3	
2	110																											52,6	68,1	
3	120	0,96	0,98																									52,9	67,8	
4	120	0,96	0,99																									52,9	67,8	
5	130	0,85	0,89	0,97																								53,1	67,6	
6	140	0,75	0,81	0,88	0,92																							53,3	67,3	
7	140	0,75	0,81	0,88	0,92																							53,3	67,3	
8	150	0,68	0,74	0,81	0,84	0,92																						53,5	67,1	
9	160	0,62	0,68	0,74	0,77	0,84	0,92	0,94																				53,7	66,9	
10	120	0,99	0,99																									52,9	67,8	
11	130	0,88	0,88	0,93																								53,1	67,6	
12	140	0,78	0,78	0,84	0,92	0,97																						53,3	67,3	
13	140	0,78	0,78	0,84	0,91	0,97																						53,3	67,3	
14	150	0,69	0,71	0,77	0,81	0,88	0,96	0,98																				53,5	67,1	
15	160	0,61	0,64	0,70	0,73	0,80	0,87	0,90	0,98																			53,7	66,9	
16	160	0,61	0,65	0,70	0,73	0,80	0,87	0,90	0,99																			53,7	66,9	
17	170	0,55	0,59	0,64	0,67	0,74	0,80	0,82	0,90	0,98	1,00																	53,9	66,7	
18	180	0,50	0,55	0,59	0,62	0,68	0,73	0,76	0,83	0,90	0,92																	53,9	66,4	
19	140	0,81	0,81	0,82	0,95	0,95																						53,3	67,3	
20	150	0,72	0,72	0,74	0,85	0,85	0,93	0,99																				53,5	67,1	
21	160	0,65	0,65	0,67	0,76	0,77	0,84	0,88	0,95																			53,7	66,9	
22	160	0,64	0,64	0,68	0,75	0,78	0,84	0,88	0,95																			53,7	66,9	
23	170	0,57	0,57	0,62	0,67	0,71	0,77	0,79	0,87	0,95	0,96																	53,9	66,7	
24	180	0,51	0,52	0,56	0,60	0,65	0,70	0,73	0,80	0,87	0,88	0,96																54,1	66,4	
25	180	0,51	0,52	0,57	0,60	0,65	0,71	0,73	0,80	0,87	0,88	0,97																54,1	66,4	
26	190	0,46	0,48	0,52	0,55	0,60	0,65	0,67	0,73	0,80	0,81	0,89	0,97	0,97														54,3	66,2	
27	200	0,41	0,45	0,48	0,51	0,55	0,60	0,62	0,68	0,74	0,75	0,82	0,89	0,89	0,98													54,5	66,0	

Figure 8-16: CLT_5_r3_c2 configuration

CLT_5 panel configuration: TCC_5_S_r4_c2																														
Resistance to fire: R 30, concrete screed depth: 120 mm, self-weight including concrete g_{k2} : 4,46 kN/m ² , screws as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			acoustic	
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	R_w	L_w_eq
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	100	0,82	0,90	0,98																								55,9	64,6	
2	110	0,75	0,82	0,89	0,94																							56,0	64,4	
3	120	0,69	0,75	0,81	0,85	0,93																						56,2	64,2	
4	120	0,69	0,75	0,81	0,86	0,94																						56,2	64,2	
5	130	0,63	0,69	0,74	0,79	0,86	0,93	0,96																				56,4	64,0	
6	140	0,59	0,64	0,69	0,72	0,79	0,85	0,88	0,96																			56,6	63,8	
7	140	0,59	0,64	0,69	0,73	0,79	0,85	0,89	0,97																			56,6	63,8	
8	150	0,54	0,59	0,64	0,67	0,73	0,79	0,82	0,89	0,96	0,98																	56,7	63,6	
9	160	0,51	0,55	0,59	0,62	0,68	0,73	0,76	0,82	0,89	0,91	0,99																56,9	63,4	
10	120	0,67	0,73	0,79	0,84	0,91	0,99																					56,2	64,2	
11	130	0,62	0,67	0,72	0,76	0,83	0,90	0,94																				56,4	64,0	
12	140	0,57	0,62	0,66	0,70	0,76	0,82	0,86	0,93																			56,6	63,8	
13	140	0,57	0,62	0,67	0,70	0,77	0,83	0,86	0,94																			56,6	63,8	
14	150	0,53	0,57	0,61	0,65	0,70	0,76	0,79	0,86	0,93	0,95																	56,7	63,6	
15	160	0,49	0,53	0,57	0,60	0,65	0,70	0,73	0,79	0,86	0,88	0,96																56,9	63,4	
16	160	0,49	0,53	0,57	0,60	0,65	0,70	0,73	0,80	0,86	0,88	0,96																56,9	63,4	
17	170	0,45	0,49	0,53	0,56	0,60	0,65	0,68	0,74	0,80	0,82	0,89	0,96	0,97														57,1	63,3	
18	180	0,42	0,46	0,49	0,52	0,56	0,61	0,63	0,68	0,74	0,76	0,82	0,89	0,90	0,98													57,2	63,1	
19	140	0,56	0,61	0,65	0,69	0,75	0,81	0,84	0,92	1,00																		56,6	63,8	
20	150	0,51	0,56	0,60	0,63	0,69	0,74	0,77	0,84	0,91	0,93																	56,7	63,6	
21	160	0,47	0,51	0,55	0,58	0,63	0,68	0,71	0,77	0,84	0,86	0,93																56,9	63,4	
22	160	0,48	0,51	0,55	0,59	0,64	0,69	0,71	0,78	0,84	0,86	0,94																56,9	63,4	
23	170	0,44	0,48	0,51	0,54	0,59	0,63	0,66	0,72	0,77	0,79	0,86	0,93	0,95														57,1	63,3	
24	180	0,41	0,44	0,47	0,50	0,55	0,59	0,61	0,66	0,72	0,74	0,80	0,86	0,87	0,95													57,2	63,1	
25	180	0,41	0,44	0,48	0,51	0,55	0,59	0,61	0,67	0,72	0,74	0,80	0,86	0,88	0,95													57,2	63,1	
26	190	0,38	0,41	0,44	0,47	0,51	0,55	0,57	0,62	0,67	0,68	0,74	0,80	0,81	0,89	0,96	0,96											57,4	62,9	
27	200	0,36	0,39	0,41	0,44	0,47	0,51	0,53	0,58	0,62	0,64	0,69	0,75	0,76	0,82	0,89	0,89	0,97										57,6	62,7	

Figure 8-17: CLT_5_r4_c2 configuration

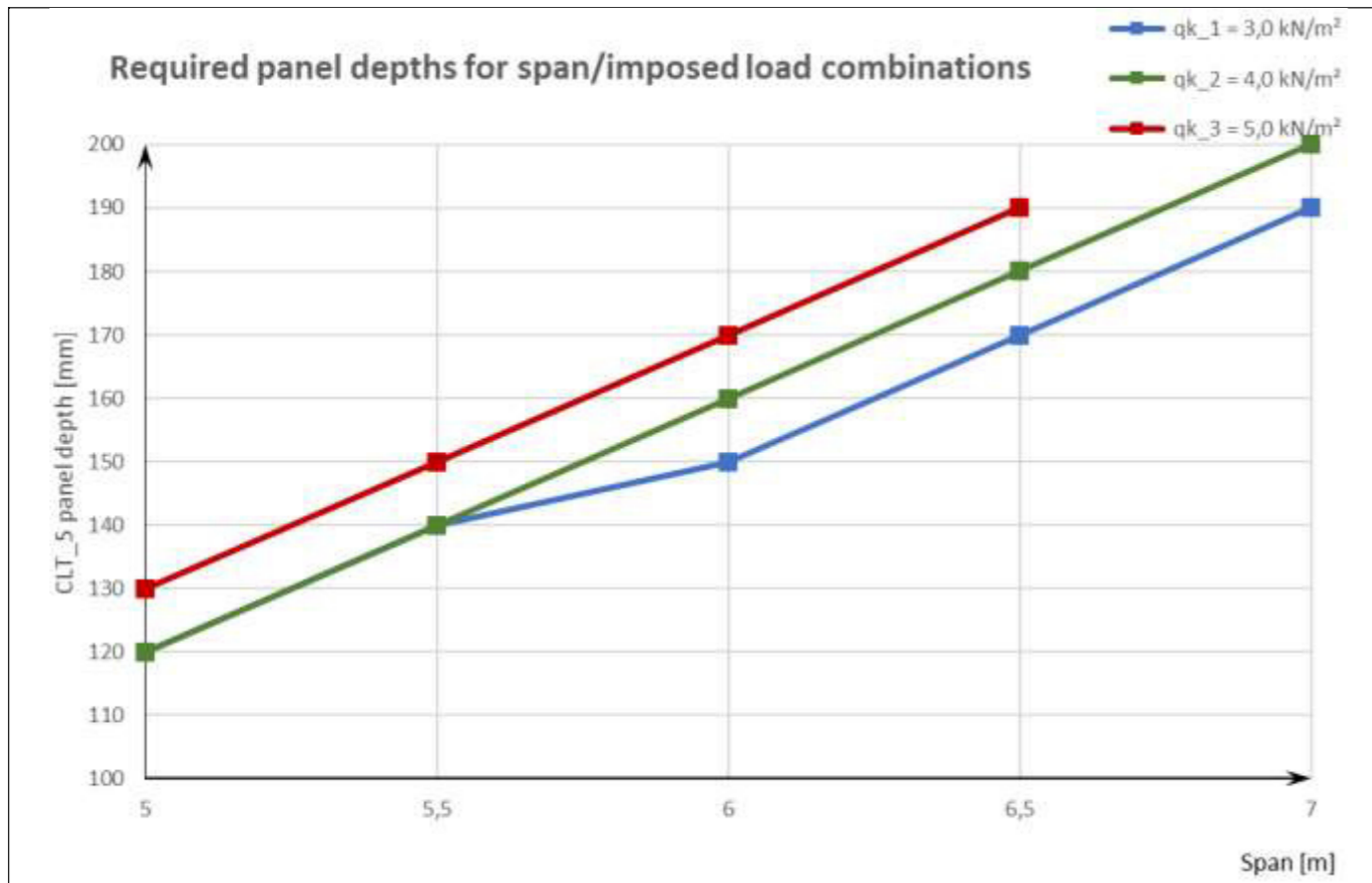


Figure 8-18: Minimum panel depths in regard to span for TCC_5_s_r1_c2

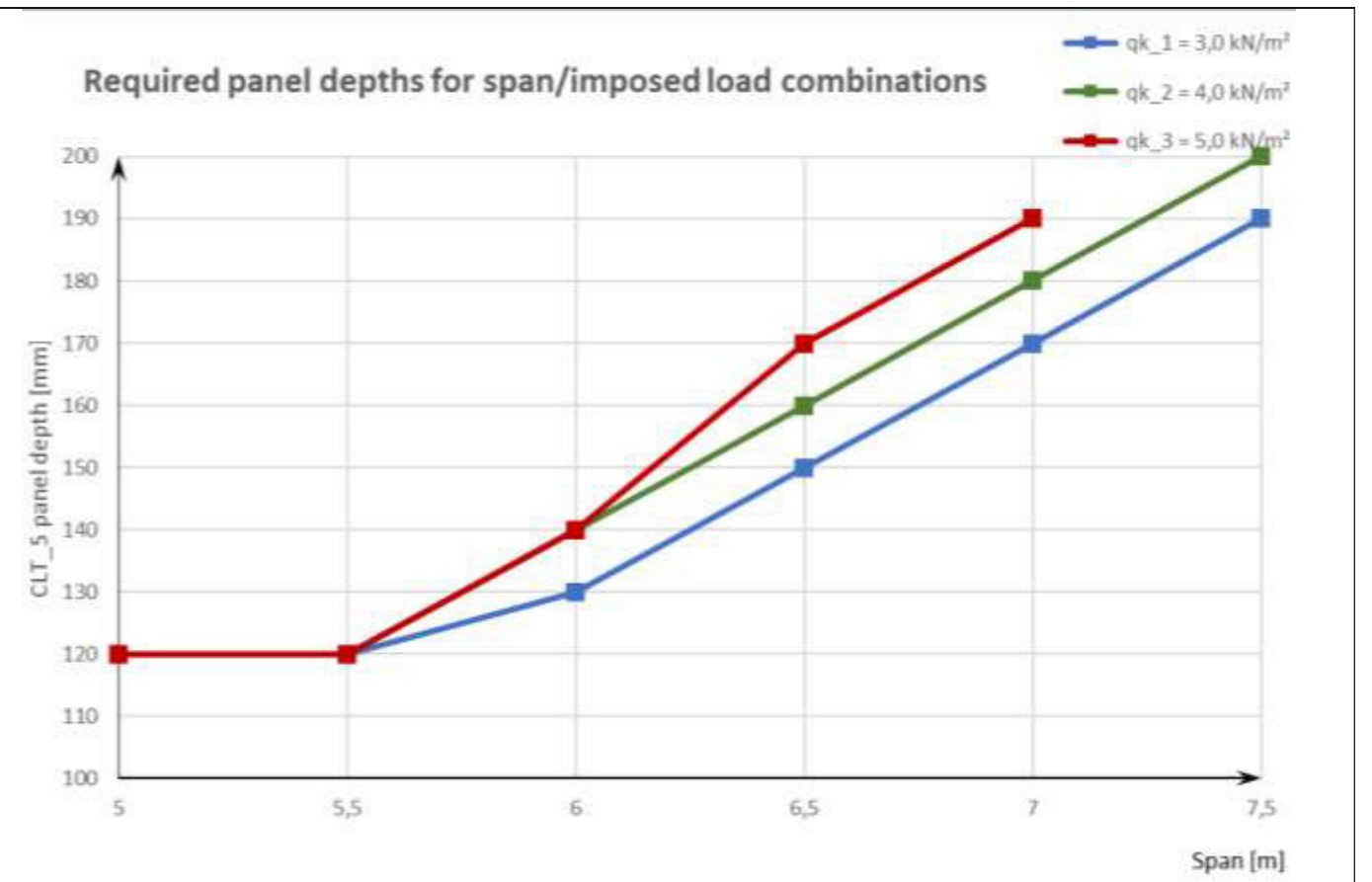


Figure 8-19: Minimum panel depths in regard to span for TCC_5_s_r2_c2

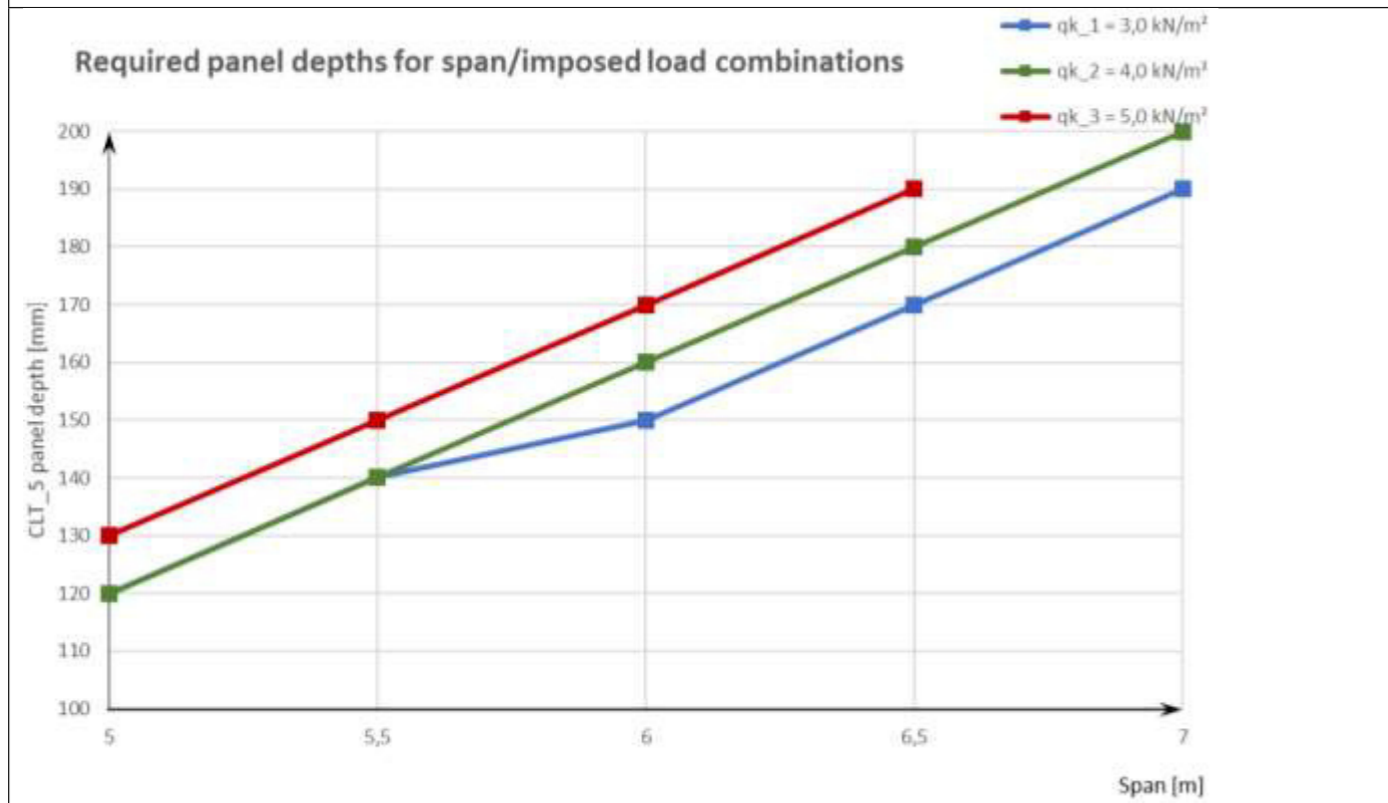


Figure 8-20: Minimum panel depths in regard to span for TCC_5_s_r3_c2

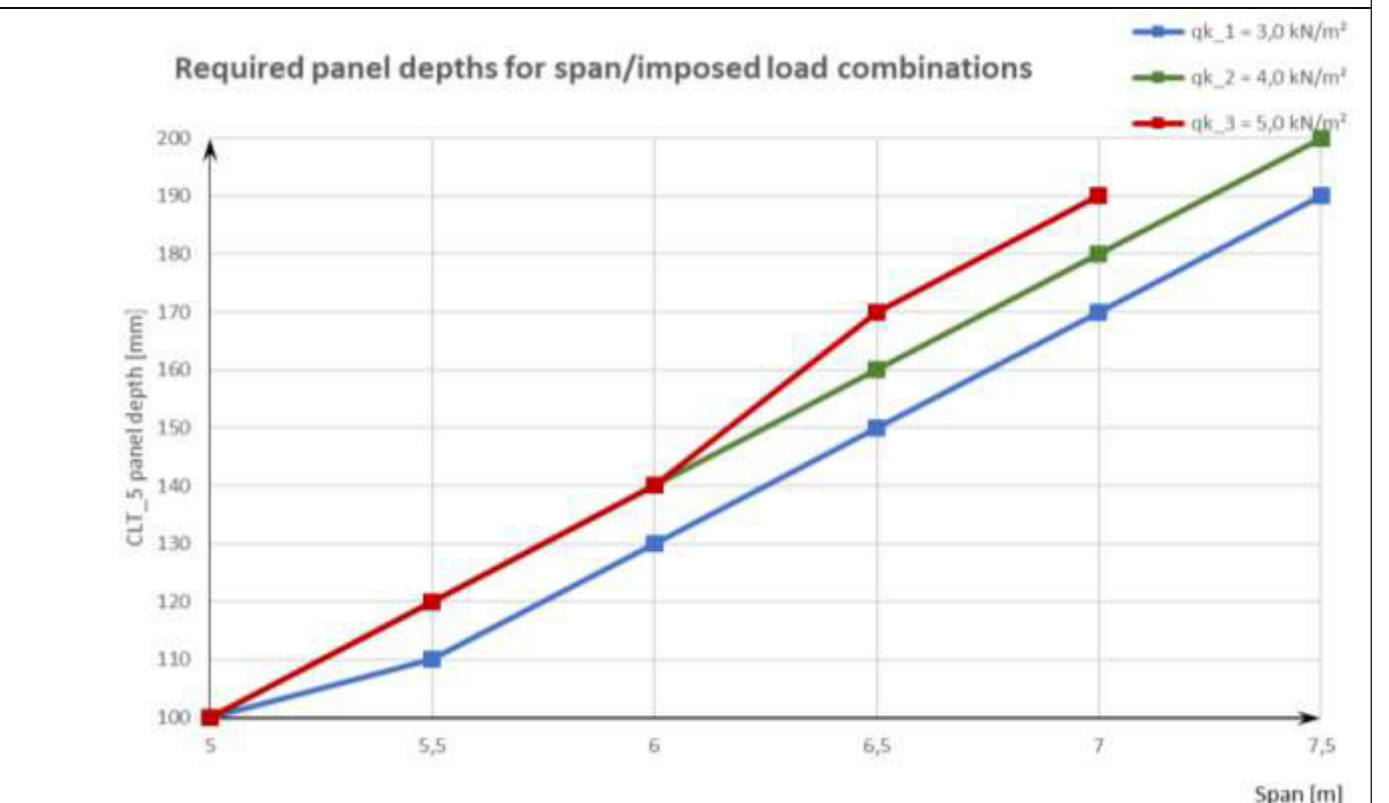


Figure 8-21: Minimum panel depths in regard to span for TCC_5_s_r4_c2

A few observations can be made concerning the results shown in **Figure 8-14** to **Figure 8-16**:

The influence of the concrete screed depth is considerable, as it allows to reach a span of 7,5 m coupled with 120 mm of the concrete screed. If the concrete screed thickness amounts to 90 mm, the maximum reachable span is 7,0 m. Thanks to the increased total bending stiffness, a wealth of solutions suddenly becomes available, especially for lower spans coupled with smaller panels.

Another noteworthy thing is the low fire resistance duration influence. When it amounts to 60 min, the fire at “t_fin” becomes the verification yielding the highest degrees of utilization for CLT panels with low spans and load levels paired with concrete screed depths of 90 mm. When the concrete screed depth rises to 120 mm, results influenced by fire duration are nowhere to be found, since the added concrete depth heavily contributes to total load-carrying capability. Fire protection durations of 30 min have no impact on results, independently from the concrete screed depth. In this case, the SLS verifications become more relevant due to their higher degrees of utilization.

Noteworthy is the fact that the SLS verifications at “t_fin” yield the maximum usages for lower characteristic imposed loads (namely 3,0 kN/m²) while SLS at a point in time “t_mid” is more relevant for panels configurations subject to higher imposed load levels. At this point in time, concrete displays different creeping and thus deformational behaviour than timber (see **Figure 7-5**) and loads are partially transferred from concrete to timber. The higher the concrete screed depth is, the more creep is going to happen. This results in SLS “t_mid” being the leading verification for 120 mm concrete screed and high imposed load levels.

Therefore, we can conclude that the shift towards a shorter exposure to fire coupled with a high concrete screed depth leads to configurations dictated by SLS verifications. On the other end of the scale, the small span area is governed by the ULS_fi requirement for low spans and thin panels and SLS “t_fin” requirement for thin panels. As we shift towards higher spans, the SLS “t_mid” requirement becomes the leading one. SLS “t_0” is never relevant because at this point no creeping and therefore no reduction of overall bending stiffness has happened yet.

On the subject of minimal panel depth to span lengths (see **Figure 8-18** to **Figure 8-21**), the behaviour is linear dependent on the span increase. **Figure 8-18** and **Figure 8-20** are identical, which means that fire protection duration has no influence on the most cost-effective solutions. This influence is visible after comparing **Figure 8-19** to **Figure 8-21**, as fire protection duration dictates panel dimensions in the lower span range. Otherwise, both figures are identical, indicating a shift towards SLS verifications as the leading ones during the dimensioning process. As for the same span, its highest imposed load does require a smaller CLT panel depth compared to the other two load levels. This happens because of the different bending stiffness of the CLT panel itself because two panels of the same depth but contrasting lamella disposition have not the same

stiffness. In these cases, the panel configuration can be found after searching the corresponding panel number (at the left-hand side of **Figure 8-18** to **Figure 8-21**, respectively) and double-check with **Table 20**. When two result courses in the previous graphs yield the same results the stiffness criterium, which is independent of the actual loading situation, is the relevant one.

8.2.5 7-layer CLT panel (CLT_7a)

Table 32 overview over the different combinations between load and built-in situation (namely presence of concrete screed or not) and the implemented duration of the fire.

Variations of CLT_7a		Self-weight		
		g_k1	g_k2	g_k3
Variant	R 60, 90 mm screed	TCC_7a_s_r1_c1	TCC_7a_s_r1_c2	TCC_7a_s_r1_c3
	R 60, 120 mm screed	TCC_7a_s_r2_c1	TCC_7a_s_r2_c2	TCC_7a_s_r2_c3
	R 30, 90 mm screed	TCC_7a_s_r3_c1	TCC_7a_s_r3_c2	TCC_7a_s_r3_c3
	R 30, 120 mm screed	TCC_7a_s_r4_c1	TCC_7a_s_r4_c2	TCC_7a_s_r4_c3

Table 32: Variation overview for TCC_7a_screws

8 Visualization and discussion of obtained results

CLT_7a panel configuration: TCC_7a_s_r1_c2																														
Resistance to fire: R 60, concrete screed depth: 90 mm, self-weight including concrete g_k2: 4,46 kN/m ² , screws as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			R_w	L_w_eq
		dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0		
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]	
1	140	0,90	0,89	0,90																									53,3	67,3
2	150	0,80	0,80	0,81	0,93	0,93																							53,5	67,1
3	160	0,72	0,72	0,73	0,83	0,84	0,92	0,96																					53,7	66,9
4	160	0,71	0,71	0,74	0,83	0,84	0,92	0,95																					53,7	66,9
5	170	0,64	0,63	0,67	0,74	0,77	0,84	0,86	0,94																				53,9	66,7
6	180	0,57	0,57	0,61	0,66	0,70	0,76	0,78	0,86	0,94	0,94																		54,1	66,4
7	180	0,57	0,58	0,62	0,68	0,72	0,77	0,82	0,86	0,94	0,97																		54,1	66,4
8	190	0,52	0,54	0,57	0,63	0,66	0,70	0,76	0,79	0,86	0,89	0,96																	54,3	66,2
9	200	0,48	0,50	0,52	0,58	0,61	0,65	0,69	0,73	0,79	0,81	0,88	0,96	0,96															54,5	66,0
10	160	0,74	0,74	0,74	0,86	0,86	0,90	1,00																					53,7	66,9
11	170	0,67	0,67	0,67	0,78	0,78	0,81	0,90	0,92																				53,9	66,7
12	180	0,60	0,60	0,60	0,70	0,70	0,74	0,81	0,83	0,91	0,92																		54,1	66,4
13	180	0,60	0,59	0,60	0,69	0,69	0,74	0,80	0,84	0,91	0,93																		54,1	66,4
14	190	0,53	0,53	0,55	0,62	0,64	0,68	0,73	0,77	0,83	0,86	0,93																	54,3	66,2
15	200	0,48	0,49	0,51	0,57	0,59	0,62	0,67	0,71	0,77	0,79	0,85	0,93	0,92															54,5	66,0
16	200	0,50	0,53	0,55	0,62	0,64	0,67	0,74	0,77	0,81	0,87	0,91	0,95																54,5	66,0
17	210	0,47	0,49	0,51	0,57	0,60	0,63	0,68	0,71	0,75	0,80	0,84	0,88	0,92	0,97														54,7	65,8
18	220	0,43	0,45	0,48	0,53	0,55	0,58	0,63	0,66	0,69	0,73	0,77	0,80	0,84	0,88	0,95	0,96												54,9	65,6
19	180	0,62	0,62	0,62	0,73	0,73	0,73	0,84	0,84	0,90	0,96	1,00																	54,1	66,4
20	190	0,56	0,56	0,56	0,66	0,66	0,67	0,76	0,76	0,82	0,87	0,91	0,99	0,99															54,3	66,2
21	200	0,51	0,51	0,51	0,59	0,59	0,61	0,68	0,69	0,75	0,78	0,83	0,91	0,90	0,99														54,5	66,0
22	200	0,50	0,50	0,53	0,59	0,61	0,64	0,70	0,73	0,76	0,82	0,86	0,91	0,94	1,00														54,5	66,0
23	210	0,45	0,47	0,49	0,54	0,57	0,59	0,65	0,68	0,71	0,75	0,79	0,83	0,87	0,92	1,00	0,99												54,7	65,8
24	220	0,41	0,43	0,45	0,50	0,52	0,54	0,59	0,62	0,65	0,69	0,72	0,77	0,79	0,84	0,92	0,91	1,00											54,9	65,6
25	220	0,43	0,45	0,48	0,53	0,55	0,58	0,63	0,66	0,69	0,74	0,77	0,81	0,85	0,89	0,93	0,97												54,9	65,6
26	230	0,41	0,43	0,44	0,49	0,52	0,54	0,58	0,61	0,64	0,68	0,72	0,75	0,79	0,83	0,86	0,90	0,94											55,1	65,4
27	240	0,37	0,39	0,42	0,45	0,47	0,50	0,54	0,56	0,59	0,63	0,66	0,69	0,72	0,76	0,79	0,82	0,86	0,94	0,92									55,3	65,2
28	160	0,74	0,74	0,74	0,86	0,86	0,90	1,00																					53,7	66,9
29	170	0,67	0,67	0,67	0,78	0,78	0,81	0,90	0,92																				53,9	66,7
30	180	0,60	0,60	0,60	0,70	0,70	0,74	0,81	0,84	0,91	0,92																		54,1	66,4
31	180	0,60	0,59	0,60	0,69	0,69	0,74	0,80	0,84	0,91	0,93																		54,1	66,4
32	190	0,53	0,53	0,55	0,62	0,64	0,68	0,73	0,77	0,83	0,86	0,93																	54,3	66,2
33	200	0,48	0,49	0,51	0,56	0,59	0,62	0,67	0,70	0,77	0,78	0,85	0,93	0,92															54,5	66,0
34	200	0,50	0,52	0,55	0,61	0,64	0,67	0,73	0,77	0,80	0,86	0,90	0,94	1,00															54,5	66,0
35	210	0,47	0,49	0,51	0,57	0,59	0,62	0,68	0,71	0,74	0,79	0,83	0,87	0,92	0,96														54,7	65,8
36	220	0,43	0,45	0,47	0,52	0,55	0,57	0,62	0,65	0,68	0,73	0,76	0,80	0,84	0,88	0,95	0,96												54,9	65,6
37	180	0,62	0,62	0,62	0,73	0,73	0,73	0,84	0,84	0,90	0,96	1,00																	54,1	66,4
38	190	0,56	0,56	0,56	0,66	0,66	0,67	0,76	0,76	0,82	0,87	0,91	0,99	0,99															54,3	66,2
39	200	0,51	0,51	0,51	0,59	0,59	0,61	0,68	0,69	0,75	0,78	0,83	0,91	0,90	0,99														54,5	66,0
40	200	0,50	0,51	0,53	0,59	0,62	0,65	0,71	0,74	0,78	0,83	0,87	0,91	0,96															54,5	66,0
41	210	0,46	0,48	0,50	0,55	0,58	0,61	0,66	0,69	0,72	0,77	0,81	0,85	0,89	0,93	1,00													54,7	65,8
42	220	0,42	0,44	0,46	0,51	0,53	0,56	0,60	0,63	0,66	0,71	0,74	0,77	0,81	0,85	0,92	0,92	1,00											54,9	65,6
43	220	0,44	0,47	0,49	0,54	0,57	0,59	0,64	0,68	0,71	0,76	0,79	0,83	0,87	0,92	0,96	1,00												54,9	65,6
44	230	0,41	0,43	0,45	0,50	0,53	0,55	0,60	0,63	0,65	0,70	0,73	0,77	0,81	0,84	0,88	0,92	0,96											55,1	65,4
45	240	0,38	0,40	0,42	0,46	0,48	0,51	0,55	0,57	0,60	0,64	0,67	0,70	0,73	0,77	0,80	0,84	0,87	0,94	0,94									55,3	65,2
46	200	0,53	0,53	0,53	0,62	0,62	0,62	0,71	0,71	0,74	0,82	0,82	0,90	0,92	0,98														54,5	66,0
47	210	0,49	0,49	0,49	0,56	0,56	0,56	0,65	0,65	0,68	0,74	0,75	0,82	0,84	0,90	0,98	0,97												54,7	65,8
48	220	0,47	0,47	0,47	0,51	0,51	0,53	0,59	0,59	0,62	0,67	0,69	0,75	0,76	0,83	0,90	0,89	0,98											54,9	65,6
49	220	0,46	0,46	0,46	0,50	0,50	0,53	0,58	0,60	0,62	0,67	0,70	0,76	0,77	0,83	0,90	0,90	0,98											54,9	65,6
50	230	0,43	0,43	0,43	0,46	0,47	0,51	0,53	0,56	0,60	0,62	0,65	0,70	0,72	0,77	0,84	0,83	0,91	0,99	0,97									55,1	65,4
51	240	0,41	0,41	0,41	0,42	0,44	0,49	0,49	0,52	0,58	0,57	0,60	0,67	0,66	0,71	0,77	0,77	0,84	0,92	0,90	0,99								55,3	65,2
52	240	0,40	0,40	0,41	0,44	0,46	0,49	0,52	0,54	0,58	0,60	0,63	0,67	0,70	0,73	0,77	0,79	0,84	0,92	0,90	0,99								55,3	65,2
53	250	0,37	0,37	0,40	0,41	0,43	0,48	0,49	0,51	0,56	0,57	0,59	0,64	0,65	0,68	0,73	0,74	0,78	0,85	0,84	0,92	1,00	0,97					55,5	65,0	
54	260	0,35	0,35	0,39	0,38	0,41	0,46	0,45	0,49	0,54	0,53	0,56	0,62	0,60	0,64	0,71	0,69	0,73	0,79	0,78	0,86	0,93	0,91	0,99						

8 Visualization and discussion of obtained results

CLT_7a panel configuration: TCC_7a_s_r2_c2																														
Resistance to fire: R 60, concrete screed depth: 120 mm, self-weight including concrete g_k2: 4,46 kN/m ² , screws as shear connectors																														
Panel Nr.	depth_tot [mm]	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			acoustic	
		q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	R_w	L_w,eq
1	140	0,63	0,67	0,72	0,76	0,83	0,89	0,92																					53,3	67,3
2	150	0,56	0,61	0,66	0,69	0,76	0,82	0,84	0,92	1,00																			53,5	67,1
3	160	0,52	0,56	0,61	0,64	0,70	0,75	0,78	0,85	0,92	0,93																	53,7	66,9	
4	160	0,54	0,57	0,61	0,64	0,70	0,75	0,78	0,85	0,92	0,93																	53,7	66,9	
5	170	0,49	0,52	0,56	0,59	0,64	0,70	0,72	0,78	0,85	0,86	0,94																53,9	66,7	
6	180	0,45	0,48	0,52	0,55	0,60	0,64	0,67	0,72	0,78	0,80	0,87	0,94	0,95														53,9	66,4	
7	180	0,47	0,49	0,52	0,55	0,60	0,65	0,67	0,73	0,78	0,80	0,87	0,94	0,95														54,1	66,4	
8	190	0,43	0,45	0,49	0,51	0,56	0,60	0,62	0,67	0,73	0,74	0,81	0,87	0,88	0,96													54,3	66,2	
9	200	0,39	0,42	0,45	0,48	0,52	0,56	0,58	0,63	0,68	0,69	0,75	0,81	0,82	0,89	0,97	0,96											54,5	66,0	
10	160	0,51	0,56	0,60	0,63	0,69	0,74	0,77	0,84	0,90	0,92																	53,7	66,9	
11	170	0,47	0,51	0,55	0,58	0,63	0,68	0,70	0,77	0,83	0,85	0,92																53,9	66,7	
12	180	0,44	0,47	0,51	0,54	0,58	0,63	0,65	0,71	0,77	0,78	0,85	0,92	0,93														54,1	66,4	
13	180	0,46	0,48	0,51	0,54	0,58	0,63	0,65	0,71	0,77	0,78	0,85	0,92	0,93														54,1	66,4	
14	190	0,42	0,44	0,47	0,50	0,54	0,58	0,60	0,66	0,71	0,72	0,79	0,85	0,86	0,94													54,3	66,2	
15	200	0,39	0,41	0,44	0,46	0,50	0,54	0,56	0,61	0,66	0,67	0,73	0,79	0,80	0,87	0,94	0,94											54,5	66,0	
16	200	0,41	0,43	0,44	0,48	0,50	0,54	0,57	0,61	0,66	0,68	0,73	0,79	0,80	0,87	0,94	0,94											54,5	66,0	
17	210	0,39	0,40	0,42	0,45	0,47	0,51	0,54	0,57	0,61	0,65	0,68	0,74	0,76	0,81	0,88	0,87	0,95										54,7	65,8	
18	220	0,36	0,37	0,40	0,43	0,45	0,49	0,51	0,54	0,57	0,61	0,64	0,69	0,71	0,76	0,82	0,82	0,89	0,96	0,95								54,9	65,6	
19	180	0,44	0,47	0,50	0,53	0,58	0,62	0,64	0,70	0,76	0,77	0,84	0,91	0,92														54,1	66,4	
20	190	0,40	0,43	0,47	0,49	0,53	0,57	0,60	0,65	0,70	0,71	0,78	0,84	0,85	0,92	1,00												54,3	66,2	
21	200	0,37	0,40	0,43	0,46	0,49	0,53	0,55	0,60	0,65	0,66	0,72	0,78	0,78	0,85	0,92	0,92											54,5	66,0	
22	200	0,39	0,41	0,43	0,46	0,49	0,53	0,55	0,60	0,65	0,66	0,72	0,78	0,79	0,86	0,93	0,92											54,5	66,0	
23	210	0,37	0,39	0,41	0,43	0,46	0,49	0,52	0,56	0,60	0,62	0,67	0,72	0,73	0,79	0,86	0,86	0,93	1,00									54,7	65,8	
24	220	0,34	0,36	0,40	0,41	0,43	0,48	0,49	0,52	0,56	0,58	0,62	0,67	0,68	0,74	0,80	0,80	0,87	0,94	0,93								54,9	65,6	
25	220	0,36	0,37	0,40	0,43	0,45	0,48	0,52	0,54	0,56	0,62	0,64	0,67	0,72	0,75	0,80	0,83	0,87	0,94	0,95								54,9	65,6	
26	230	0,34	0,35	0,39	0,41	0,43	0,47	0,49	0,52	0,55	0,58	0,61	0,64	0,68	0,71	0,75	0,78	0,82	0,88	0,89	0,95							55,1	65,4	
27	240	0,32	0,34	0,38	0,39	0,41	0,46	0,46	0,49	0,54	0,55	0,57	0,62	0,64	0,66	0,72	0,73	0,76	0,82	0,83	0,89	0,96	0,94				55,3	65,2		
28	160	0,51	0,56	0,60	0,63	0,69	0,74	0,77	0,84	0,90	0,92																	53,7	66,9	
29	170	0,47	0,51	0,55	0,58	0,63	0,68	0,70	0,77	0,83	0,85	0,92																53,9	66,7	
30	180	0,44	0,47	0,51	0,54	0,58	0,63	0,65	0,71	0,77	0,78	0,85	0,92	0,93														54,1	66,4	
31	180	0,46	0,47	0,51	0,54	0,58	0,63	0,65	0,71	0,77	0,78	0,85	0,92	0,93														54,1	66,4	
32	190	0,42	0,44	0,47	0,50	0,54	0,58	0,60	0,66	0,71	0,72	0,79	0,85	0,86	0,94													54,3	66,2	
33	200	0,38	0,41	0,44	0,46	0,50	0,54	0,56	0,61	0,66	0,67	0,73	0,79	0,80	0,87	0,94	0,94											54,5	66,0	
34	200	0,41	0,43	0,44	0,48	0,50	0,54	0,57	0,61	0,66	0,68	0,73	0,79	0,80	0,87	0,94	0,94											54,5	66,0	
35	210	0,38	0,40	0,41	0,45	0,47	0,51	0,54	0,57	0,61	0,64	0,68	0,74	0,75	0,81	0,88	0,87	0,95										54,7	65,8	
36	220	0,36	0,37	0,40	0,43	0,44	0,49	0,51	0,53	0,57	0,61	0,64	0,69	0,71	0,76	0,82	0,82	0,89	0,96	0,95								54,9	65,6	
37	180	0,44	0,47	0,50	0,53	0,58	0,62	0,64	0,70	0,76	0,77	0,84	0,91	0,92														54,1	66,4	
38	190	0,41	0,43	0,47	0,49	0,53	0,57	0,60	0,65	0,70	0,71	0,78	0,84	0,85	0,92	1,00												54,3	66,2	
39	200	0,37	0,40	0,43	0,46	0,49	0,53	0,55	0,60	0,65	0,66	0,72	0,78	0,78	0,85	0,92	0,92											54,5	66,0	
40	200	0,40	0,42	0,43	0,47	0,49	0,53	0,55	0,60	0,65	0,66	0,72	0,78	0,79	0,86	0,93	0,92											54,5	66,0	
41	210	0,38	0,39	0,41	0,44	0,46	0,49	0,53	0,56	0,60	0,63	0,67	0,72	0,73	0,79	0,86	0,86	0,93	1,00									54,7	65,8	
42	220	0,35	0,36	0,40	0,41	0,43	0,48	0,50	0,52	0,56	0,59	0,62	0,67	0,69	0,74	0,80	0,80	0,87	0,94	0,93								54,9	65,6	
43	220	0,36	0,38	0,40	0,44	0,46	0,48	0,53	0,55	0,58	0,63	0,66	0,68	0,74	0,77	0,80	0,85	0,88	0,94	0,97								54,9	65,6	
44	230	0,34	0,36	0,39	0,42	0,44	0,47	0,50	0,52	0,55	0,60	0,62	0,65	0,69	0,72	0,75	0,80	0,83	0,88	0,91	0,95							55,1	65,4	
45	240	0,32	0,34	0,38	0,39	0,41	0,46	0,47	0,49	0,54	0,56	0,58	0,62	0,65	0,67	0,72	0,74	0,78	0,82	0,84	0,89	0,96	0,95				55,3	65,2		
46	200	0,38	0,40	0,43	0,45	0,49	0,53	0,55	0,59	0,64	0,66	0,71	0,77	0,78	0,85	0,92	0,91	1,00										54,5	66,0	
47	210	0,37	0,37	0,40	0,42	0,45	0,49	0,51	0,55	0,59	0,61	0,66	0,71	0,72	0,78	0,85	0,85	0,92	1,00	0,99								54,7	65,8	
48	220	0,36	0,36	0,39	0,39	0,43	0,47	0,47	0,51	0,56	0,57	0,61	0,66	0,67	0,73	0,79	0,79	0,86	0,93	0,92								54,9	65,6	
49	220	0,36	0,36	0,39	0,40	0,43	0,47	0,48	0,51	0,56	0,57	0,61	0,66	0,67	0,73	0,79	0,79	0,86	0,93	0,92								54,9	65,6	
50	230	0,35	0,35	0,38	0,38	0,42	0,46	0,46	0,49	0,54	0,54	0,57	0,63	0,63	0,68	0,73	0,73	0,80	0,86	0,86	0,93	0,99					55,1	65,4		
51	240	0,34	0,34	0,37	0,36	0,41	0,45	0,43	0,48	0,53	0,51	0,56	0,62	0,59	0,64	0,71	0,69	0,75	0,81	0,80	0,87	0,94	0,92				55,3	65,2		
52	240	0,33	0,34	0,37	0,38	0,41	0,45	0,45	0,48	0,53	0,53	0,56	0,62	0,62	0,65	0,71	0,71	0,75	0,81	0,81	0,87	0,94	0,93				55,3	65,2		
53	250	0,32	0,33	0,37	0,36	0,40	0,44	0,43	0,47	0,52	0,51	0,54	0,60	0,59	0,62	0,69	0,68	0,7												

8 Visualization and discussion of obtained results

CLT_7a panel configuration: TCC_7a_s_r4_c2																														
Resistance to fire: R 30, concrete screed depth: 120 mm, self-weight including concrete g_{k2} : 4,46 kN/m ² , screws as shear connectors																														
Panel Nr.	depth_tot [mm]	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			R_w [dB]	L_w_eq [dB]
		q _k = 3,0	q _k = 4,0	q _k = 5,0	q _k = 3,0	q _k = 4,0	q _k = 5,0	q _k = 3,0	q _k = 4,0	q _k = 5,0	q _k = 3,0	q _k = 4,0	q _k = 5,0	q _k = 3,0	q _k = 4,0	q _k = 5,0	q _k = 3,0	q _k = 4,0	q _k = 5,0	q _k = 3,0	q _k = 4,0	q _k = 5,0	q _k = 3,0	q _k = 4,0	q _k = 5,0	q _k = 3,0	q _k = 4,0	q _k = 5,0		
1	140	0,61	0,67	0,72	0,76	0,83	0,89	0,92																					53,3	67,3
2	150	0,56	0,61	0,66	0,69	0,76	0,82	0,84	0,92	1,00																			53,5	67,1
3	160	0,52	0,56	0,61	0,64	0,70	0,75	0,78	0,85	0,92	0,93																		53,7	66,9
4	160	0,52	0,57	0,61	0,64	0,70	0,75	0,78	0,85	0,92	0,93																		53,7	66,9
5	170	0,48	0,52	0,56	0,59	0,64	0,70	0,72	0,78	0,85	0,86	0,94																	53,9	66,7
6	180	0,45	0,48	0,52	0,55	0,60	0,64	0,67	0,72	0,78	0,80	0,87	0,94	0,95															54,1	66,4
7	180	0,45	0,49	0,52	0,55	0,60	0,65	0,67	0,73	0,78	0,80	0,87	0,94	0,95															54,1	66,4
8	190	0,42	0,45	0,49	0,51	0,56	0,60	0,62	0,67	0,73	0,74	0,81	0,87	0,88	0,96														54,3	66,2
9	200	0,39	0,42	0,45	0,48	0,52	0,56	0,58	0,63	0,68	0,69	0,75	0,81	0,82	0,89	0,97	0,96												54,5	66,0
10	160	0,51	0,56	0,60	0,63	0,69	0,74	0,77	0,84	0,90	0,92																		53,7	66,9
11	170	0,47	0,51	0,55	0,58	0,63	0,68	0,70	0,77	0,83	0,85	0,92																	53,9	66,7
12	180	0,44	0,47	0,51	0,54	0,58	0,63	0,65	0,71	0,77	0,78	0,85	0,92	0,93															54,1	66,4
13	180	0,44	0,47	0,51	0,54	0,58	0,63	0,65	0,71	0,77	0,78	0,85	0,92	0,93															54,1	66,4
14	190	0,41	0,44	0,47	0,50	0,54	0,58	0,60	0,66	0,71	0,72	0,79	0,85	0,86	0,94														54,3	66,2
15	200	0,38	0,41	0,44	0,46	0,50	0,54	0,56	0,61	0,66	0,67	0,73	0,79	0,80	0,87	0,94	0,94												54,5	66,0
16	200	0,38	0,41	0,44	0,46	0,50	0,54	0,56	0,61	0,66	0,67	0,73	0,79	0,80	0,87	0,94	0,94												54,5	66,0
17	210	0,35	0,38	0,41	0,43	0,47	0,51	0,53	0,57	0,61	0,63	0,68	0,74	0,74	0,81	0,88	0,87	0,95											54,7	65,8
18	220	0,33	0,37	0,40	0,41	0,44	0,49	0,49	0,53	0,57	0,59	0,64	0,69	0,69	0,76	0,82	0,82	0,89	0,96	0,95									54,9	65,6
19	180	0,44	0,47	0,50	0,53	0,58	0,62	0,64	0,70	0,76	0,77	0,84	0,91	0,92															54,1	66,4
20	190	0,40	0,43	0,47	0,49	0,53	0,57	0,60	0,65	0,70	0,71	0,78	0,84	0,85	0,92	1,00													54,3	66,2
21	200	0,37	0,40	0,43	0,46	0,49	0,53	0,55	0,60	0,65	0,66	0,72	0,78	0,78	0,85	0,92	0,92												54,5	66,0
22	200	0,37	0,40	0,43	0,46	0,49	0,53	0,55	0,60	0,65	0,66	0,72	0,78	0,79	0,86	0,93	0,92												54,5	66,0
23	210	0,35	0,37	0,41	0,42	0,46	0,49	0,51	0,56	0,60	0,62	0,67	0,72	0,73	0,79	0,86	0,86	0,93	1,00										54,7	65,8
24	220	0,33	0,36	0,40	0,40	0,43	0,48	0,48	0,52	0,56	0,57	0,62	0,67	0,68	0,74	0,80	0,80	0,87	0,94	0,93									54,9	65,6
25	220	0,33	0,36	0,40	0,40	0,43	0,48	0,48	0,52	0,56	0,57	0,62	0,67	0,68	0,74	0,80	0,80	0,87	0,94	0,93									54,9	65,6
26	230	0,32	0,35	0,39	0,38	0,42	0,47	0,45	0,50	0,55	0,54	0,58	0,64	0,64	0,69	0,75	0,75	0,81	0,88	0,87	0,95								55,1	65,4
27	240	0,31	0,34	0,38	0,37	0,41	0,46	0,44	0,49	0,54	0,51	0,57	0,62	0,60	0,65	0,72	0,70	0,76	0,82	0,81	0,89	0,96	0,94					55,3	65,2	
28	160	0,51	0,56	0,60	0,63	0,69	0,74	0,77	0,84	0,90	0,92																		53,7	66,9
29	170	0,47	0,51	0,55	0,58	0,63	0,68	0,70	0,77	0,83	0,85	0,92																	53,9	66,7
30	180	0,44	0,47	0,51	0,54	0,58	0,63	0,65	0,71	0,77	0,78	0,85	0,92	0,93															54,1	66,4
31	180	0,44	0,47	0,51	0,54	0,58	0,63	0,65	0,71	0,77	0,78	0,85	0,92	0,93															54,1	66,4
32	190	0,41	0,44	0,47	0,50	0,54	0,58	0,60	0,66	0,71	0,72	0,79	0,85	0,86	0,94														54,3	66,2
33	200	0,38	0,41	0,44	0,46	0,50	0,54	0,56	0,61	0,66	0,67	0,73	0,79	0,80	0,87	0,94	0,94												54,5	66,0
34	200	0,38	0,41	0,44	0,46	0,50	0,54	0,56	0,61	0,66	0,67	0,73	0,79	0,80	0,87	0,94	0,94												54,5	66,0
35	210	0,35	0,38	0,41	0,43	0,47	0,51	0,53	0,57	0,61	0,63	0,68	0,74	0,74	0,81	0,88	0,87	0,95											54,7	65,8
36	220	0,33	0,37	0,40	0,41	0,44	0,49	0,49	0,53	0,57	0,59	0,64	0,69	0,69	0,76	0,82	0,82	0,89	0,96	0,95									54,9	65,6
37	180	0,44	0,47	0,50	0,53	0,58	0,62	0,64	0,70	0,76	0,77	0,84	0,91	0,92															54,1	66,4
38	190	0,40	0,43	0,47	0,49	0,53	0,57	0,60	0,65	0,70	0,71	0,78	0,84	0,85	0,92	1,00													54,3	66,2
39	200	0,37	0,40	0,43	0,46	0,49	0,53	0,55	0,60	0,65	0,66	0,72	0,78	0,78	0,85	0,92	0,92												54,5	66,0
40	200	0,37	0,40	0,43	0,46	0,49	0,53	0,55	0,60	0,65	0,66	0,72	0,78	0,79	0,86	0,93	0,92												54,5	66,0
41	210	0,35	0,37	0,41	0,42	0,46	0,49	0,51	0,56	0,60	0,62	0,67	0,72	0,73	0,79	0,86	0,86	0,93	1,00										54,7	65,8
42	220	0,33	0,36	0,40	0,40	0,43	0,48	0,48	0,52	0,56	0,57	0,62	0,67	0,68	0,74	0,80	0,80	0,87	0,94	0,93									54,9	65,6
43	220	0,33	0,36	0,40	0,40	0,43	0,48	0,48	0,52	0,56	0,57	0,62	0,67	0,68	0,74	0,80	0,80	0,87	0,94	0,93									54,9	65,6
44	230	0,32	0,35	0,39	0,38	0,42	0,47	0,45	0,50	0,55	0,54	0,58	0,64	0,64	0,69	0,75	0,75	0,81	0,88	0,87	0,95								55,1	65,4
45	240	0,31	0,34	0,38	0,37	0,41	0,46	0,44	0,49	0,54	0,51	0,57	0,62	0,60	0,65	0,72	0,70	0,76	0,82	0,81	0,89	0,96	0,94					55,3	65,2	
46	200	0,38	0,40	0,43	0,45	0,49	0,53	0,55	0,59	0,64	0,66	0,71	0,77	0,78	0,85	0,92	0,91	1,00											54,5	66,0
47	210	0,37	0,37	0,40	0,42	0,45	0,49	0,51	0,55	0,59	0,61	0,66	0,71	0,72	0,78	0,85	0,85	0,92	1,00	0,99									54,7	65,8
48	220	0,36	0,36	0,39	0,39	0,43	0,47	0,47	0,51	0,56	0,57	0,61	0,66	0,67	0,73	0,79	0,79	0,86	0,93	0,92									54,9	65,6
49	220	0,36	0,36	0,39	0,39	0,43	0,47	0,47	0,51	0,56	0,57	0,61	0,66	0,67	0,73	0,79	0,79	0,86	0,93	0,92									54,9	65,6
50	230	0,35	0,35	0,38	0,37	0,42	0,46	0,44	0,49	0,54	0,53	0,57	0,63	0,63	0,68	0,73	0,73	0,80	0,86	0,86	0,93	0,99							55,1	65,4
51	240	0,34	0,34	0,37	0,36	0,41	0,45	0,43	0,48	0,53	0,50	0,56	0,62	0,59	0,64	0,71	0,69	0,75	0,81	0,80	0,87	0,94	0,92					55,3	65,2	
52	240	0,33	0,34	0,37	0,37	0,41	0,45																							

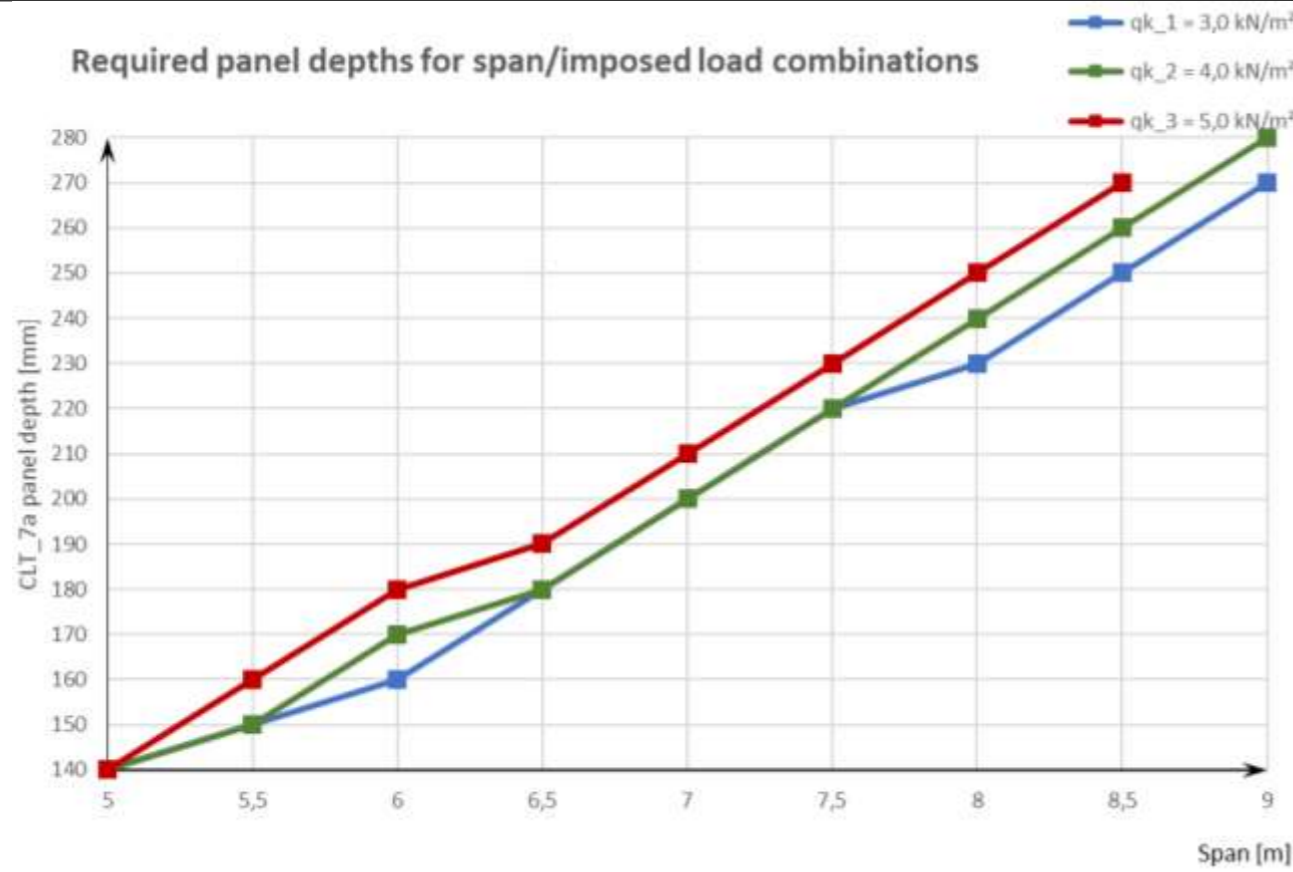


Figure 8-26: Minimum panel depths in regard to span for TCC_7a_s_r1_c2

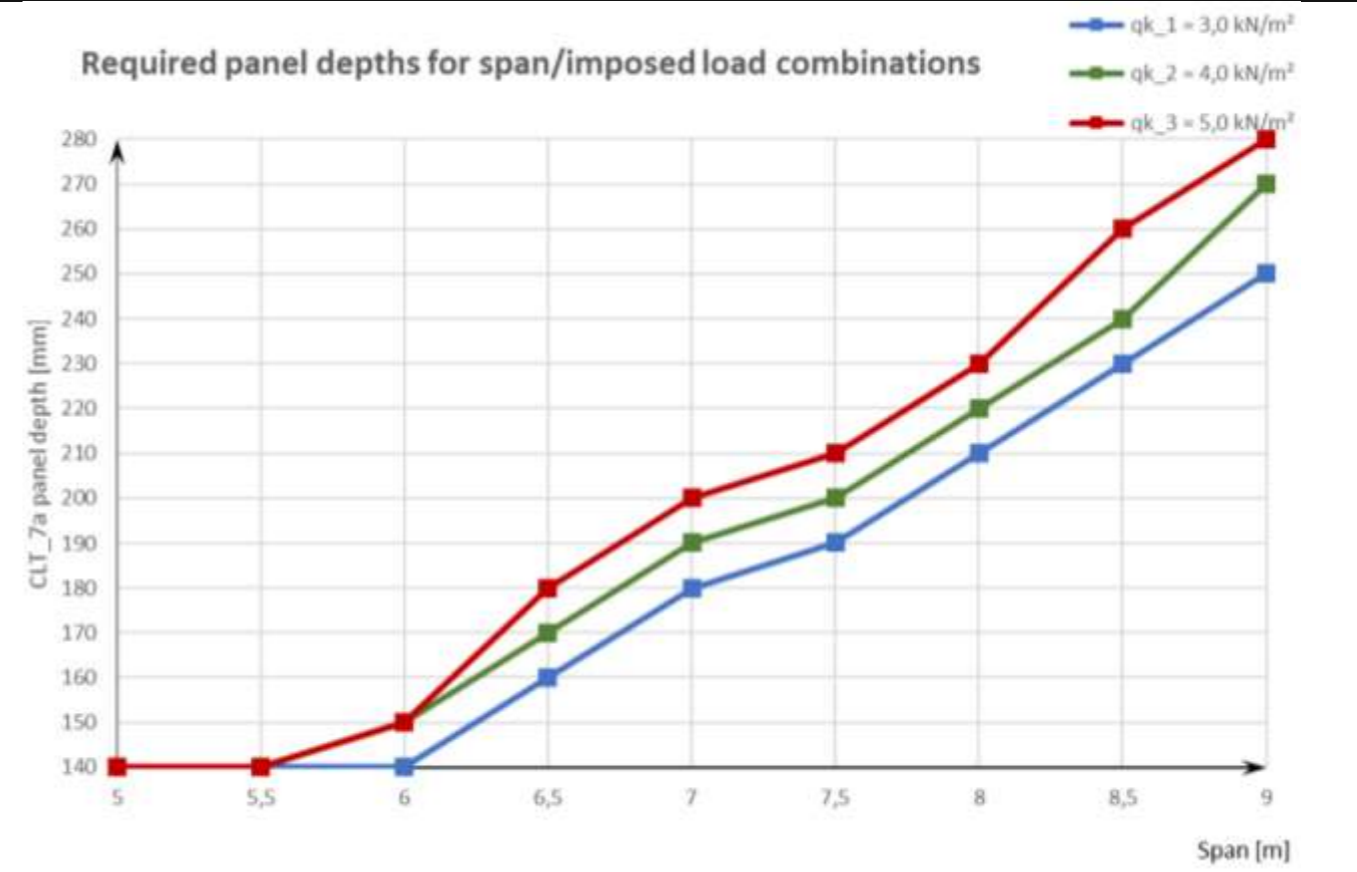


Figure 8-27: Minimum panel depths in regard to span for TCC_7a_s_r2_c2

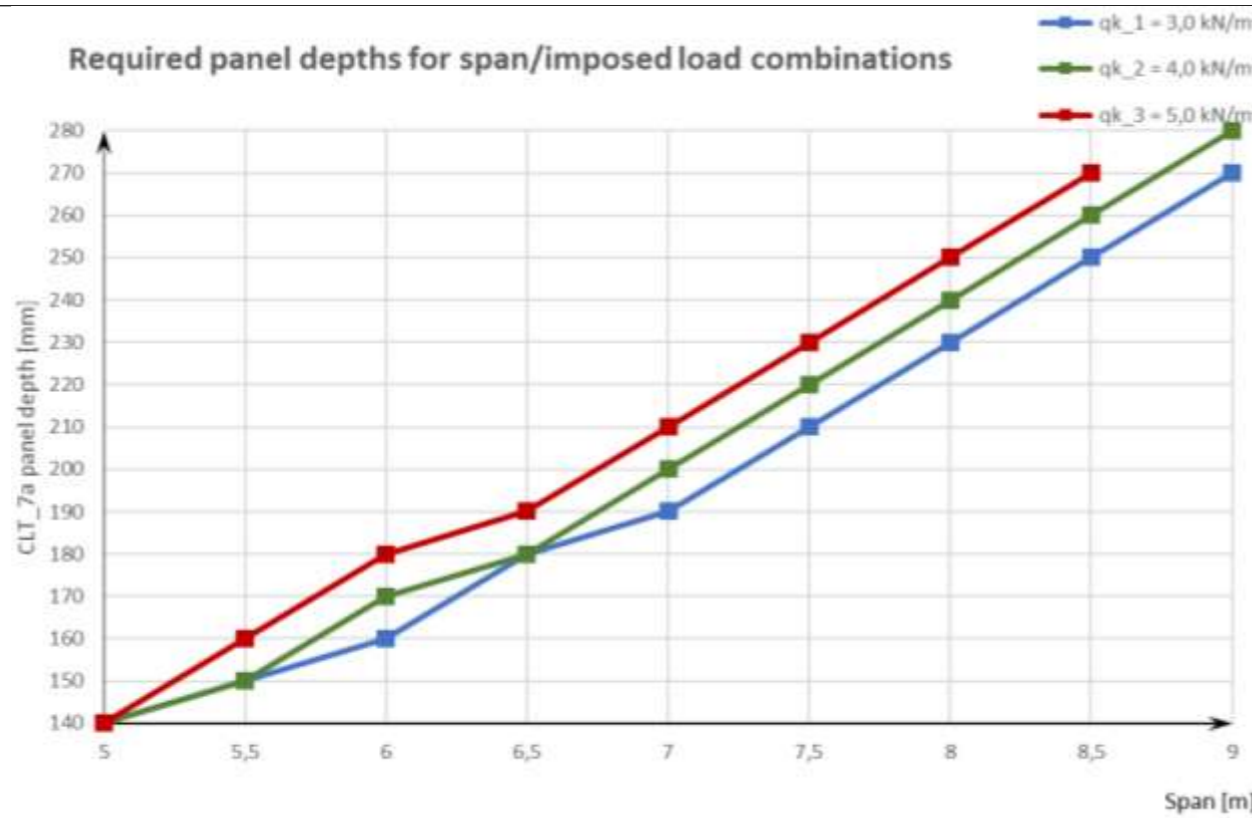


Figure 8-28: Minimum panel depths in regard to span for TCC_7a_s_r3_c2

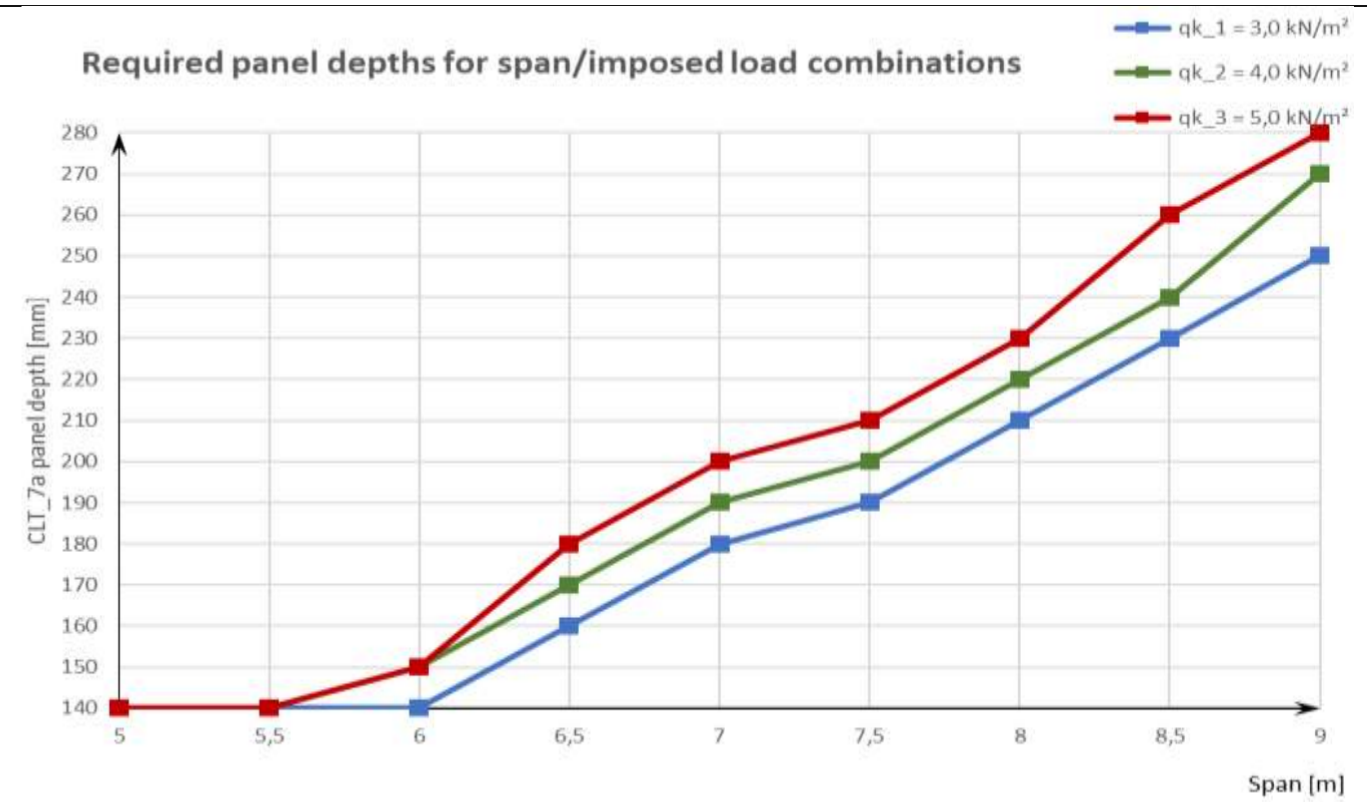


Figure 8-29: Minimum panel depths in regard to span for TCC_7a_s_s4_c2

8.2.6 7-layer CLT panel (CLT_7b)

Since the results are not dramatically different from what is shown in the previous chapter, the related results are presented in **Annex B** but commented here. This choice has been made to allow better readability and thus overview and understand the obtained results. As stated before, these two seven-layered panel types are different in their bending stiffness parallel to the span. The chosen connection type and stiffness (slip modulus) remain the same to obtain more comparable results.

Table 33 overviews the different combinations between load and built-in situation (namely the presence of concrete screed or not) and the fire's implemented duration.

Variations of CLT_7b		Self-weight		
		g_k1	g_k2	g_k3
Variant	R 60, 90 mm screed	TCC_7b_s_r1_c1	TCC_7b_s_r1_c2	TCC_7b_s_r1_c3
	R 60, 120 mm screed	TCC_7b_s_r2_c1	TCC_7b_s_r2_c2	TCC_7b_s_r2_c3
	R 30, 90 mm screed	TCC_7b_s_r3_c1	TCC_7b_s_r3_c2	TCC_7b_s_r3_c3
	R 30, 120 mm screed	TCC_7b_s_r4_c1	TCC_7b_s_r4_c2	TCC_7b_s_r4_c3

Table 33: Variation overview for TCC_7b_screws

Due to the lower panel stiffness of CLT_7b compared to its CLT-7a counterpart, the maximum span of 9,0 m is reached only for the lower and middle imposed load level. One important aspect has to be highlighted: the dimensioning under fire conditions (especially with the R60 requirement) has a lesser impact for a CLT_7b panels than on the similar CLT_7a type. This is caused due to the different disposition of lamellas, as the CLT-7b panel has a higher remaining section stiffness parallel to span as approximately said it loses the lower lamellas to fire (one parallel and one cross to span), while the CLT-7a panel loses the two lower lamellas which both are parallel to the span. Because of this different lamella position, such substantial differences are notable. Therefore, the leading dimensioning criterium becomes more and more the SLS for "t=0" as the concrete depth rises, and the fire requirements are lowered. Contrarily to the previous chapter, ULS verifications become leading for small spans, low concrete screed depths but high imposed loads. When concrete screed depth rises, SLS requirements become relevant due to added weight. For the description of further differences, refer to **chapter 8.2.5**.

On the subject of minimal panel depth to span lengths (see **Figure 14-1** to **Figure 14-4**), the behaviour is linear dependent on the span increase. When two or more results yield the same panel depth, the stiffness criterium is probably the relevant one. This happens because of the different bending stiffness of the CLT panel itself because two panels of the same depth but contrasting lamella disposition have not the same stiffness. In these cases, the panel configuration can be found after searching the corresponding panel number (at the left-hand side of **Figure 14-1** to **Figure**

14-4, respectively) and double-check with **Table 20**. **Figure 14-1** and **Figure 14-3** share the same concrete screed depth and result course. This means that the fire protection duration has no influence on the minimal required CLT panel depth. The same thing can be observed after comparing **Figure 14-2** to **Figure 14-4**.

8.3 TCC floor with notches as shear connectors

8.3.1 Characterizing Parameters

Two main parameters distinguish the tables one from another, namely the resistance to fire and the concrete screed depth above the CLT panel itself. Since we are talking TCC floors, the screed and CLT panel are connected by screws. This screed, consisting of two different overall depths (90 mm and 120 mm), contributes to the floor panel's total stiffness and thus to the load-carrying capabilities of the floor itself. In regard to the fire resistance as a requirement for timber floors, two different fire durations have been implemented in the tool: 30 and 60 minutes. This means that four different tables per CLT panel types are the output and sixteen tables overall for the CLT panel solution. To avoid a further varying parameter, the notch depth ($h_n = 30 \text{ mm}$) as well as notch width ($b_n = 400 \text{ mm}$) per span is constant for all four pre-dimensioning tables.

In order to understand which type of verification is the leading one during the dimensioning process for each combination, colours have been awarded. They are visible in every single table (see **Figure 8-1**). This allows the reader to recognize if the ULS, SLS or ULS under fire conditions verifications are crucial. Because the observation of different points is necessary, these three main groups are further divided into subgroups characterized by their related point in time: “ t_0 ”, “ t_{mid} ” and “ t_{fin} ”. The ULS group contains all the verifications undertaken in **chapter 7.2.7**, the SLS group all formulas applied in **chapter 7.2.8**, and the ULS under fire conditions includes all material verifications present in **chapter 7.2.9**.

Legend: CRUCIAL CRITERIUMS		
SLS_fin	ULS_fi_fin	ULS_fin
SLS_mid	ULS_fi_mid	ULS_mid
SLS-t0	ULS_fi_t0	ULS_t0

Figure 8-30: Legend of crucial criteriums

8.3.2 3-layer CLT panel (CLT_3)

No CLT panel configuration can fulfil the needed requirements for any of the analysed spans, be it with a 90 mm or 120 mm screed. Therefore, no results will be shown.

8.3.3 5-layer CLT panel (CLT_5)

Variations of CLT_5	Self-weight
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8 Visualization and discussion of obtained results

		g_k1	g_k2	g_k3
Variant	R 60, 90 mm screed	TCC_5_n_r1_c1	TCC_5_n_r1_c2	TCC_5_n_r1_c3
	R 60, 120 mm screed	TCC_5_n_r2_c1	TCC_5_n_r2_c2	TCC_5_n_r2_c3
	R 30, 90 mm screed	TCC_5_n_r3_c1	TCC_5_n_r3_c2	TCC_5_n_r3_c3
	R 30, 120 mm screed	TCC_5_n_r4_c1	TCC_5_n_r4_c2	TCC_5_n_r4_c3

Table 34: Variation overview for TCC_5_screws

CLT_5 panel configuration: TCC_5_n_r1_c2																														
Resistance to fire: R 60, concrete screed depth: 90 mm, self-weight including concrete g_k2: 4,46 kN/m ² , notches as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			acoustic	
[-]	[mm]	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	R_w	L_w_eq			
		[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[kN/m ²]	[dB]		
1	100																											52,4	68,3	
2	110																											52,6	68,1	
3	120																											52,9	67,8	
4	120																											52,9	67,8	
5	130																											53,1	67,6	
6	140																											53,3	67,3	
7	140																											53,3	67,3	
8	150																											53,5	67,1	
9	160																											53,7	66,9	
10	120																											52,9	67,8	
11	130																											53,1	67,6	
12	140																											53,3	67,3	
13	140																											53,3	67,3	
14	150																											53,5	67,1	
15	160	0,92																										53,7	66,9	
16	160																											53,7	66,9	
17	170	0,94																										53,9	66,7	
18	180	0,89																										54,1	66,4	
19	140																											53,3	67,3	
20	150	0,96	0,96																									53,5	67,1	
21	160	0,84	0,84	0,92																								53,7	66,9	
22	160	0,94	0,96																									53,7	66,9	
23	170	0,82	0,87	0,97	0,99																							53,9	66,7	
24	180	0,73	0,82	0,91	0,92																							54,1	66,4	
25	180	0,84	0,95																									54,1	66,4	
26	190	0,79	0,90																									54,3	66,2	
27	200	0,75	0,85	0,94	0,95																							54,5	66,0	

Figure 8-31: TCC_5_n_r1_c2 configuration

8 Visualization and discussion of obtained results

CLT_5 panel configuration: TCC_5_n_r2_c2																														
Resistance to fire: R 60, concrete screed depth: 120 mm, self-weight including concrete g_{k2} : 4,46 kN/m ² , notches as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			R_w	L_w_eq
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0		
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	100																											55,9	64,6	
2	110																												56,0	64,4
3	120																												56,2	64,2
4	120																												56,2	64,2
5	130																												56,4	64,0
6	140	0,97																											56,6	63,8
7	140																												56,6	63,8
8	150																												56,7	63,6
9	160	0,92																											56,9	63,4
10	120																												56,2	64,2
11	130	0,88	0,96																										56,4	64,0
12	140	0,79	0,87	0,94																									56,6	63,8
13	140	0,92																											56,6	63,8
14	150	0,83	0,91	0,98																									56,7	63,6
15	160	0,75	0,82	0,89	0,95																								56,9	63,4
16	160	0,86	0,94																										56,9	63,4
17	170	0,78	0,85	0,91	0,98																								57,1	63,3
18	180	0,71	0,77	0,83	0,89	0,97																							57,2	63,1
19	140	0,78	0,85	0,92	0,98																								56,6	63,8
20	150	0,70	0,77	0,83	0,89	0,97																							56,7	63,6
21	160	0,64	0,70	0,75	0,80	0,88	0,95	1,00																					56,9	63,4
22	160	0,72	0,79	0,85	0,91	1,00																							56,9	63,4
23	170	0,66	0,71	0,77	0,83	0,90	0,98																						57,1	63,3
24	180	0,60	0,65	0,70	0,75	0,82	0,89	0,93																					57,2	63,1
25	180	0,67	0,73	0,79	0,84	0,92	1,00																						57,2	63,1
26	190	0,61	0,66	0,71	0,77	0,84	0,90	0,95																					57,4	62,9
27	200	0,56	0,61	0,68	0,70	0,78	0,86	0,87	0,97																				57,6	62,7

Figure 8-32: TCC_5_n_r2_c2 configuration

CLT_5 panel configuration: TCC_5_n_r3_c2																														
Resistance to fire: R 30, concrete screed depth: 90 mm, self-weight including concrete g_{k2} : 4,46 kN/m ² , notches as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			R_w	L_w_eq
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0		
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	100																												52,4	68,3
2	110																												52,6	68,1
3	120																												52,9	67,8
4	120																												52,9	67,8
5	130																												53,1	67,6
6	140																												53,3	67,3
7	140																												53,3	67,3
8	150																												53,5	67,1
9	160																												53,7	66,9
10	120																												52,9	67,8
11	130																												53,1	67,6
12	140																												53,3	67,3
13	140																												53,3	67,3
14	150																												53,5	67,1
15	160	0,92																											53,7	66,9
16	160																												53,7	66,9
17	170	0,94																											53,9	66,7
18	180	0,89																											54,1	66,4
19	140																												53,3	67,3
20	150	0,96	0,96																										53,5	67,1
21	160	0,84	0,84	0,92																									53,7	66,9
22	160	0,94	0,96																										53,7	66,9
23	170	0,82	0,87	0,97	0,99																								53,9	66,7
24	180	0,73	0,82	0,91	0,92																								54,1	66,4
25	180	0,84	0,95																										54,1	66,4
26	190	0,79	0,90																										54,3	66,2
27	200	0,75	0,85	0,94	0,95																								54,5	66,0

Figure 8-33: TCC_5_n_r3_c2 configuration

8 Visualization and discussion of obtained results

CLT_5 panel configuration: TCC_5_n_r4_c2																														
Resistance to fire: R 30, concrete screed depth: 120 mm, self-weight including concrete g_{k2} : 4,46 kN/m ² , notches as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			acoustic	
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	R_w	L_w,eq			
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	100																									55,9	64,6			
2	110																										56,0	64,4		
3	120																										56,2	64,2		
4	120																										56,2	64,2		
5	130																										56,4	64,0		
6	140	0,97																									56,6	63,8		
7	140																										56,6	63,8		
8	150																										56,7	63,6		
9	160	0,92																									56,9	63,4		
10	120	0,98																									56,2	64,2		
11	130	0,88	0,96																								56,4	64,0		
12	140	0,79	0,87	0,94																							56,6	63,8		
13	140	0,92																									56,6	63,8		
14	150	0,83	0,91	0,98																							56,7	63,6		
15	160	0,75	0,82	0,89	0,95																						56,9	63,4		
16	160	0,86	0,94																								56,9	63,4		
17	170	0,78	0,85	0,91	0,98																						57,1	63,3		
18	180	0,71	0,77	0,83	0,89	0,97																					57,2	63,1		
19	140	0,78	0,85	0,92	0,98																						56,6	63,8		
20	150	0,70	0,77	0,83	0,89	0,97																					56,7	63,6		
21	160	0,64	0,70	0,75	0,80	0,88	0,95	1,00																			56,9	63,4		
22	160	0,72	0,79	0,85	0,91	1,00																					56,9	63,4		
23	170	0,66	0,71	0,77	0,83	0,90	0,98																				57,1	63,3		
24	180	0,60	0,65	0,70	0,75	0,82	0,89	0,93																			57,2	63,1		
25	180	0,67	0,73	0,79	0,84	0,92	1,00																				57,2	63,1		
26	190	0,61	0,66	0,71	0,77	0,84	0,90	0,95																			57,4	62,9		
27	200	0,56	0,61	0,68	0,70	0,78	0,86	0,87	0,97																		57,6	62,7		

Figure 8-34: TCC_5_n_r4_c2 configuration

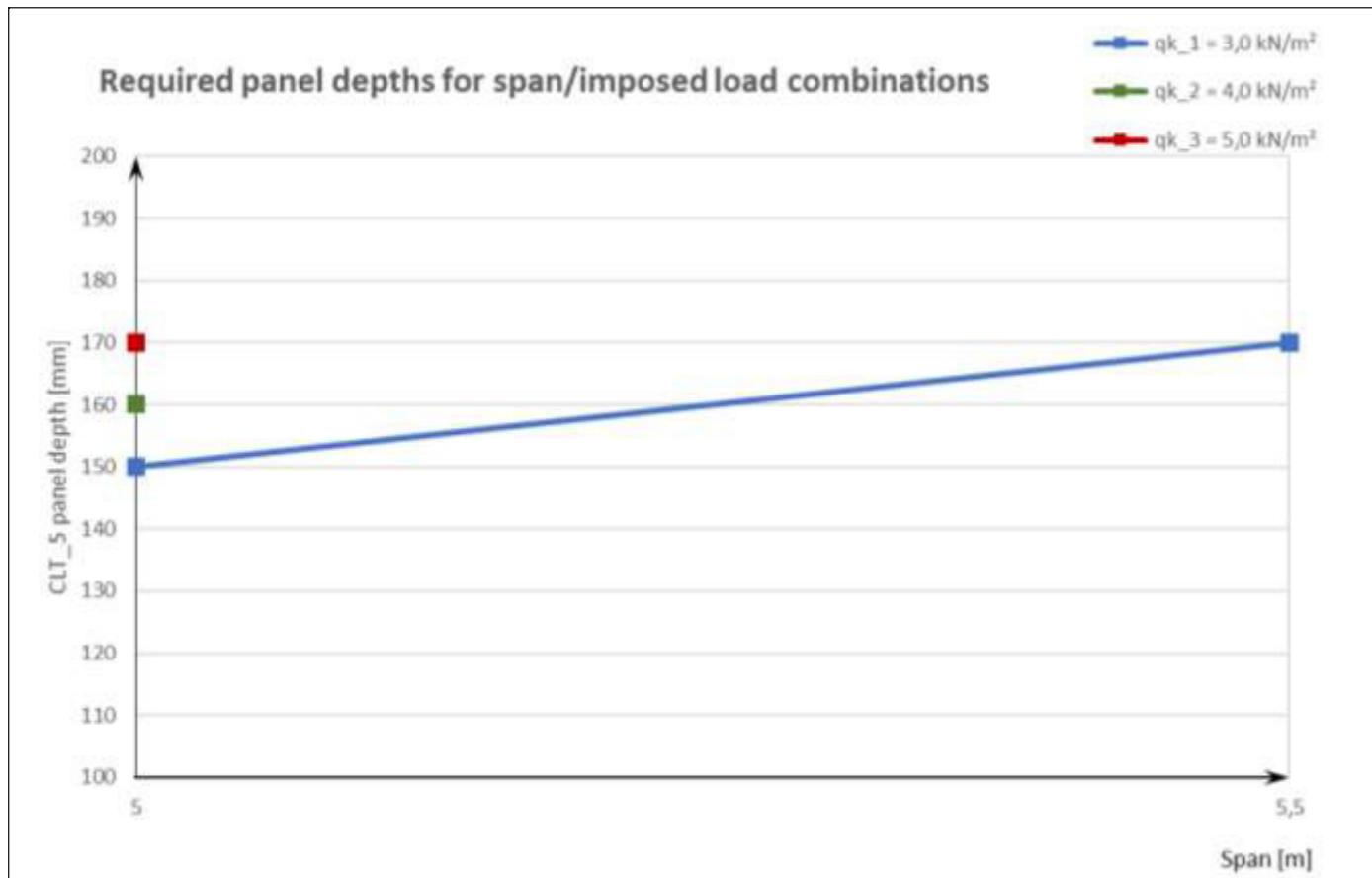


Figure 8-35: Minimum panel depths in regard to span for TCC_5_n_r1_c2

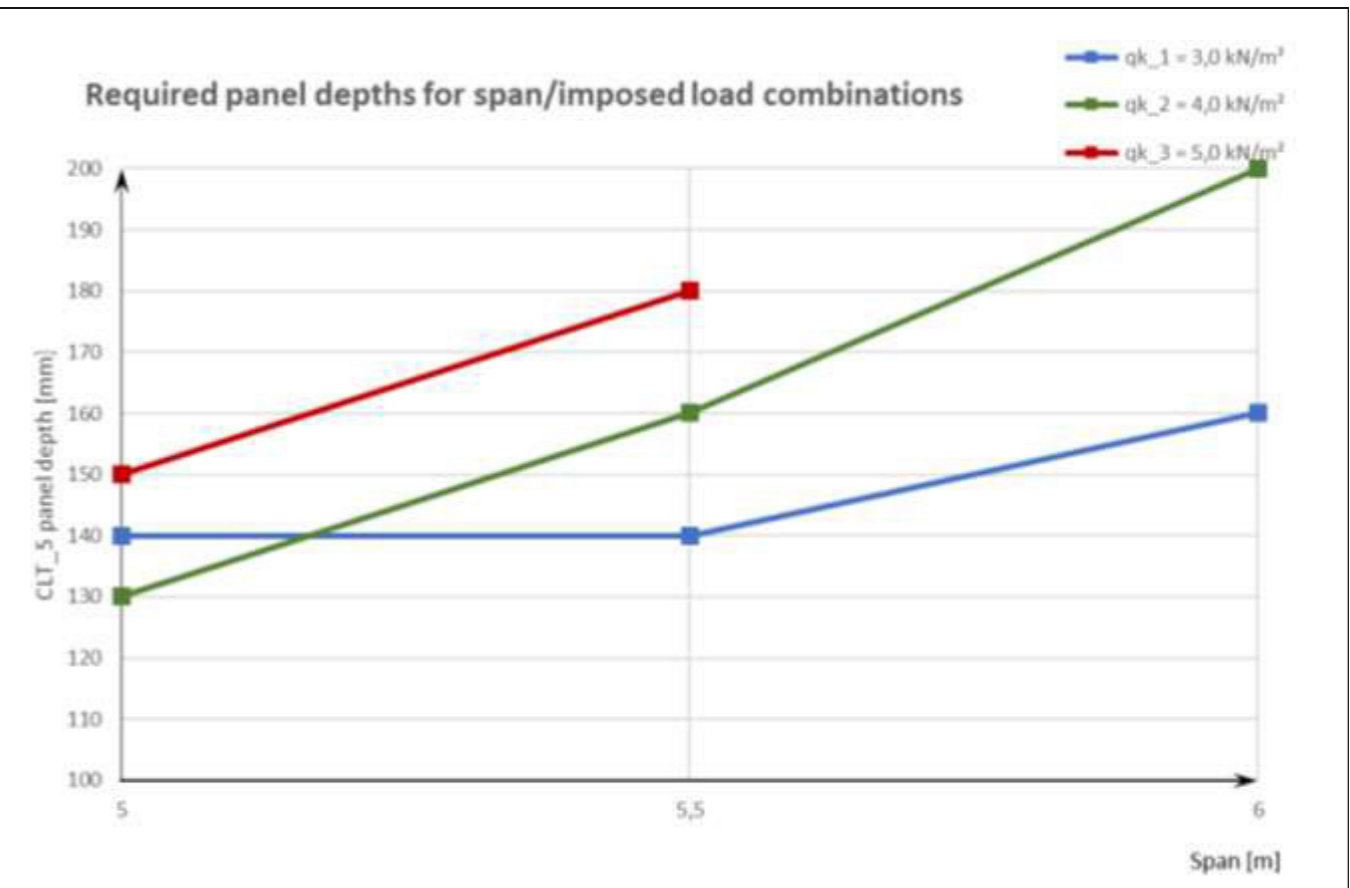


Figure 8-36: Minimum panel depths in regard to span for TCC_5_n_r2_c2

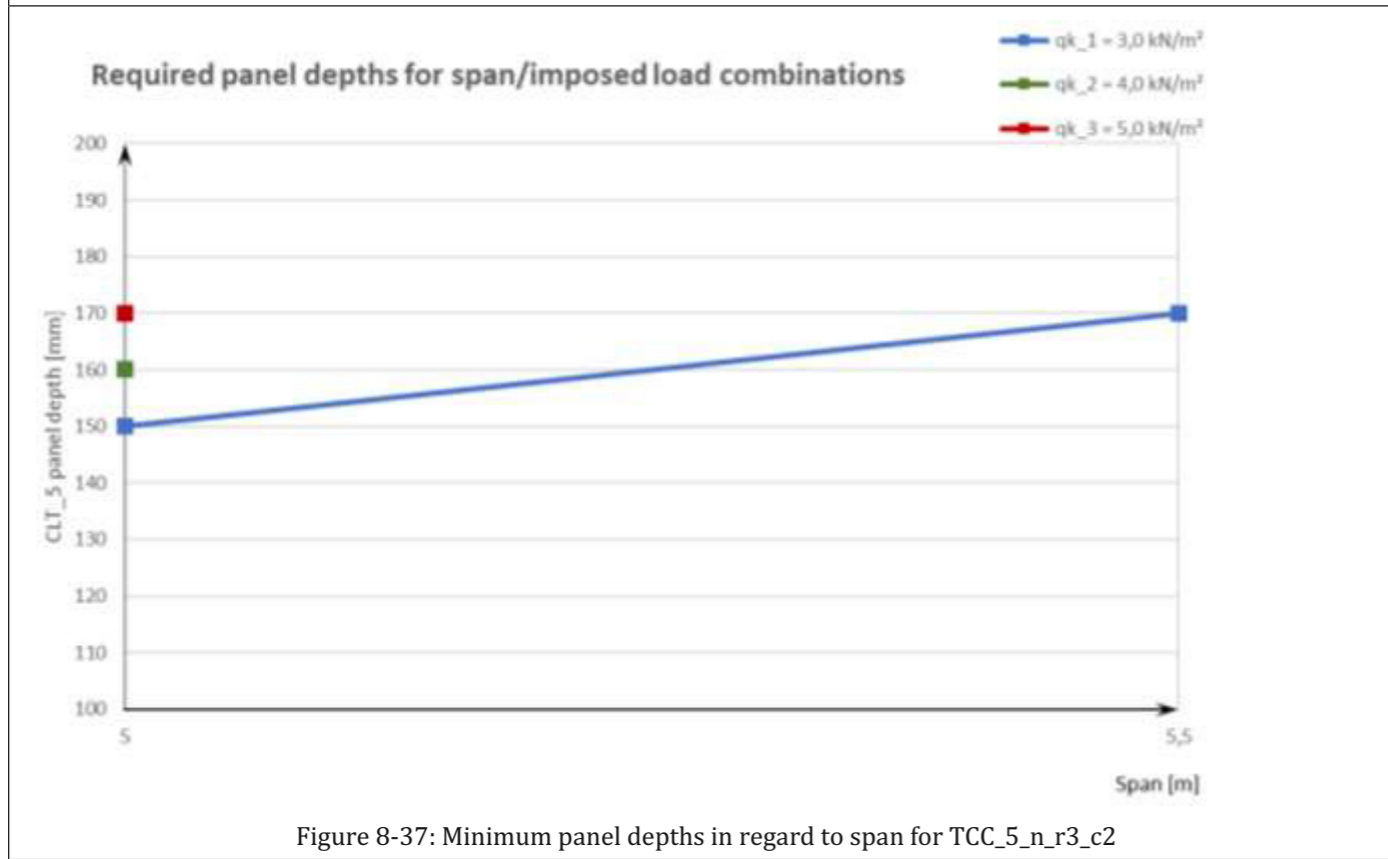
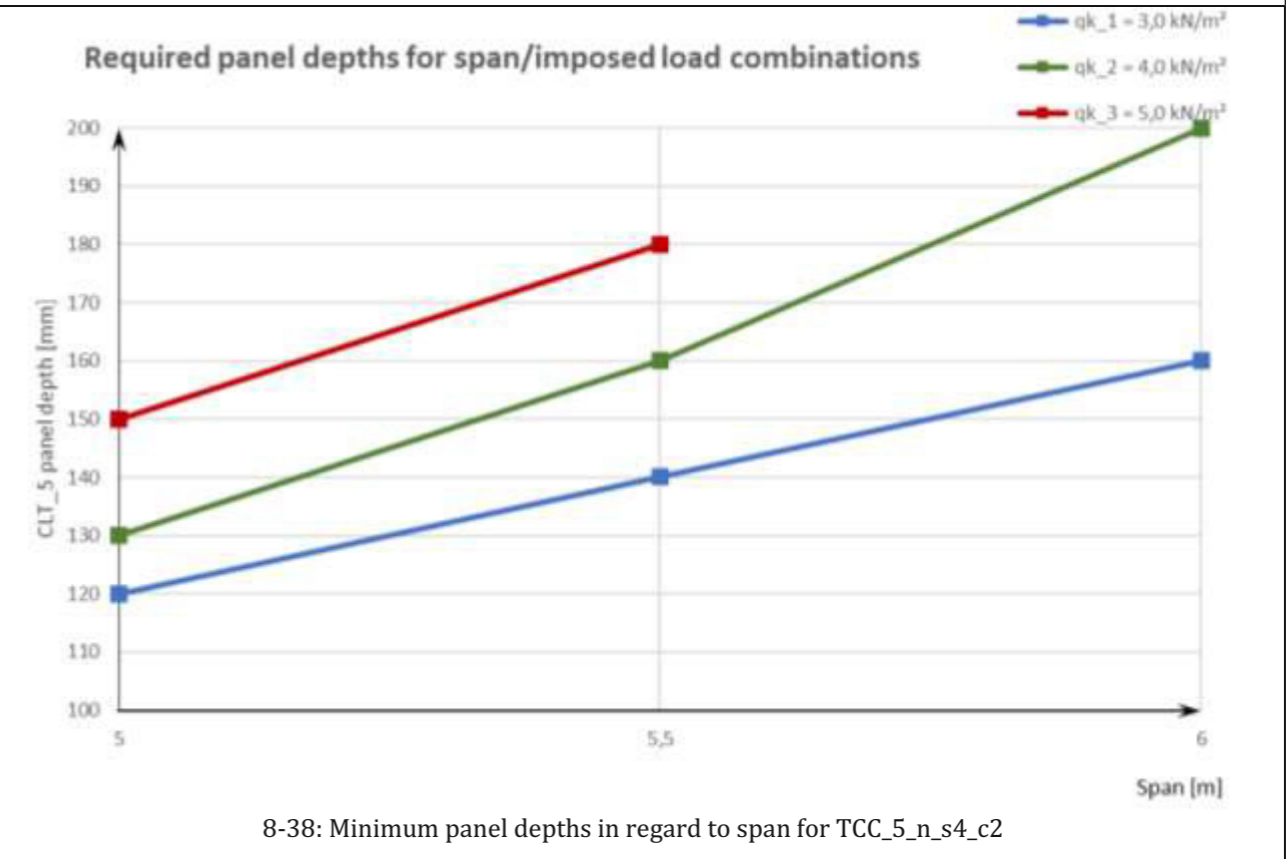


Figure 8-37: Minimum panel depths in regard to span for TCC_5_n_r3_c2

Figure



8-38: Minimum panel depths in regard to span for TCC_5_n_s4_c2

The first noticeable thing is the lesser number of possible solutions compared to the results shown in **chapter 8.2.3** that this notched connection allows due to the lower overall connection slip modulus and thus γ -factor. The maximum obtained span amounts to 6,0 m coupled with a concrete screed depth of 120 mm, while it amounted to 7,5 m when screws are used as shear connectors. To obtain better comparability between notches and their dimensions, the overall stiffness should have been modelled as a constant parameter, which might be interchangeable regardless of the exact type of shear connector. This approach would have helped create a different, more integrated view. Since the difference in gamma factors amounts to around 28% in favour of the screw connections, the connection stiffness's massive influence is visible. Therefore, all efforts put in the creation of very stiff and efficient shear connectors are explainable. It can be argued that the γ -factor has a higher influence on the overall static capabilities than the concrete screed depth. This aspect shall not be forgotten at any time during the design process and is further underlined by the results characterising this section. Also, the design is mainly characterized by the SLS design “t=mid” and partially by the ULS design at “t=0” for thicker panels. As observed in **chapter 8.2.3**, the duration of resistance to fire has no influence on the dimensioning of five-layered CLT panels with notches as shear connectors. Due to the lower number of possible solutions, no panel depth to span diagrams are displayed.

8.3.4 7-layer CLT panel (CLT_7a)

Variations of CLT_7a		Self-weight		
		g_k1	g_k2	g_k3
Variant	R 60, 90 mm screed	TCC_7a_n_r1_c1	TCC_7a_n_r1_c2	TCC_7a_n_r1_c3
	R 60, 120 mm screed	TCC_7a_n_r2_c1	TCC_7a_n_r2_c2	TCC_7a_n_r2_c3
	R 30, 90 mm screed	TCC_7a_n_r3_c1	TCC_7a_n_r3_c2	TCC_7a_n_r3_c3
	R 30, 120 mm screed	TCC_7a_n_r4_c1	TCC_7a_n_r4_c2	TCC_7a_n_r4_c3

Table 35: Variation overview for TCC_7a_notches

Table 32 overview over the different combinations between load and built-in situation (namely presence of concrete screed or not) and the implemented duration of the fire.

8 Visualization and discussion of obtained results

CLT_7a panel configuration: TCC_7a_n_r2_c2																														
Resistance to fire: R 60, concrete screed depth: 120 mm, self-weight including concrete g_k2: 4,46 kN/m ² , notches as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			R_w	L_w_eq
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0		
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	140	0,60	0,66	0,71	0,75	0,82	0,89	0,93																					56,6	63,8
2	150	0,55	0,60	0,65	0,69	0,76	0,82	0,85	0,93	1,00																			56,7	63,6
3	160	0,51	0,55	0,60	0,64	0,69	0,75	0,78	0,86	0,93	0,91	1,00																	56,9	63,4
4	160	0,51	0,56	0,60	0,64	0,70	0,75	0,79	0,86	0,93	0,92																		56,9	63,4
5	170	0,47	0,51	0,55	0,59	0,64	0,69	0,73	0,79	0,86	0,85	0,92	1,00																57,1	63,3
6	180	0,44	0,48	0,51	0,55	0,60	0,64	0,67	0,73	0,79	0,78	0,85	0,92	0,94															57,2	63,1
7	180	0,44	0,48	0,51	0,57	0,60	0,64	0,71	0,75	0,79	0,78	0,85	0,93	0,94															57,2	63,1
8	190	0,42	0,44	0,48	0,54	0,56	0,60	0,68	0,71	0,74	0,73	0,79	0,86	0,87	0,95														57,4	62,9
9	200	0,40	0,42	0,45	0,51	0,53	0,56	0,64	0,66	0,69	0,68	0,74	0,80	0,81	0,89	0,96	0,97												57,6	62,7
10	160	0,50	0,55	0,59	0,63	0,68	0,74	0,77	0,85	0,92	0,90	0,99																	56,9	63,4
11	170	0,46	0,50	0,54	0,58	0,63	0,68	0,71	0,78	0,84	0,83	0,91	0,98	1,00															57,1	63,3
12	180	0,43	0,47	0,50	0,54	0,58	0,63	0,66	0,72	0,78	0,77	0,84	0,90	0,92															57,2	63,1
13	180	0,43	0,47	0,50	0,55	0,58	0,63	0,69	0,72	0,78	0,77	0,84	0,91	0,92															57,2	63,1
14	190	0,41	0,43	0,47	0,52	0,55	0,58	0,65	0,68	0,72	0,71	0,77	0,84	0,85	0,93														57,4	62,9
15	200	0,39	0,40	0,43	0,49	0,52	0,54	0,62	0,64	0,67	0,66	0,72	0,78	0,79	0,86	0,93	0,94												57,6	62,7
16	200	0,42	0,44	0,46	0,54	0,56	0,59	0,67	0,70	0,73	0,72	0,75	0,79	0,87	0,91	0,95													57,6	62,7
17	210	0,40	0,42	0,43	0,51	0,53	0,55	0,64	0,67	0,69	0,68	0,71	0,74	0,82	0,85	0,89	0,97												57,7	62,6
18	220	0,38	0,39	0,41	0,48	0,50	0,52	0,60	0,62	0,65	0,63	0,66	0,69	0,76	0,79	0,83	0,90	0,94	0,98	0,93									57,9	62,4
19	180	0,42	0,46	0,50	0,53	0,58	0,62	0,65	0,71	0,77	0,76	0,83	0,89	0,91	0,99														57,2	63,1
20	190	0,39	0,43	0,46	0,49	0,53	0,57	0,61	0,65	0,71	0,70	0,76	0,83	0,84	0,92	0,99	1,00												57,4	62,9
21	200	0,37	0,39	0,43	0,46	0,49	0,54	0,58	0,61	0,67	0,65	0,71	0,76	0,78	0,85	0,92	0,92												57,6	62,7
22	200	0,40	0,42	0,44	0,51	0,53	0,56	0,64	0,67	0,69	0,68	0,71	0,76	0,82	0,85	0,92	0,97												57,6	62,7
23	210	0,38	0,40	0,42	0,49	0,51	0,53	0,61	0,63	0,66	0,64	0,67	0,71	0,77	0,80	0,85	0,91	0,95											57,7	62,6
24	220	0,36	0,37	0,41	0,45	0,47	0,51	0,57	0,59	0,63	0,60	0,62	0,66	0,71	0,75	0,79	0,85	0,88	0,94	0,91	1,00								57,9	62,4
25	220	0,38	0,40	0,41	0,49	0,51	0,53	0,61	0,63	0,66	0,65	0,67	0,70	0,78	0,81	0,84	0,92	0,96	1,00	0,95	1,00								57,9	62,4
26	230	0,36	0,38	0,40	0,46	0,48	0,50	0,57	0,60	0,62	0,61	0,63	0,66	0,73	0,76	0,79	0,86	0,90	0,94	0,89	0,93								58,0	62,2
27	240	0,34	0,35	0,39	0,43	0,45	0,49	0,54	0,56	0,60	0,56	0,59	0,61	0,68	0,71	0,73	0,80	0,84	0,87	0,82	0,87	0,94	0,95					58,2	62,1	
28	160	0,50	0,55	0,59	0,63	0,68	0,74	0,77	0,85	0,92	0,90	0,99																	56,9	63,4
29	170	0,46	0,50	0,54	0,58	0,63	0,68	0,71	0,78	0,84	0,83	0,91	0,98	1,00															57,1	63,3
30	180	0,43	0,47	0,50	0,54	0,58	0,63	0,66	0,72	0,78	0,77	0,84	0,90	0,92															57,2	63,1
31	180	0,43	0,47	0,50	0,55	0,58	0,63	0,68	0,72	0,78	0,77	0,84	0,91	0,92															57,2	63,1
32	190	0,41	0,43	0,47	0,52	0,54	0,58	0,65	0,68	0,72	0,71	0,77	0,84	0,85	0,93														57,4	62,9
33	200	0,39	0,40	0,43	0,49	0,51	0,54	0,61	0,64	0,67	0,66	0,72	0,78	0,79	0,86	0,93	0,94												57,6	62,7
34	200	0,42	0,44	0,46	0,54	0,56	0,58	0,67	0,70	0,73	0,72	0,75	0,78	0,87	0,90	0,94													57,6	62,7
35	210	0,40	0,42	0,43	0,51	0,53	0,55	0,63	0,66	0,69	0,68	0,71	0,73	0,81	0,85	0,88	0,96												57,7	62,6
36	220	0,38	0,39	0,41	0,48	0,50	0,52	0,60	0,62	0,65	0,63	0,66	0,69	0,76	0,79	0,82	0,90	0,94	0,98	0,93									57,9	62,4
37	180	0,42	0,46	0,50	0,53	0,58	0,62	0,65	0,71	0,77	0,76	0,83	0,89	0,91	0,99														57,2	63,1
38	190	0,39	0,43	0,46	0,50	0,53	0,57	0,62	0,65	0,71	0,70	0,76	0,83	0,84	0,92	0,99	1,00												57,4	62,9
39	200	0,37	0,39	0,43	0,47	0,49	0,54	0,59	0,62	0,67	0,65	0,71	0,76	0,78	0,85	0,92	0,92												57,6	62,7
40	200	0,41	0,42	0,44	0,52	0,54	0,56	0,65	0,68	0,70	0,69	0,72	0,76	0,83	0,87	0,92	0,99												57,6	62,7
41	210	0,39	0,40	0,42	0,49	0,51	0,54	0,61	0,64	0,67	0,65	0,68	0,71	0,78	0,82	0,85	0,93	0,97											57,7	62,6
42	220	0,36	0,38	0,41	0,46	0,48	0,51	0,58	0,60	0,63	0,61	0,63	0,66	0,73	0,76	0,79	0,86	0,90	0,94	0,91	1,00								57,9	62,4
43	220	0,39	0,41	0,42	0,50	0,52	0,54	0,62	0,65	0,67	0,66	0,69	0,72	0,79	0,83	0,86	0,94	0,98	0,97										57,9	62,4
44	230	0,37	0,38	0,40	0,47	0,49	0,51	0,58	0,61	0,63	0,62	0,64	0,67	0,74	0,77	0,81	0,88	0,92	0,95	0,90	0,94								58,0	62,2
45	240	0,34	0,36	0,39	0,44	0,46	0,49	0,54	0,57	0,60	0,57	0,60	0,62	0,69	0,72	0,75	0,81	0,85	0,88	0,83	0,87	0,94	0,96					58,2	62,1	
46	200	0,38	0,39	0,42	0,46	0,49	0,54	0,57	0,60	0,66	0,64	0,70	0,76	0,77	0,84	0,91	0,92	1,00											57,6	62,7
47	210	0,37	0,37	0,41	0,44	0,47	0,52	0,54	0,58	0,64	0,60	0,65	0,70	0,72	0,78	0,84	0,85	0,93	0,97										57,7	62,6
48	220	0,36	0,36	0,40	0,41	0,46	0,51	0,51	0,57	0,63	0,56	0,60	0,65	0,67	0,72	0,78	0,79	0,86	0,93	0,90	0,98								57,9	62,4
49	220	0,36	0,36	0,40	0,44	0,46	0,51	0,55	0,58	0,63	0,58	0,61	0,65	0,70	0,73	0,78	0,83	0,87	0,93	0,90	0,99								57,9	62,4
50	230	0,35	0,35	0,39	0,42	0,45	0,49	0,53	0,55	0,61	0,55	0,58	0,62	0,66	0,69	0,74	0,78	0,82	0,87	0,84	0,92	0,99	0,98						58,0	62,2
51	240	0,33	0,35	0,38	0,40	0,44	0,48	0,50	0,54	0,59	0,52	0,55	0,60	0,62	0,65	0,72	0,73	0,77	0,85	0,79	0,86	0,92	0,92	1,00						

8 Visualization and discussion of obtained results

CLT_7a panel configuration: TCC_7a_n_r4_c2																														
Resistance to fire: R 30, concrete screed depth: 120 mm, self-weight including concrete g_k2: 4,46 kN/m ² , notches as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			R_w	L_w_eiq
		q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0		
1	140	0,60	0,66	0,71	0,75	0,82	0,89	0,93																					56,6	63,8
2	150	0,55	0,60	0,65	0,69	0,76	0,82	0,85	0,93	1,00																			56,7	63,6
3	160	0,51	0,55	0,60	0,64	0,69	0,75	0,78	0,86	0,93	0,91	1,00																56,9	63,4	
4	160	0,51	0,56	0,60	0,64	0,70	0,75	0,79	0,86	0,93	0,92																	56,9	63,4	
5	170	0,47	0,51	0,55	0,59	0,64	0,69	0,73	0,79	0,86	0,85	0,92	1,00															57,1	63,3	
6	180	0,44	0,48	0,51	0,55	0,60	0,64	0,67	0,73	0,79	0,78	0,85	0,92	0,94														57,2	63,1	
7	180	0,44	0,48	0,51	0,55	0,60	0,64	0,67	0,73	0,79	0,78	0,85	0,93	0,94														57,2	63,1	
8	190	0,41	0,44	0,48	0,51	0,55	0,60	0,63	0,68	0,74	0,73	0,79	0,86	0,87	0,95													57,4	62,9	
9	200	0,38	0,41	0,45	0,48	0,52	0,56	0,58	0,64	0,69	0,68	0,74	0,80	0,81	0,89	0,96	0,96											57,6	62,7	
10	160	0,50	0,55	0,59	0,63	0,68	0,74	0,77	0,85	0,92	0,90	0,99																56,9	63,4	
11	170	0,46	0,50	0,54	0,58	0,63	0,68	0,71	0,78	0,84	0,83	0,91	0,98	1,00														57,1	63,3	
12	180	0,43	0,47	0,50	0,54	0,58	0,63	0,66	0,72	0,78	0,77	0,84	0,90	0,92														57,2	63,1	
13	180	0,43	0,47	0,50	0,54	0,58	0,63	0,66	0,72	0,78	0,77	0,84	0,91	0,92														57,2	63,1	
14	190	0,40	0,43	0,47	0,50	0,54	0,58	0,61	0,67	0,72	0,71	0,77	0,84	0,85	0,93													57,4	62,9	
15	200	0,37	0,40	0,43	0,46	0,50	0,54	0,57	0,62	0,67	0,66	0,72	0,78	0,79	0,86	0,93	0,94											57,6	62,7	
16	200	0,37	0,40	0,43	0,46	0,50	0,55	0,57	0,62	0,67	0,66	0,72	0,78	0,79	0,86	0,93	0,94											57,6	62,7	
17	210	0,35	0,38	0,42	0,43	0,48	0,53	0,53	0,59	0,66	0,62	0,67	0,72	0,74	0,80	0,87	0,88	0,95										57,7	62,6	
18	220	0,33	0,37	0,41	0,42	0,47	0,52	0,52	0,58	0,64	0,58	0,63	0,67	0,69	0,75	0,81	0,82	0,89	0,96	0,93								57,9	62,4	
19	180	0,42	0,46	0,50	0,53	0,58	0,62	0,65	0,71	0,77	0,76	0,83	0,89	0,91	0,99													57,2	63,1	
20	190	0,39	0,43	0,46	0,49	0,53	0,57	0,60	0,65	0,71	0,70	0,76	0,83	0,84	0,92	0,99	1,00											57,4	62,9	
21	200	0,37	0,39	0,43	0,45	0,49	0,54	0,56	0,61	0,67	0,65	0,71	0,76	0,78	0,85	0,92	0,92											57,6	62,7	
22	200	0,37	0,40	0,43	0,46	0,49	0,54	0,56	0,61	0,67	0,65	0,71	0,76	0,78	0,85	0,92	0,92											57,6	62,7	
23	210	0,35	0,38	0,42	0,42	0,48	0,53	0,52	0,59	0,65	0,61	0,66	0,71	0,72	0,79	0,85	0,86	0,94			0,98							57,7	62,6	
24	220	0,33	0,37	0,41	0,41	0,46	0,51	0,51	0,57	0,63	0,56	0,61	0,66	0,67	0,73	0,79	0,80	0,87	0,94	0,91	1,00							57,9	62,4	
25	220	0,33	0,37	0,41	0,41	0,46	0,51	0,51	0,57	0,63	0,57	0,61	0,66	0,68	0,73	0,79	0,80	0,87	0,94	0,92	1,00							57,9	62,4	
26	230	0,32	0,36	0,40	0,40	0,45	0,50	0,50	0,56	0,62	0,53	0,57	0,63	0,63	0,69	0,75	0,75	0,81	0,88	0,86	0,93	1,00						58,0	62,2	
27	240	0,31	0,35	0,39	0,39	0,44	0,49	0,49	0,54	0,60	0,50	0,55	0,61	0,59	0,66	0,73	0,70	0,77	0,86	0,80	0,87	0,94	0,93				58,2	62,1		
28	160	0,50	0,55	0,59	0,63	0,68	0,74	0,77	0,85	0,92	0,90	0,99																56,9	63,4	
29	170	0,46	0,50	0,54	0,58	0,63	0,68	0,71	0,78	0,84	0,83	0,91	0,98	1,00														57,1	63,3	
30	180	0,43	0,47	0,50	0,54	0,58	0,63	0,66	0,72	0,78	0,77	0,84	0,90	0,92														57,2	63,1	
31	180	0,43	0,47	0,50	0,54	0,58	0,63	0,66	0,72	0,78	0,77	0,84	0,91	0,92														57,2	63,1	
32	190	0,40	0,43	0,47	0,50	0,54	0,58	0,61	0,67	0,72	0,71	0,77	0,84	0,85	0,93													57,4	62,9	
33	200	0,37	0,40	0,43	0,46	0,50	0,54	0,57	0,62	0,67	0,66	0,72	0,78	0,79	0,86	0,93	0,94											57,6	62,7	
34	200	0,37	0,40	0,43	0,46	0,50	0,55	0,57	0,62	0,67	0,66	0,72	0,78	0,79	0,86	0,93	0,94											57,6	62,7	
35	210	0,35	0,38	0,42	0,43	0,48	0,53	0,53	0,59	0,66	0,62	0,67	0,72	0,74	0,80	0,87	0,88	0,95										57,7	62,6	
36	220	0,33	0,37	0,41	0,42	0,47	0,52	0,52	0,58	0,64	0,58	0,63	0,67	0,69	0,75	0,81	0,82	0,89	0,96	0,93								57,9	62,4	
37	180	0,42	0,46	0,50	0,53	0,58	0,62	0,65	0,71	0,77	0,76	0,83	0,89	0,91	0,99													57,2	63,1	
38	190	0,39	0,43	0,46	0,49	0,53	0,57	0,60	0,65	0,71	0,70	0,76	0,83	0,84	0,92	0,99	1,00											57,4	62,9	
39	200	0,37	0,39	0,43	0,45	0,49	0,54	0,56	0,61	0,67	0,65	0,71	0,76	0,78	0,85	0,92	0,92											57,6	62,7	
40	200	0,37	0,40	0,43	0,46	0,49	0,54	0,56	0,61	0,67	0,65	0,71	0,76	0,78	0,85	0,92	0,92											57,6	62,7	
41	210	0,35	0,38	0,42	0,43	0,48	0,53	0,53	0,59	0,65	0,61	0,66	0,71	0,72	0,79	0,85	0,86	0,94			0,98							57,7	62,6	
42	220	0,33	0,37	0,41	0,41	0,46	0,51	0,51	0,57	0,63	0,56	0,61	0,66	0,68	0,73	0,79	0,80	0,87	0,94	0,91	1,00							57,9	62,4	
43	220	0,33	0,37	0,41	0,41	0,46	0,51	0,51	0,57	0,63	0,57	0,61	0,66	0,68	0,73	0,79	0,80	0,87	0,94	0,92	1,00							57,9	62,4	
44	230	0,32	0,36	0,40	0,40	0,45	0,50	0,50	0,56	0,62	0,53	0,57	0,63	0,63	0,69	0,75	0,75	0,81	0,88	0,86	0,93	1,00						58,0	62,2	
45	240	0,31	0,35	0,39	0,39	0,44	0,49	0,49	0,54	0,60	0,50	0,55	0,61	0,59	0,66	0,73	0,70	0,77	0,86	0,80	0,87	0,94	0,93				58,2	62,1		
46	200	0,38	0,39	0,42	0,45	0,49	0,54	0,55	0,60	0,66	0,64	0,70	0,76	0,77	0,84	0,91	0,92	1,00										57,6	62,7	
47	210	0,37	0,37	0,41	0,42	0,47	0,52	0,52	0,58	0,64	0,60	0,65	0,70	0,72	0,78	0,84	0,85	0,93			0,97							57,7	62,6	
48	220	0,36	0,36	0,40	0,41	0,46	0,51	0,51	0,57	0,63	0,56	0,60	0,65	0,67	0,72	0,78	0,79	0,86	0,93	0,90	0,98							57,9	62,4	
49	220	0,36	0,36	0,40	0,41	0,46	0,51	0,51	0,57	0,63	0,56	0,60	0,65	0,67	0,72	0,78	0,79	0,86	0,93	0,90	0,99							57,9	62,4	
50	230	0,35	0,35	0,39	0,40	0,45	0,49	0,49	0,55	0,61	0,52	0,56	0,62	0,62	0,68	0,74	0,74	0,80	0,87	0,84	0,92	0,99	0,98				58,0	62,2		
51	240	0,33	0,35	0,38	0,39	0,44	0,48	0,48	0,54	0,59	0,49	0,55	0,60	0,58	0,65	0,72	0,69	0,77	0,85	0,79	0,86	0,92	0,92	1,00			58,2	62,1		
52	240	0,33	0,35	0,38	0,39	0,44	0,48	0,48	0,54	0,59	0,49	0,55	0,60	0,58	0,65	0,72	0,69	0,77	0,85	0,79	0,86	0,93	0,92	1,00			58,2	62,1		
53	250	0,32	0,34	0,37	0,38	0,42</																								

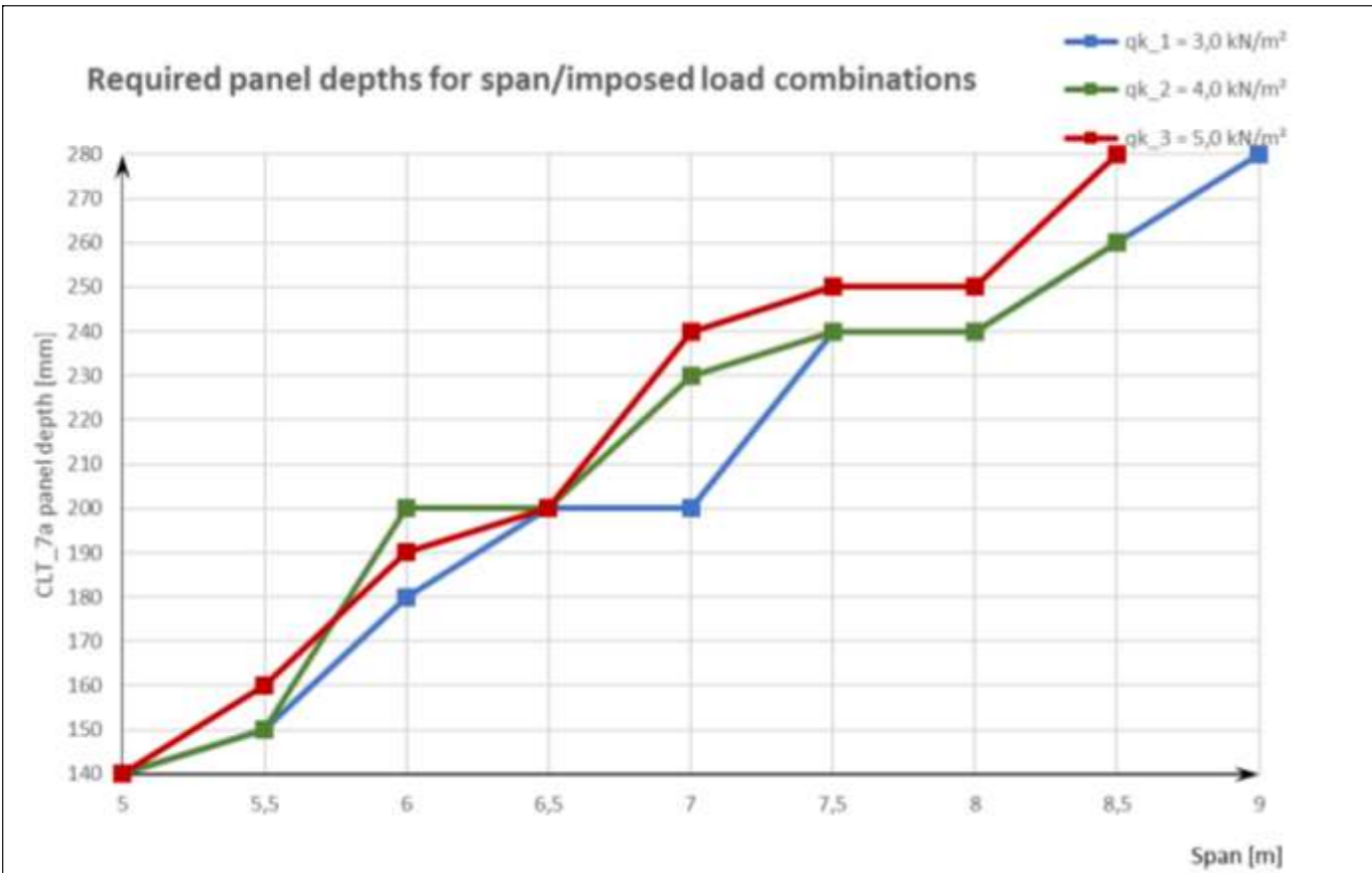


Figure 8-43: Minimum panel depths in regard to span for TCC_7a_n_r1_c2

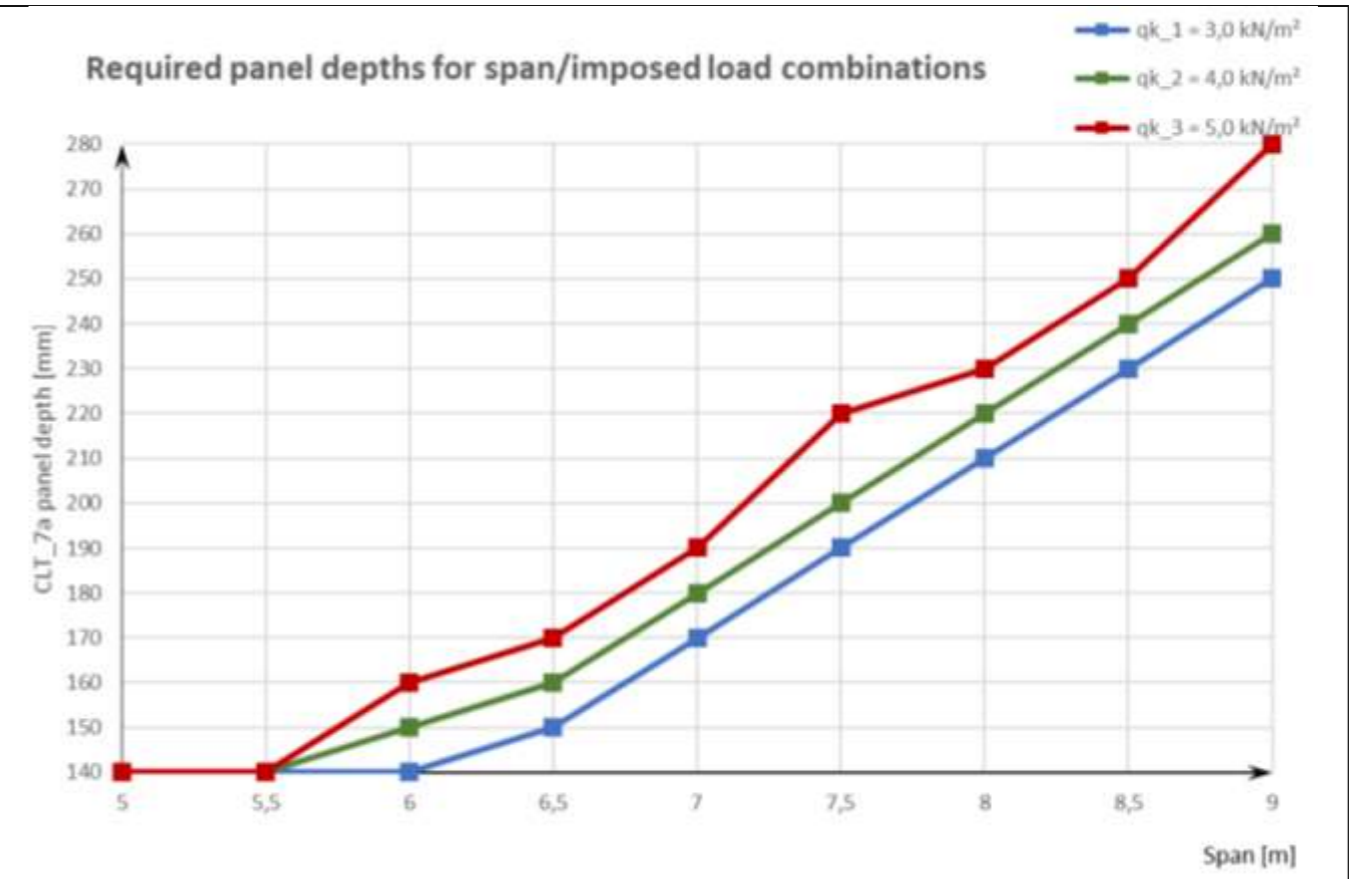


Figure 8-44: Minimum panel depths in regard to span for TCC_7a_n_r2_c2

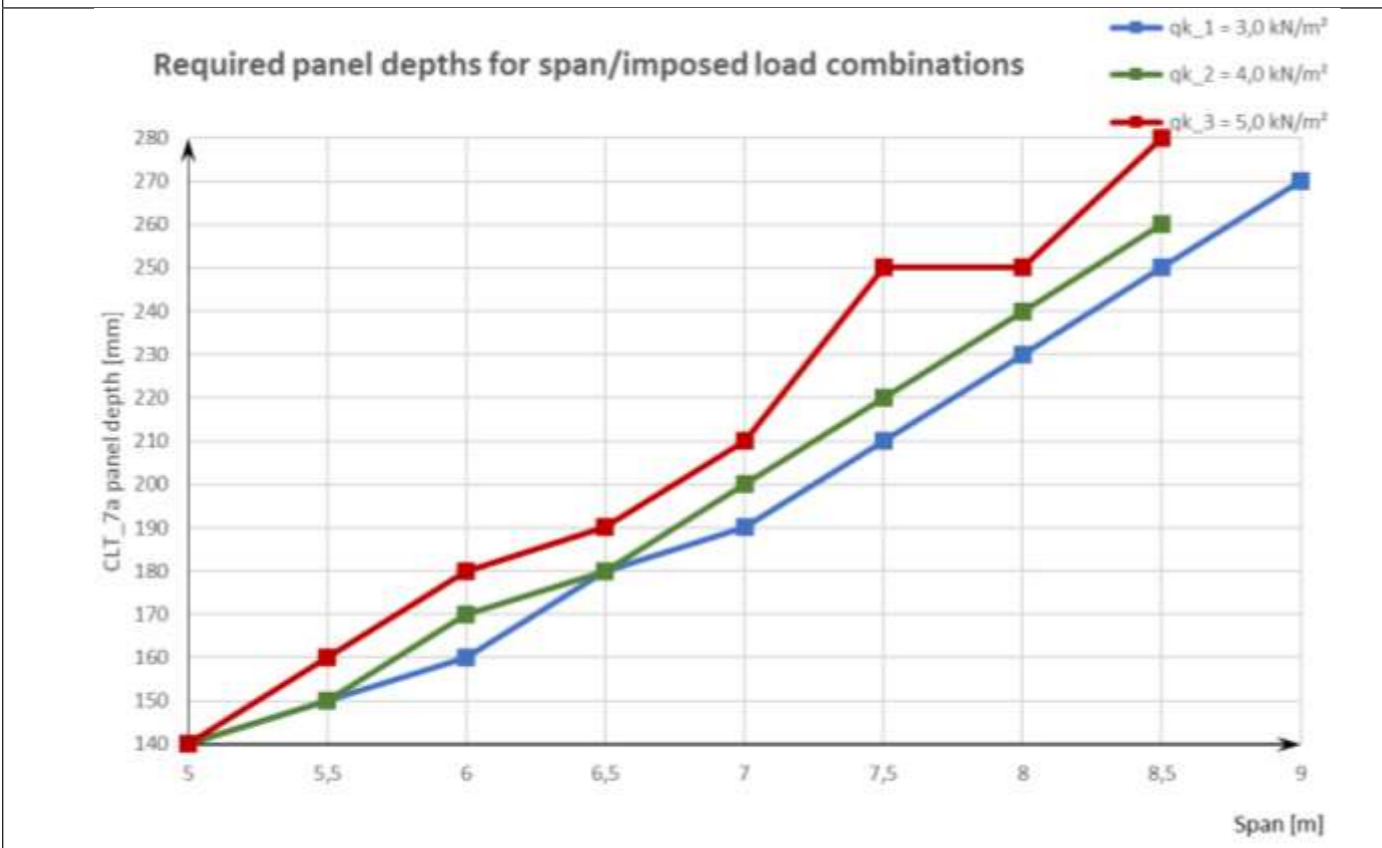


Figure 8-45: Minimum panel depths in regard to span for TCC_7a_s_r3_c2

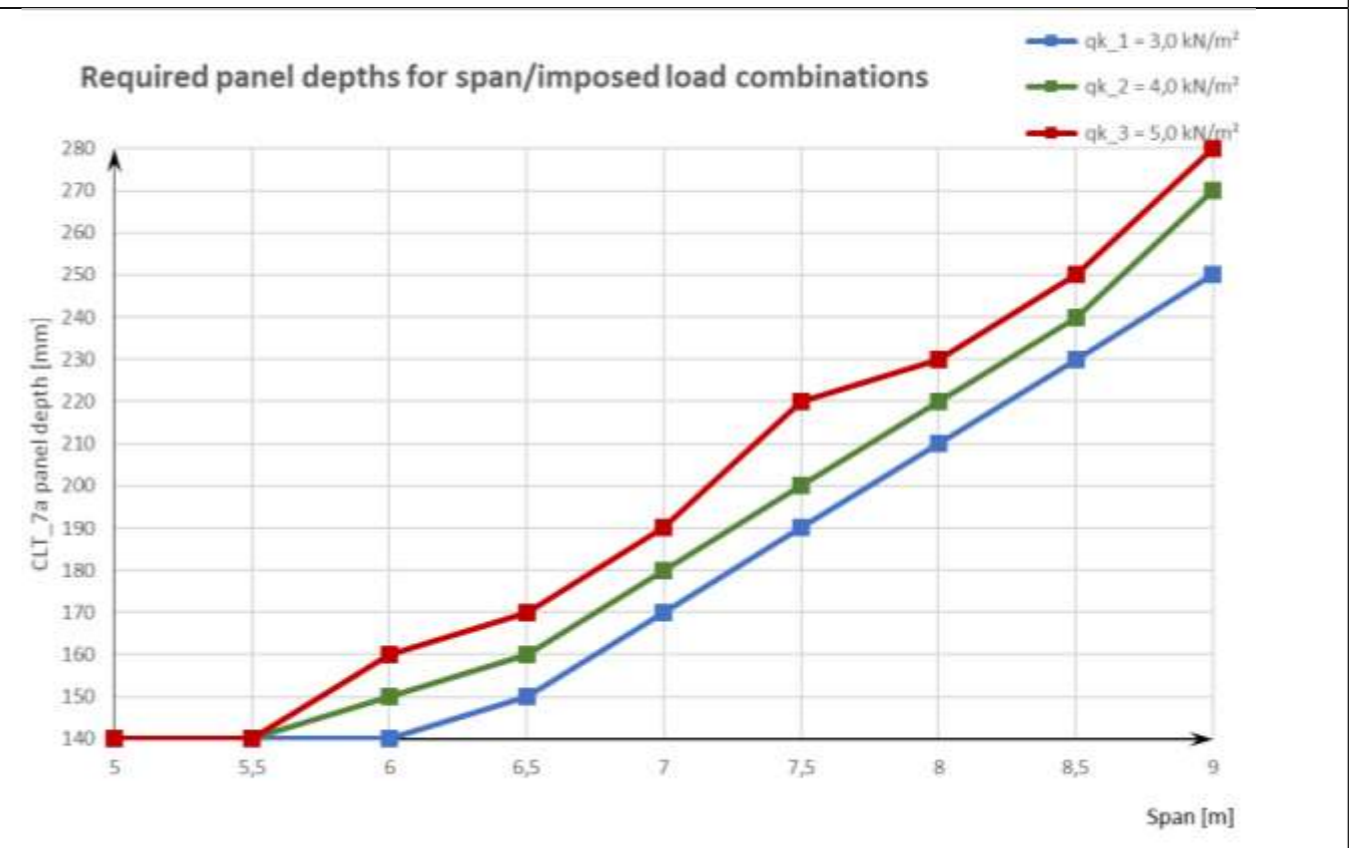


Figure 8-46: Minimum panel depths in regard to span for TCC_7a_s_s4_c2

In contrast to the previous chapter results, the number of possible solutions is similar to when screws are used as shear connectors, which means that the γ -factors are more comparable. In both cases, the maximum span of 9,0 m is reached using the panel depths of 260 – 280 mm. Generally speaking, the thicker concrete screed allows more options, especially for middle-of-the-pack spans and panel dimensions. At the same time, it doesn't move the needle at the higher end of the spectrum of spans and panel dimensions.

Given the multitude of available options, it is quite difficult to talk about general trends in a given pre-dimensioning table. Generally speaking, a 120 mm concrete screed coupled with R30 fire duration implies that the leading verification becomes the SLS at "t₀". On the other hand, fire durations of 60 mm coupled with screed depths of 90 mm make the ULS_{fi} verification (mostly for "t₀" but also for "t_{fin}") the leading one. The increase in concrete depth shifts the focus from ULS_{fire} to SLS, while the ULS tests become relevant for the high-end spectrum of CLT panels. Also, the fire resistance R 60 at "t_{fin}" requirement plays a prominent role in the dimensioning of thinner panels and smaller spans, while R60 at "t₀" is relevant for thicker panels but the lower end of the imposed loads. When the higher imposed loads are to be applied, the highest degrees of utilization are given by the ULS requirement at "t₀". With increasing span, the SLS "t_{mid}" becomes the leading verification. What we are observing is the following: when thin concrete screeds are coupled with high fire resistance requirements the fire requirements play the leading role. When concrete screed depths jump to 120 mm, the SLS verification becomes the leading one for thinner panels while fire protection remains leading for thicker panels. When fire protection is lowered, we observe the jump from "ULS_{t0}" to "SLS t_{mid}". The importance of "ULS_{t0}" is given due to the lower connection stiffness of notched connections.

On the subject of minimal panel depth to span lengths (see **Figure 8-43** to **Figure 8-46**), the behaviour is linear dependent on the span increase. When two or more results yield the same panel depth, the stiffness criterium is probably the relevant one. This happens because of the different bending stiffness of the CLT panel itself because two panels of the same depth but contrasting lamella disposition have not the same stiffness. In these cases, the panel configuration can be found after searching the corresponding panel number (at the left-hand side of to **Figure 8-29**, respectively) and double-check with **Table 20**. **Figure 8-44** and **Figure 8-46** share the same concrete screed depth and result course. This means that the fire protection duration has no influence on the minimal required CLT panel depth. The same thing cannot be observed after comparing **Figure 8-43** to **Figure 8-45**: fire protection has massive influence on the first of mentioned graphic representations, thus determining the required depths while it would be SLS requirements for lower fire durations.

8.3.5 7-layer CLT panel (CLT_7b)

Since the results are not dramatically different from the previous chapter, the related results are presented in **Annex B** but commented here. This choice has been made to allow better readability and thus overview and understand the obtained results. As stated before, these two seven-layered panel types are different in their bending stiffness parallel to the span. The chosen connection type and stiffness (slip modulus) remain the same to obtain more comparable results.

Variations of CLT_7b		Self-weight		
		g_k1	g_k2	g_k3
Variant	R 60, 90 mm screed	TCC_7b_n_r1_c1	TCC_7b_n_r1_c2	TCC_7b_n_r1_c3
	R 60, 120 mm screed	TCC_7b_n_r2_c1	TCC_7b_n_r2_c2	TCC_7b_n_r2_c3
	R 30, 90 mm screed	TCC_7b_n_r3_c1	TCC_7b_n_r3_c2	TCC_7b_n_r3_c3
	R 30, 120 mm screed	TCC_7b_n_r4_c1	TCC_7b_n_r4_c2	TCC_7b_n_r4_c3

Table 36: Variation overview for TCC_7b_notches

Due to the lower panel stiffness of CLT_7b compared to its CLT-7a counterpart, the maximum span of 9,0 m is reached only for the lower and middle imposed load level. One important aspect has to be highlighted: the dimensioning under fire conditions (especially with the R60 requirement) has a lesser impact for a CLT_7b panels than on the similar CLT_7a type. This is caused due to the different disposition of lamellas, as the CLT-7b panel has a higher remaining section stiffness parallel to span as approximately said it loses the lower lamellas to fire (one parallel and one cross to span), while the CLT-7a panel loses the two lower lamellas which both are parallel to the span. Due to the different lamella positions, such substantial differences are notable. This gap is filled by the ULS “t=0” requirements, which a little bit surprisingly become the ones with the highest utilization degrees. This is especially relevant when quite independently from the concrete layer depth, the span stays below 6,5 m. As it increases above that mark, SLS “t=0” verifications become relevant, especially when the concrete screed depth amounts to 120 mm.

With increasing span, the SLS “t_mid” becomes the leading verification. What we are observing is the following: when thin concrete screeds are coupled with high fire resistance requirements the fire requirements play the leading role. When concrete screed depths jump to 120 mm, the SLS verification becomes the leading one for thinner panels while fire protection remains leading for thicker panels. When fire protection is lowered, we observe the jump from “ULS_t0” to “SLS t_mid”. The importance of “ULS_t0” is given due to the lower connection stiffness of notched connections.

8.4 Result comparison

It would be ideal to have a graphic presentation of how the CLT panels fare against the TCC floors and how both TCC floors stack against each other. The following representations are obtained from the graphs shown in **chapter 8.1**, **chapter 8.2** and **chapter 8.3**. All analysed floor constructions

8 Visualization and discussion of obtained results

are shown together, distinguishing basing on the required fire resistance length and the concrete screed depth. Every figure relates to one level of imposed load and dead load, respectively. Otherwise, the results would be impossible to distinguish from each other. The following four cases are presented and later discussed:

	Resistance to fire	Concrete screed depth TCC	Concrete screed depth CLT
	[min]	[mm]	[mm]
Variant 1	60	90	0
Variant 2	60	120	60
Variant 3	30	90	0
Variant 4	30	120	60

Table 37: Result comparison overview for imposed load $q_{k,2}$ and dead load $g_{k,2}$

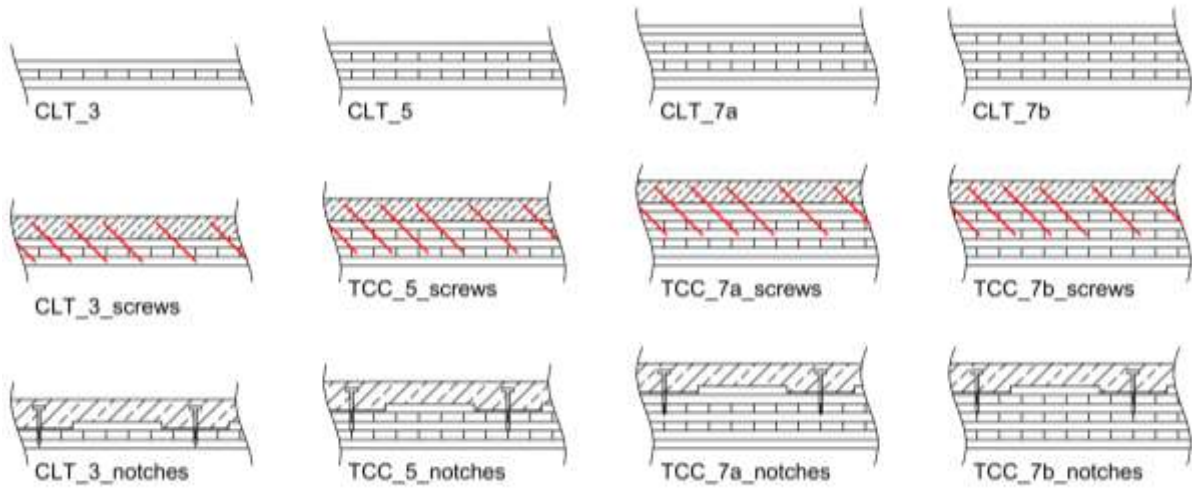


Figure 8-47: Schematic representation of implemented floor construction

8 Visualization and discussion of obtained results

COMPARISON GRAPH between span and floor/panel type

$R\ 60$, $qk_2 = 4,00\text{ kN/m}^2$, $gk_2 = 2,30\text{ kN/m}^2 + \gamma_c \cdot \text{depth}_{rc}$
 No RC screed (CLT), 90 mm RC screed (TCC)

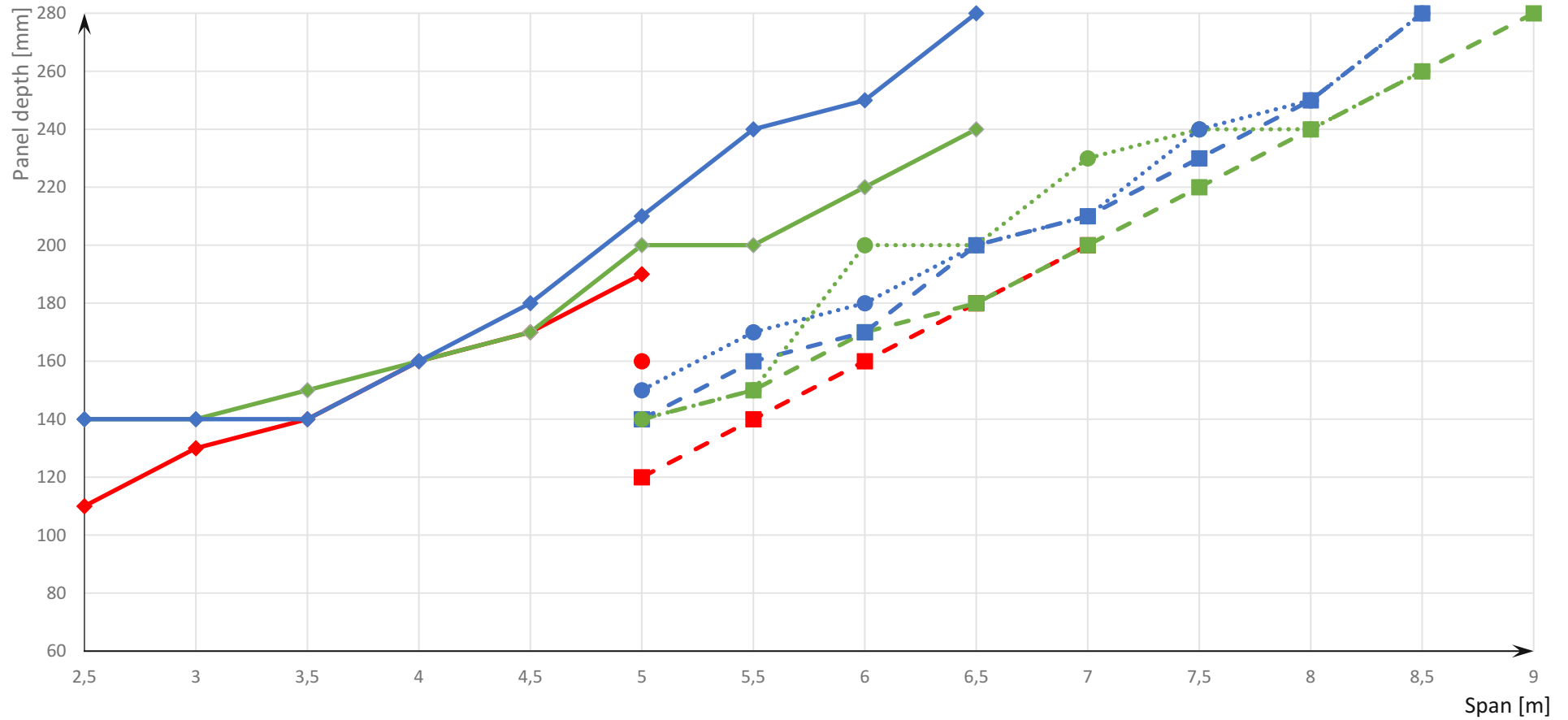
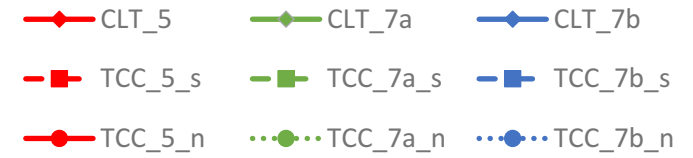


Figure 8-48: Comparison results for variant 1

COMPARISON GRAPH between span and floor/panel type

$R\ 60, qk_2 = 4,00\text{ kN/m}^2, gk_2 = 2,30\text{ kN/m}^2 + \gamma_c \cdot \text{depth}_{rc}$
 60 mm rc screed (CLT), 120 mm rc screed (TCC)

- CLT_3
- ◆ CLT_5
- ◆ CLT_7a
- ◆ CLT_7b
- TCC_5_s
- TCC_7a_s
- TCC_7b_s
- TCC_5_n
- TCC_7a_n
- TCC_7b_n

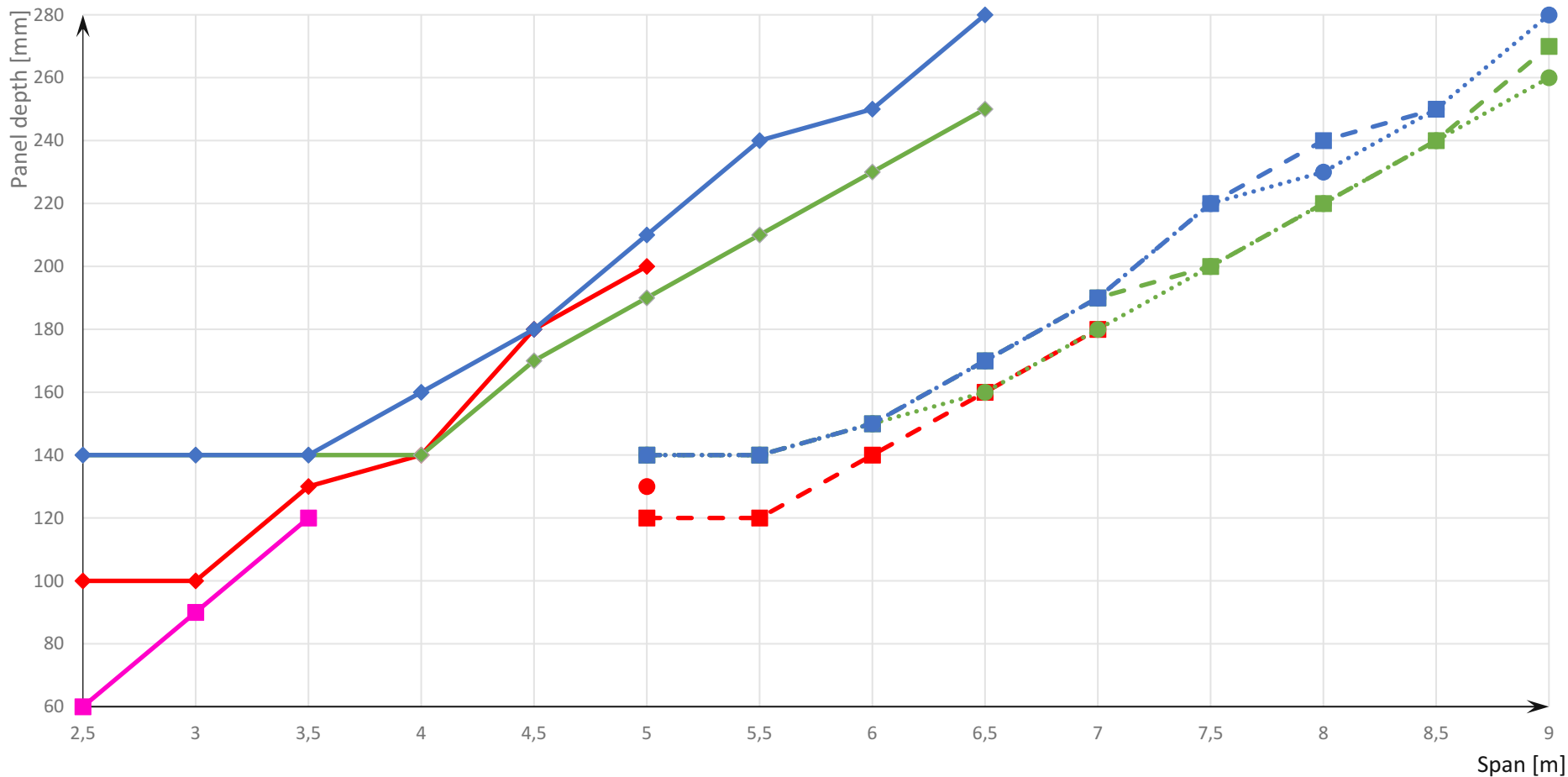


Figure 8-49: Comparison results for variant 2

8 Visualization and discussion of obtained results

COMPARISON GRAPH between span and floor/panel type

$R\ 30$, $q_{k_2} = 4,00\text{ kN/m}^2$, $g_{k_2} = 2,30\text{ kN/m}^2 + \gamma_c \cdot \text{depth}_{rc}$
 No RC screed (CLT), 90 mm RC screed (TCC)

- CLT_3
- CLT_5
- CLT_7a
- CLT_7b
- TCC_5_s
- TCC_7a_s
- TCC_7b_s
- TCC_5_n
- TCC_7a_n
- TCC_7b_n

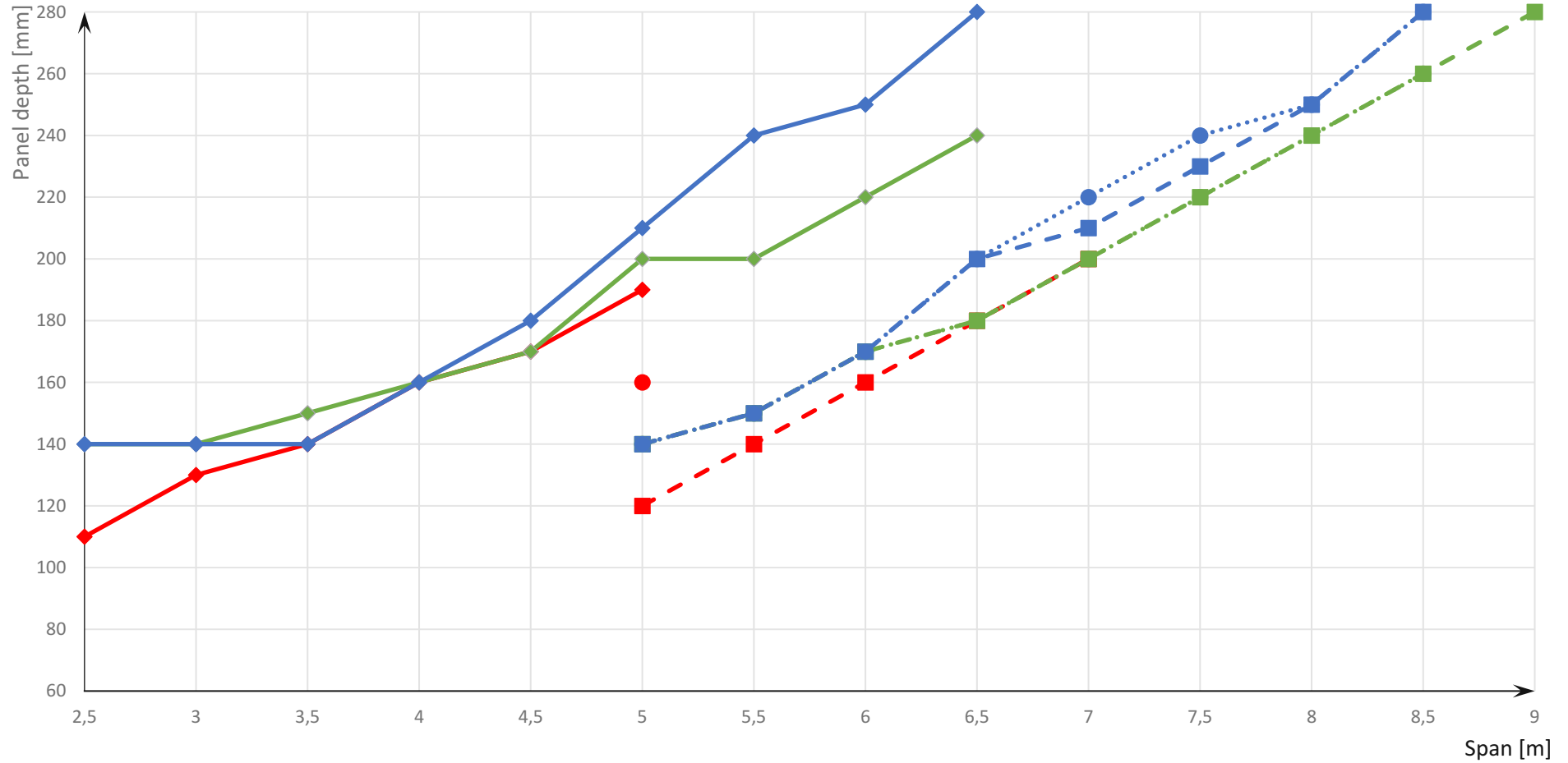


Figure 8-50: Comparison results for variant 3

COMPARISON GRAPH between span and floor/panel type

*R 30, $qk_2 = 4,00 \text{ kN/m}^2$, $gk_2 = 2,30 \text{ kN/m}^2 + \gamma_c \cdot \text{depth}_{rc}$
 60 mm rc screed (CLT), 120 mm rc screed (TCC)*

- CLT_3
- ◆ CLT_5
- ◆ CLT_7a
- ◆ CLT_7b
- TCC_5_s
- TCC_7a_s
- TCC_7b_s
- TCC_5_n
- TCC_7a_n
- TCC_7b_n

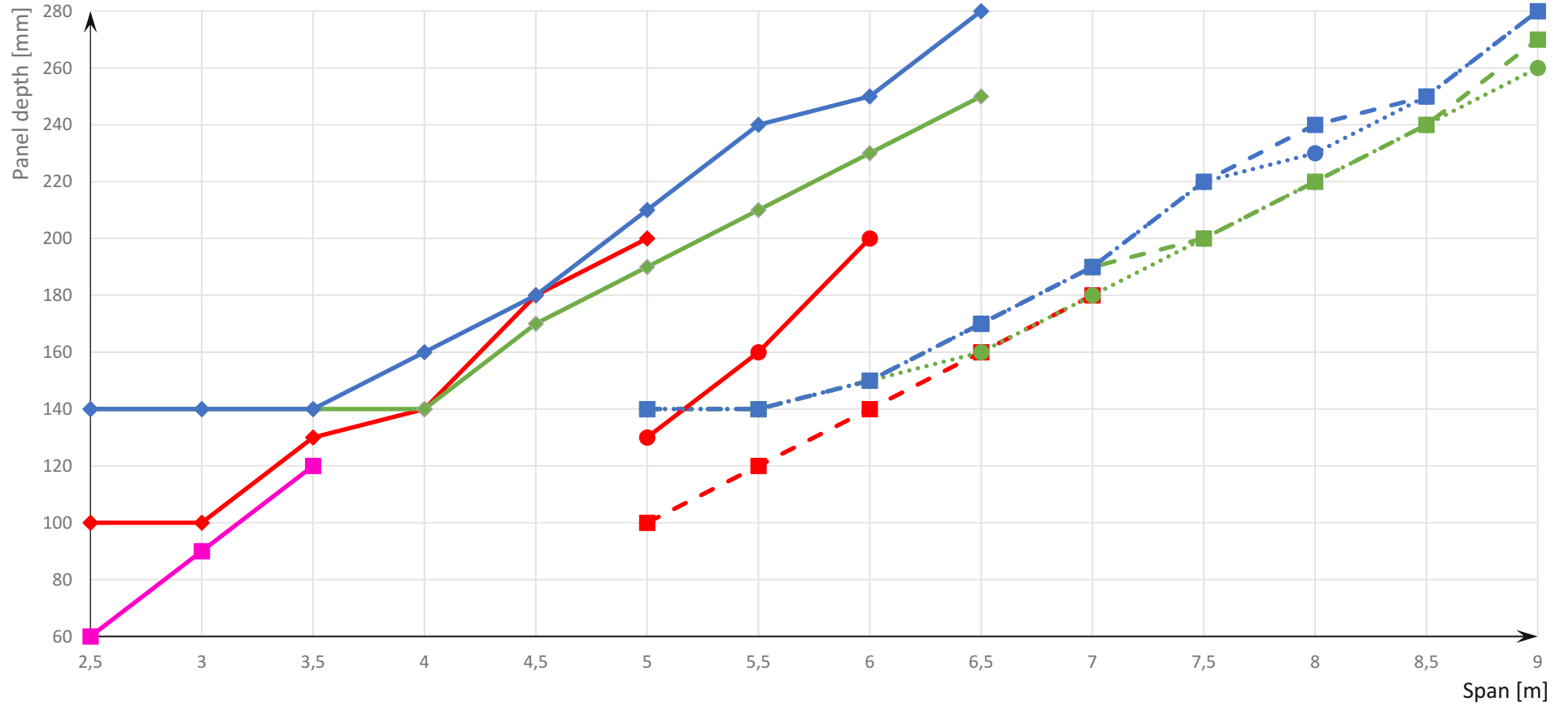


Figure 8-51: Comparison results for variant 4

The first noticeable thing in all four figures is how the floor constructions fare against each other in the overlapping span range, ranging from 5,0 – 6,5 m. There we can see how the required panel depth is significantly lower for TCC floor constructions as it is at the end of this range, they start becoming more cost-effective than simple CLT panels. Obviously, the concrete screed depth shall be considered when comparing overall package depths. In any conformation, CLT floors stop being cost-effective at a span of 6,0 m and entirely possible (at least for the analysed panel dimensions) at the 6,5 m mark, which fully corresponds to expectations. From that mark onwards, the TCC floors are the only possible way to cover such long spans.

A few considerations shall also help readers in the choice between simple CLT panels and TCC floors: Firstly, graphic representations above just contain the minimum required CLT panel depth. The concrete depth, which shall be added separately is not considered, as it is dependent on the used graph. The usage of CLT panels in this span range brings some advantages, such as the construction simplicity and quickness compared to TCC floors. The structural details are easier and thus more cost-effective and no shear connectors have to be brought into place. Since there's no concrete, no precious construction time is lost waiting for the concrete strengthening itself. On the downside, the overall floor package is considerably thicker, because the complete floor construction that also needs to fulfil sound insulation requirements needs to be brought into place. Hence, construction volume is lost. This consideration becomes very important when the building overall height and single floor height are limited due to local normative. In this cases TCC floors might make more sense, as they are also able to considerably help in the fulfilling of sound insulation requirements. Another advantage of simple CLT panels is the possibility of achieving dry constructions. Contrarily this would not be the case for TCC floors. Also, the design process of CLT floors is less onerous for engineers. When span ranges from 5,0 – 6,5 m the author recommends distinguishing basing on the building's utilization: generally speaking, in commercial buildings floor heights do not matter as much as in residential ones, because architects are not trying as hard as for residential buildings to fit the maximum number of units in a building. Therefore, simple CLT panels might be better suited even though they have thicker overall package depths. Sound insulation requirements are lower for commercial buildings too. If the to projecting construction is the one of a residential building, the author recommends the implementation of TCC floors, since they achieve very lean construction depths for small spans while also helping in regard to sound insulation. TCC floors need more time to be fully functional because the notches are to be cut in the panels or the screws are to be applied. After the concrete is cast into places, a few days where the floor construction cannot be stepped onto because the concrete is hardening. Also, the floor needs additional provisory supports while the concrete is reaching its load capacity (which fully happens after 28 days). These supports also may hinder works in the floors below. Another aspect needs to be considered too: when TCC floors are chosen, the timber construction company has to be coordinated with the concrete executing company. This might lead to more complex constructing

8 Visualization and discussion of obtained results

schedules and costs. **Figure 8-52** to **Figure 8-55** show how seven-layered panel overall depths (including eventual concrete screed depths) stack against each other depending on the floor type, CLT or TCC with screws or notches as shear connectors) for this overlapping span range of 5-6,5 m.

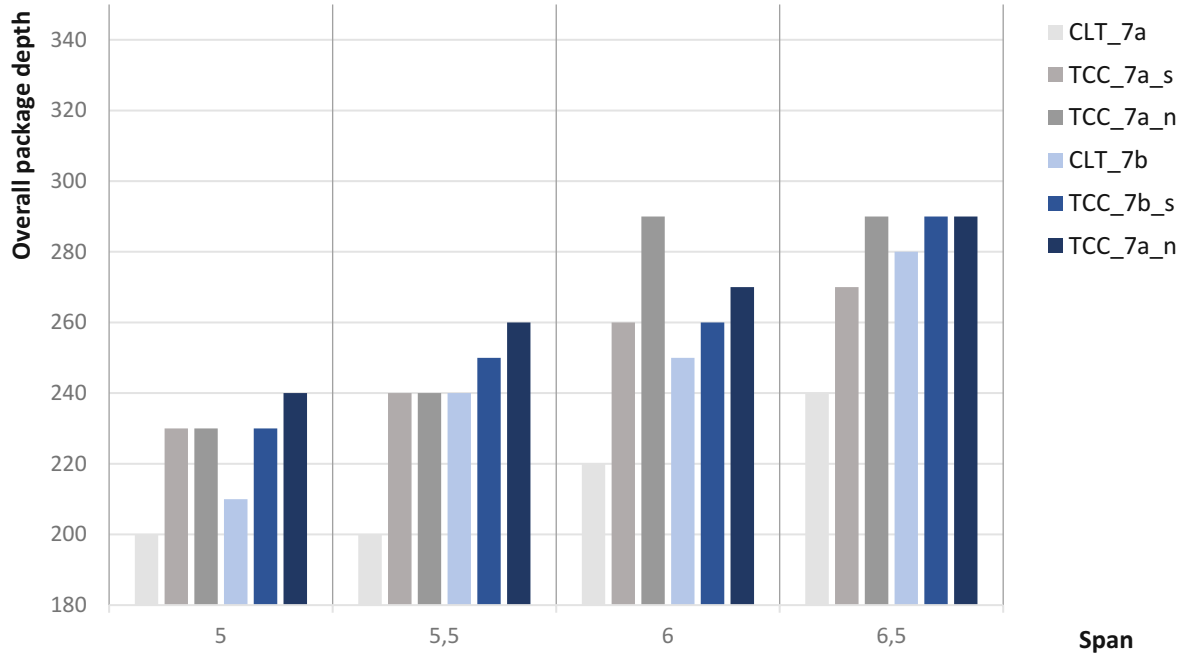


Figure 8-52: Overall depth comparison of seven-layered CLT panels for variant 1

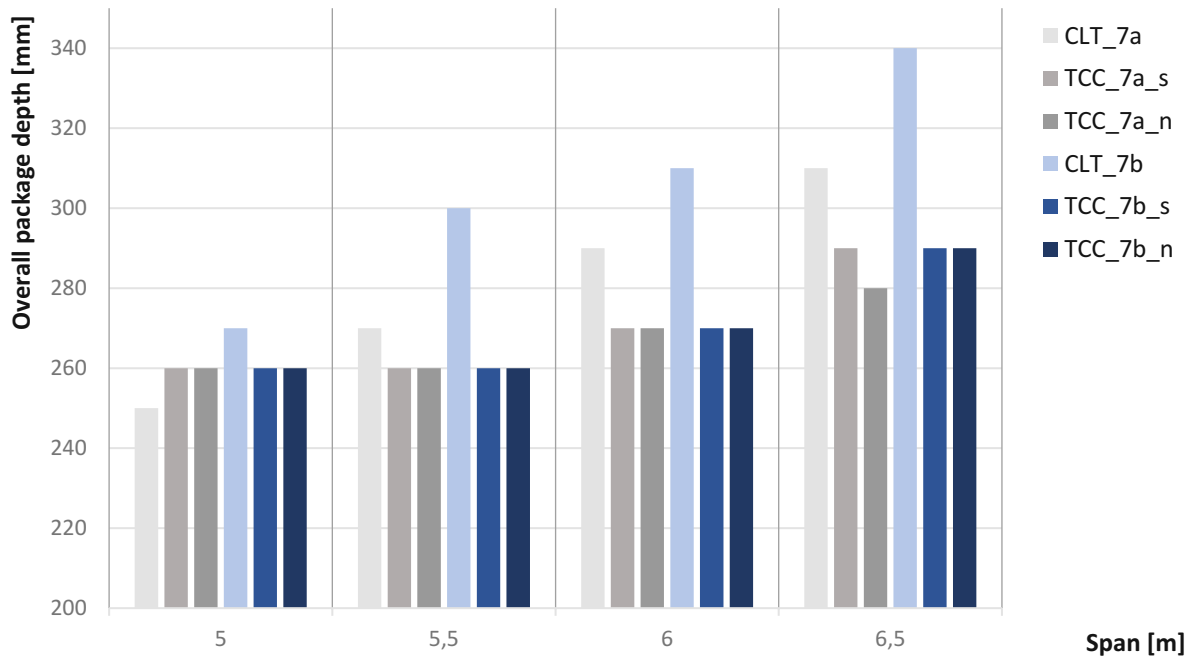


Figure 8-53: Overall depth comparison of seven-layered CLT panels for variant 2

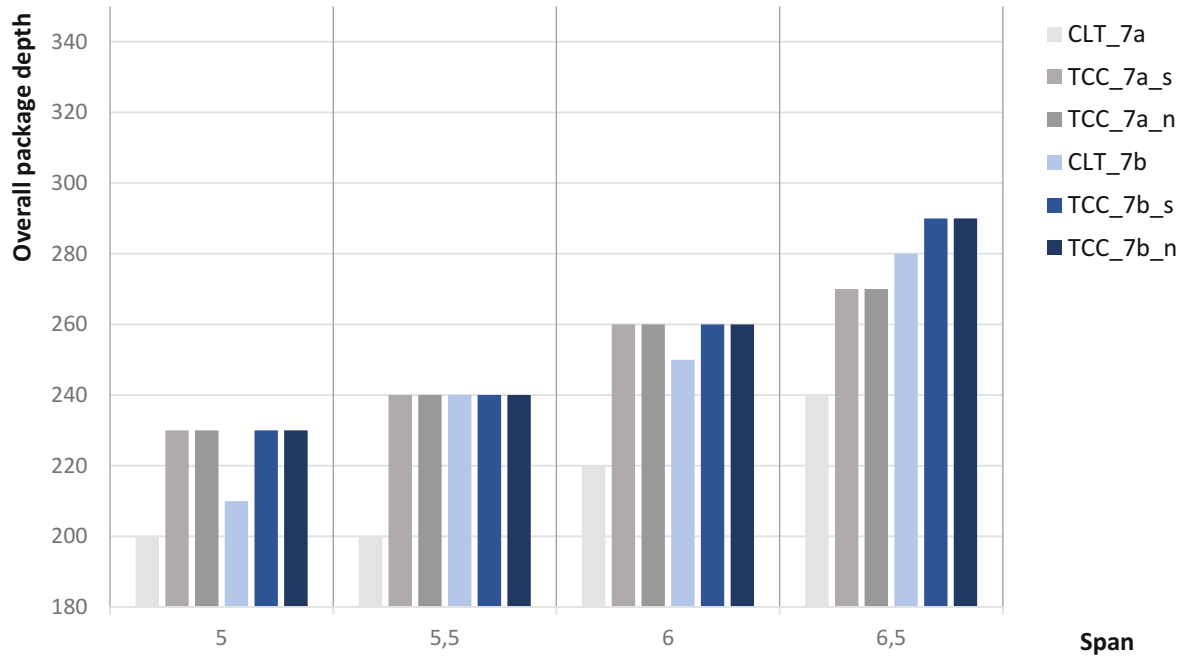


Figure 8-54: Overall depth comparison of seven-layered CLT panels for variant 3

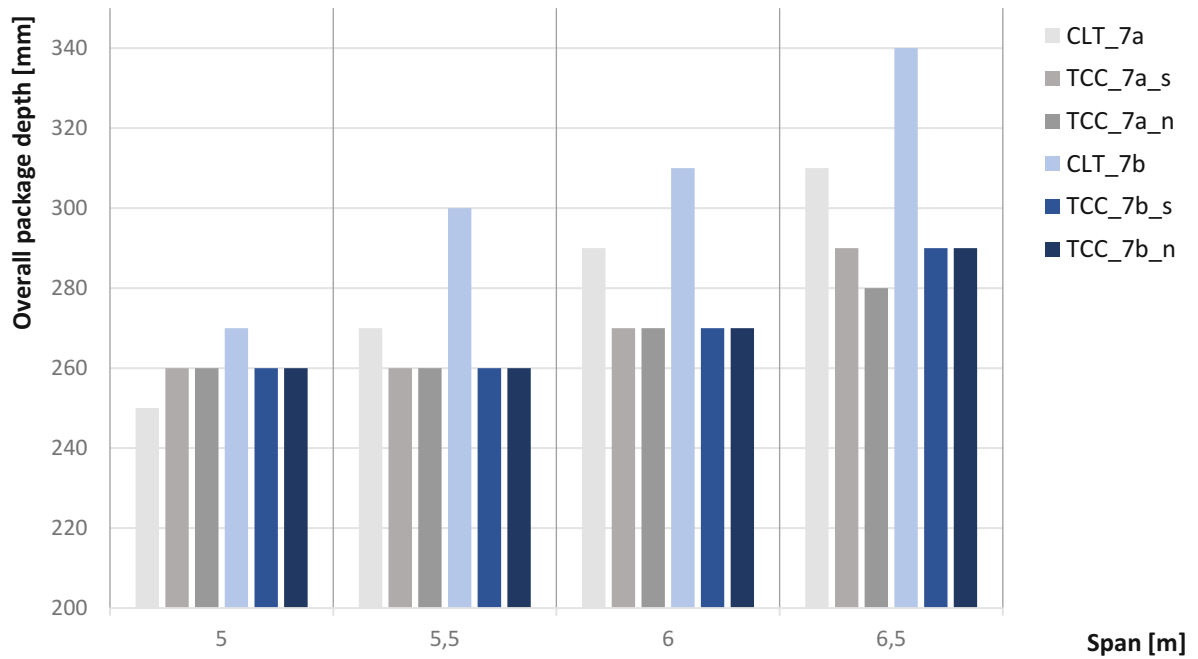


Figure 8-55: Overall depth comparison of seven-layered CLT panels for variant 4

The graphs shown in **Figure 8-48** to **Figure 8-51** refer to the imposed load level $q_{k,2}$ and dead load level $g_{k,2}$ (see Table 17); considering both other dead and imposed loads respectively would result in a total of nine combinations with four diagrams each. Since these additional representations would not yield significantly diverse results, the author decided not to show them.

On the right-hand side of **Figure 8-48** to **Figure 8-51**, differences basing on the type of used shear connection are noticeable in the required panel depth. As previously mentioned in all four cases, the screws (in the chosen conformation) are stiffer and enable the usage of smaller and, therefore, more cost-effective panels. Apart from that, differences are visible depending on the required fire-resistance duration: when the R30 criterium is chosen, a slightly smaller panel can be used. The more noticeable difference is the significant impact of the concrete depth, as its increased sectional stiffness enables the usage of smaller CLT panels. For example, the required panel depth of a seven-layered CLT panel at a span of 8,0 m coupled with screws as connectors and 90 mm reinforced concrete screed depth (see **Figure 8-50**) amounts to 240 mm while it amounts to 220 mm with the same specifications paired with a concrete layer depth of 120 mm.

The left-hand side of **Figure 8-48** to **Figure 8-51** also merits some analysing considerations regarding the smaller concrete screed's presence. Its presence allows the usage of 3-layered CLT panels, and it reduces the needed panel depth in the smaller span range. The added strength and added weight seem to nullify each other in the higher span range, culminating in similar results. Interestingly enough, the influence of fire resistance on simple CLT panels is not a knock-out criterium; this fact also emerges from **chapter 8.1**.

9 Conclusions and future research

This chapter is based on the previously presented results, and the theoretical discussion performed earlier. The research questions are again presented below to follow the conclusions better.

- a) How do CLT panels executed as statically determined one-way spanned floors perform depending on stringent parameters such as span length, resistance to fire duration, constructive, concrete depth above the CLT panel?
- b) How do TCC floors (statically determined one-way spanned floors) coupled with the same CLT panels perform depending on stringent parameters such as shear connection type, span length, resistance to fire duration, the concrete layer above the CLT panel?
- c) How do these systems perform against each other?

After implementing imposed loads (to cover residential and commercial building destinations) and dead loads, the analysis depending on the panel type and the boundary conditions mentioned above has been performed following a programmatic approach. The result is a multitude of matrices that are graphically illustrated in pre-dimensioning tables depending on the stringent parameters themselves. They are designed for daily usage by someone who is not an expert in timber and timber composite structures to help figure out what is possible, cost-effective, and what is not. These tables (based on safety and material coefficients from the German normative) show the maximum reached utilization ratio and, thanks to coloured cells, the related verification type (ULS, SLS, ULS under fire conditions) for each possible load-span-panel combination. Combinations that do not fulfil results are automatically eliminated. Such tables are designed for simple CLT-panels (see results in **chapter 8.1**) as well as for composite timber-concrete floors with screws as shear connectors (see results in **chapter 8.2**) or notches as shear connection (see results in **chapter 8.3**). In this case, the analysis has been carried out for different moments in the life of such a structure.

The performance of both systems has been compared thanks to graphs shown in **chapter 8.4**. The optimal application range is visible from these graphical representations and the influence of external boundary conditions such as the concrete screed layer depth and the required resistance to fire. The idea is to create an additional tool that helps compare massive timber floor constructions one with another. The main advantage of timber-concrete composite floor constructions is noticeable, as it allows to reach spans of up to 9,0 m with 280 mm deep CLT panels coupled with 120 mm concrete screed; this results in 400 mm of static core depth with a resulting self-weight of 4,25 kN/m². It is capable of carrying imposed loads up to 5,0 kN/m² and dead loads up to 2,8 kN/m². Considerable loads can be carried while being lighter compared to steel-concrete composite structures or other prefabricated concrete solutions. With the implementation of stiffer shear connectors (of any type), the resulting bending stiffness parallel to span improves considerably as the gamma-factor increases. So, the material used can be furtherly reduced and obtain even better structural performances and lessened structural self-weights. The ecological

factor merits to be considered because the used concrete amount is lesser than for other comparable solutions that do not use timber as a composite material.

These pre-dimensioning tables are purely theoretical decisional tools, as other elements such as sound insulation requirements, executional criteriums (i.e., notched connections are easier to execute than screw connection), etc., might have a stronger impact on a specific project. These tables are intended to help engineers, architects, and clients to know what they shall expect but obviously do not replace any project related decision-making tool. Also, they do not supplant any project-related statical design because of their more general character.

The amount of obtained data is enormous and requires a lot of commenting to be understood. The most interesting thing is that this may just be the “tip of the iceberg”, as plenty of parameters can be changed, resulting in more and more results. This is easily achievable due to the programmatic nature of the calculations. In the near future, new parameters such as the following may be implemented:

- a) More resistances to fire durations: 90 and 120 minutes.
- b) Implementation of more shear connector types with different shear stiffnesses, such as glued connections or connections with dowels.
- c) Varying shear connector dimension and thus varying shear stiffness.
- d) Implementation of other concrete screed depths, in particular 80 mm and 100 mm.
- e) A more detailed and less approximative determination of sound insulation capabilities.
- f) Consideration of other points in time, for example, due to usage destination changes or renovation and or adaptation works.
- g) Application of different safety coefficients depending on the geographical location of the project.
- h) Expansion to the design of multi-span system
- i) Design to horizontal load actions

This means that it would be quite challenging to show all pre-dimensioning tables together in a document because even the more expert users might get lost in the sheer amount of data. The solution obviously might be an informatics program or an online application with all the data obtained in this thesis and after further expansions already implemented. Users select beforehand all required restricting parameters, such as the wanted resistance to fire, concrete screed depth, shear connector type and dimensions, the building’s usage destination (imposed loads) and the dead load value. After all these selections, the program brings up the needed pre-dimensioning table, which is characterized by all parameter variables and shows it to the users. Also, the comparison of tables shall be an option, making this tool even more capable and powerful. This might also become a regular static program for the specific dimensioning of timber-concrete

composite floor constructions if the user interface and result output would need plenty of effort. In addition to that, the implementation of importing and exporting tools for BIM (building information modelling) might be worth considering, as this new way of projecting becomes more and more relevant. The road that would lead to such results is long and the result of cooperation between universities and the private timber industry. But as we all know very well: “Sky is the limit”, and a part of the foundation has been laid with this master thesis.

10 Literature

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13 Annex A – 7-layer CLT panel (CLT-7b)

CLT_7b panel configuration: CLT_7b_r1_c2																															
Resistance to fire: R 60, self-weight g_k2: 2,30 kN/m ²																															
Panel Nr.	depth_tot	SPAN 1 = 2,5 m			SPAN 2 = 3,0m			SPAN 3 = 3,5 m			SPAN 4 = 4,0 m			SPAN 5 = 4,5 m			SPAN 6 = 5,0 m			SPAN 7 = 5,5m			SPAN 8 = 6,0 m			SPAN 9 = 6,5 m			R_w	L_w_eq	
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0			
1	140	0,50	0,50	0,50	0,72	0,72	0,72	0,98	0,98																					36,1	88,9
2	150	0,39	0,39	0,39	0,56	0,56	0,56	0,76	0,76	0,81	0,99																			36,7	88,2
3	160	0,31	0,31	0,31	0,45	0,45	0,45	0,61	0,61	0,66	0,79	0,88	0,98																	37,3	87,6
4	160	0,34	0,34	0,34	0,49	0,49	0,49	0,66	0,66	0,71	0,86	0,94																	37,3	87,6	
5	170	0,27	0,27	0,27	0,38	0,38	0,38	0,52	0,52	0,56	0,68	0,75	0,84	0,93																37,7	87,0
6	180	0,22	0,22	0,22	0,31	0,31	0,31	0,42	0,42	0,46	0,55	0,61	0,69	0,76	0,87	0,97														38,0	86,5
7	180	0,24	0,24	0,24	0,34	0,34	0,34	0,46	0,46	0,50	0,60	0,67	0,75	0,83	0,95														38,0	86,5	
8	190	0,19	0,19	0,19	0,27	0,27	0,27	0,37	0,37	0,41	0,48	0,54	0,60	0,67	0,76	0,86	0,92													38,3	86,0
9	200	0,16	0,16	0,16	0,22	0,22	0,22	0,30	0,30	0,33	0,39	0,44	0,50	0,55	0,63	0,71	0,76	0,86	0,97											38,6	85,5
10	160	0,36	0,36	0,36	0,52	0,52	0,52	0,71	0,73	0,82	0,95																			37,3	87,6
11	170	0,29	0,29	0,29	0,42	0,42	0,42	0,57	0,60	0,67	0,78	0,89																	37,7	87,0	
12	180	0,24	0,24	0,24	0,34	0,34	0,35	0,47	0,50	0,56	0,65	0,74	0,84	0,93																38,0	86,5
13	180	0,26	0,26	0,26	0,37	0,37	0,38	0,51	0,54	0,60	0,70	0,80	0,90	1,00																38,0	86,5
14	190	0,21	0,21	0,21	0,30	0,30	0,31	0,41	0,44	0,49	0,58	0,66	0,74	0,82	0,93														38,3	86,0	
15	200	0,17	0,17	0,17	0,25	0,25	0,26	0,34	0,37	0,41	0,48	0,55	0,61	0,68	0,78	0,87	0,94													38,6	85,5
16	200	0,19	0,19	0,19	0,28	0,28	0,29	0,37	0,40	0,45	0,53	0,60	0,67	0,75	0,85	0,96														38,6	85,5
17	210	0,16	0,16	0,16	0,22	0,22	0,23	0,30	0,33	0,37	0,43	0,49	0,55	0,62	0,70	0,78	0,84	0,96											38,8	85,0	
18	220	0,13	0,13	0,13	0,19	0,19	0,20	0,25	0,28	0,31	0,36	0,41	0,46	0,52	0,59	0,66	0,67	0,76	0,85	0,90	0,94								39,1	84,6	
19	180	0,27	0,27	0,27	0,39	0,39	0,42	0,53	0,59	0,66	0,77	0,88	0,99																	38,0	86,5
20	190	0,23	0,23	0,23	0,32	0,32	0,35	0,44	0,50	0,56	0,65	0,74	0,83	0,93																38,3	86,0
21	200	0,19	0,19	0,19	0,27	0,27	0,30	0,37	0,43	0,48	0,56	0,63	0,71	0,79	0,90														38,6	85,5	
22	200	0,21	0,21	0,21	0,29	0,29	0,32	0,40	0,46	0,51	0,60	0,68	0,76	0,85	0,97														38,6	85,5	
23	210	0,17	0,17	0,17	0,24	0,24	0,27	0,34	0,38	0,43	0,50	0,57	0,64	0,72	0,81	0,91	0,98													38,8	85,0
24	220	0,14	0,14	0,14	0,20	0,21	0,23	0,29	0,33	0,37	0,43	0,49	0,54	0,61	0,69	0,77	0,84	0,95											39,1	84,6	
25	220	0,16	0,16	0,16	0,23	0,23	0,25	0,32	0,36	0,40	0,47	0,53	0,60	0,67	0,76	0,85	0,91													39,1	84,6
26	230	0,13	0,13	0,13	0,19	0,19	0,21	0,26	0,30	0,34	0,39	0,45	0,50	0,56	0,63	0,71	0,77	0,87	0,97											39,3	84,1
27	240	0,11	0,11	0,11	0,16	0,16	0,18	0,23	0,26	0,29	0,34	0,38	0,42	0,48	0,54	0,60	0,65	0,74	0,83	0,87	0,98								39,5	83,7	
28	160	0,34	0,34	0,34	0,49	0,49	0,49	0,66	0,66	0,66	0,86	0,86	0,91																	37,3	87,6
29	170	0,27	0,27	0,27	0,39	0,39	0,39	0,53	0,53	0,53	0,69	0,69	0,75	0,87	0,95														37,7	87,0	
30	180	0,22	0,22	0,22	0,32	0,32	0,32	0,43	0,43	0,43	0,56	0,56	0,63	0,71	0,80	0,89	0,96													38,0	86,5
31	180	0,24	0,24	0,24	0,34	0,34	0,34	0,46	0,46	0,46	0,60	0,60	0,66	0,76	0,84	0,94														38,0	86,5
32	190	0,19	0,19	0,19	0,28	0,28	0,28	0,37	0,37	0,37	0,49	0,49	0,55	0,62	0,69	0,78	0,84	0,95											38,3	86,0	
33	200	0,16	0,16	0,16	0,23	0,23	0,23	0,31	0,31	0,31	0,40	0,41	0,46	0,51	0,58	0,66	0,70	0,80	0,90	0,94										38,6	85,5
34	200	0,17	0,17	0,17	0,25	0,25	0,25	0,34	0,34	0,34	0,44	0,44	0,50	0,56	0,63	0,71	0,76	0,86	0,97											38,6	85,5
35	210	0,14	0,14	0,14	0,20	0,20	0,20	0,28	0,28	0,28	0,36	0,37	0,41	0,46	0,52	0,59	0,63	0,72	0,80	0,84	0,95								38,8	85,0	
36	220	0,12	0,12	0,12	0,17	0,17	0,17	0,23	0,23	0,23	0,30	0,31	0,35	0,39	0,44	0,50	0,53	0,61	0,68	0,71	0,81	0,90	0,92							39,1	84,6
37	180	0,25	0,25	0,25	0,35	0,35	0,35	0,48	0,48	0,49	0,62	0,65	0,73	0,81	0,93														38,0	86,5	
38	190	0,20	0,20	0,20	0,29	0,29	0,29	0,39	0,39	0,41	0,51	0,55	0,62	0,69	0,78	0,88	0,94													38,3	86,0
39	200	0,17	0,17	0,17	0,24	0,24	0,24	0,33	0,33	0,35	0,43	0,47	0,53	0,59	0,67	0,75	0,81	0,92											38,6	85,5	
40	200	0,18	0,18	0,18	0,26	0,26	0,26	0,35	0,35	0,38	0,46	0,50	0,56	0,62	0,71	0,80	0,86	0,97											38,6	85,5	
41	210	0,15	0,15	0,15	0,21	0,21	0,21	0,29	0,29	0,32	0,38	0,42	0,47	0,53	0,60	0,67	0,72	0,82	0,92	0,96										38,8	85,0
42	220	0,13	0,13	0,13	0,18	0,18	0,18	0,25	0,25	0,27	0,32	0,36	0,40	0,45	0,51	0,58	0,62	0,70	0,79	0,82	0,94								39,1	84,6	
43	220	0,14	0,14	0,14	0,20	0,20	0,20	0,27	0,27	0,29	0,35	0,39	0,44	0,49	0,55	0,62	0,67	0,76	0,85	0,89										39,1	84,6
44	230	0,11	0,11	0,11	0,16	0,16	0,16	0,22	0,22	0,25	0,29	0,33	0,37	0,41	0,47	0,52	0,57	0,64	0,72	0,75	0,85	0,96	0,98						39,3	84,1	
45	240	0,10	0,10	0,10	0,14	0,14	0,14	0,19	0,19	0,21	0,25	0,28	0,32	0,36	0,40	0,45	0,49	0,55	0,62	0,65	0,73	0,82	0,84	0,95					39,5	83,7	
46	200	0,19	0,19	0,19	0,27	0,27	0,27	0,36	0,36	0,40	0,47	0,53	0,60	0,66	0,76	0,85	0,91													38,6	85,5
47	210	0,16	0,16	0,16	0,22	0,22	0,22	0,30	0,31	0,34	0,40	0,46	0,51	0,57	0,65	0,73	0,79	0,89											38,8	85,0	
48	220	0,13	0,13	0,13	0,19	0,19	0,19	0,26	0,27	0,30	0,35	0,40	0,45	0,50	0,57	0,64	0,69	0,78	0,87	0,91											

CLT_7b panel configuration: CLT_7b_r3_c2																														
Resistance to fire: R 60, loose concrete screed depth: 60 mm, self-weight including concrete g k2: 3,74 kN/m ²																														
Panel Nr.	depth_tot	SPAN 1 = 2,5 m			SPAN 2 = 3,0 m			SPAN 3 = 3,5 m			SPAN 4 = 4,0 m			SPAN 5 = 4,5 m			SPAN 6 = 5,0 m			SPAN 7 = 5,5 m			SPAN 8 = 6,0 m			SPAN 9 = 6,5 m			R_w	L_w_eff
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0		
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]				
1	140	0,33	0,33	0,33	0,48	0,51	0,57	0,73	0,82	0,90																		43,2	77,1	
2	150	0,28	0,28	0,28	0,40	0,43	0,48	0,62	0,69	0,76	0,92																	43,4	76,9	
3	160	0,24	0,24	0,24	0,34	0,37	0,41	0,53	0,59	0,64	0,78	0,87	0,96															43,5	76,7	
4	160	0,25	0,25	0,25	0,36	0,39	0,43	0,56	0,62	0,68	0,83	0,92																43,5	76,7	
5	170	0,21	0,21	0,21	0,30	0,32	0,36	0,46	0,51	0,57	0,69	0,77	0,84	0,98														43,6	76,5	
6	180	0,18	0,18	0,18	0,25	0,27	0,30	0,39	0,43	0,48	0,58	0,65	0,71	0,83	0,92													43,7	76,3	
7	180	0,19	0,19	0,19	0,27	0,30	0,33	0,42	0,47	0,52	0,63	0,70	0,77	0,90	0,99													43,7	76,3	
8	190	0,16	0,16	0,16	0,23	0,25	0,27	0,35	0,39	0,43	0,52	0,58	0,64	0,74	0,82	0,91												43,8	76,1	
9	200	0,13	0,13	0,13	0,19	0,21	0,23	0,30	0,33	0,36	0,44	0,49	0,54	0,63	0,69	0,76	0,86	0,95										43,9	75,9	
10	160	0,27	0,27	0,28	0,39	0,44	0,48	0,62	0,69	0,76	0,93																	43,5	76,7	
11	170	0,23	0,23	0,24	0,34	0,37	0,41	0,53	0,59	0,65	0,80	0,88	0,97															43,6	76,5	
12	180	0,19	0,19	0,21	0,29	0,32	0,36	0,46	0,51	0,56	0,69	0,76	0,84	0,98														43,7	76,3	
13	180	0,21	0,21	0,22	0,31	0,34	0,38	0,49	0,54	0,60	0,73	0,81	0,89															43,7	76,3	
14	190	0,17	0,17	0,19	0,26	0,29	0,32	0,42	0,46	0,51	0,62	0,69	0,75	0,88	0,98													43,8	76,1	
15	200	0,15	0,15	0,16	0,22	0,25	0,27	0,36	0,39	0,43	0,53	0,59	0,65	0,75	0,84	0,92												43,9	75,9	
16	200	0,16	0,16	0,17	0,24	0,27	0,30	0,39	0,43	0,47	0,57	0,64	0,70	0,82	0,91	0,99												43,9	75,9	
17	210	0,14	0,14	0,15	0,21	0,23	0,25	0,33	0,36	0,40	0,48	0,54	0,59	0,69	0,76	0,84	0,94											44,0	75,8	
18	220	0,12	0,12	0,12	0,18	0,19	0,21	0,28	0,31	0,34	0,41	0,46	0,50	0,59	0,65	0,71	0,80	0,89	0,98									44,1	75,6	
19	180	0,22	0,22	0,24	0,33	0,37	0,41	0,53	0,59	0,65	0,79	0,88	0,96															43,7	76,3	
20	190	0,18	0,19	0,21	0,29	0,32	0,35	0,46	0,51	0,56	0,69	0,76	0,84	0,98														43,8	76,1	
21	200	0,16	0,16	0,18	0,25	0,28	0,31	0,40	0,45	0,49	0,60	0,67	0,73	0,86	0,95													43,9	75,9	
22	200	0,17	0,17	0,19	0,27	0,30	0,33	0,43	0,48	0,52	0,64	0,71	0,78	0,91														43,9	75,9	
23	210	0,15	0,15	0,17	0,23	0,26	0,28	0,37	0,41	0,45	0,55	0,61	0,67	0,78	0,87	0,95												44,0	75,8	
24	220	0,13	0,13	0,14	0,20	0,22	0,25	0,32	0,36	0,39	0,48	0,53	0,58	0,68	0,75	0,83	0,93											44,1	75,6	
25	220	0,14	0,14	0,16	0,22	0,24	0,27	0,35	0,39	0,42	0,52	0,57	0,63	0,74	0,82	0,89												44,1	75,6	
26	230	0,12	0,12	0,13	0,19	0,21	0,23	0,30	0,33	0,36	0,44	0,49	0,54	0,63	0,70	0,77	0,86	0,96										44,2	75,4	
27	240	0,10	0,10	0,11	0,16	0,18	0,20	0,26	0,28	0,31	0,38	0,42	0,46	0,55	0,60	0,66	0,75	0,83	0,90	0,99								44,2	75,3	
28	160	0,25	0,25	0,25	0,35	0,35	0,38	0,50	0,55	0,61	0,74	0,82	0,90															43,5	76,7	
29	170	0,21	0,21	0,21	0,30	0,30	0,33	0,42	0,47	0,51	0,63	0,70	0,77	0,89	0,99													43,6	76,5	
30	180	0,18	0,18	0,18	0,25	0,25	0,28	0,36	0,40	0,44	0,54	0,60	0,66	0,77	0,85	0,94												43,7	76,3	
31	180	0,19	0,19	0,19	0,27	0,27	0,29	0,38	0,42	0,46	0,57	0,63	0,69	0,81	0,90	0,98												43,7	76,3	
32	190	0,16	0,16	0,16	0,23	0,23	0,25	0,32	0,36	0,39	0,48	0,53	0,59	0,68	0,76	0,83	0,94											43,8	76,1	
33	200	0,14	0,14	0,14	0,19	0,19	0,21	0,28	0,31	0,34	0,41	0,46	0,50	0,59	0,65	0,71	0,80	0,89	0,98									43,9	75,9	
34	200	0,15	0,15	0,15	0,21	0,21	0,23	0,30	0,33	0,36	0,44	0,49	0,54	0,63	0,69	0,76	0,86	0,95										43,9	75,9	
35	210	0,12	0,12	0,12	0,18	0,18	0,19	0,25	0,28	0,30	0,37	0,41	0,45	0,53	0,59	0,64	0,73	0,80	0,88	0,97								44,0	75,8	
36	220	0,10	0,10	0,10	0,15	0,15	0,17	0,21	0,24	0,26	0,32	0,35	0,39	0,45	0,50	0,55	0,62	0,69	0,76	0,83	0,92							44,1	75,6	
37	180	0,19	0,19	0,19	0,28	0,29	0,32	0,41	0,46	0,50	0,62	0,68	0,75	0,88	0,97													43,7	76,3	
38	190	0,17	0,17	0,17	0,24	0,25	0,28	0,36	0,40	0,44	0,53	0,59	0,65	0,76	0,84	0,92												43,8	76,1	
39	200	0,14	0,14	0,14	0,21	0,22	0,24	0,31	0,35	0,38	0,47	0,52	0,57	0,66	0,73	0,81	0,91											43,9	75,9	
40	200	0,15	0,15	0,15	0,22	0,23	0,25	0,33	0,36	0,40	0,49	0,54	0,60	0,70	0,77	0,85	0,96											43,9	75,9	
41	210	0,13	0,13	0,13	0,22	0,20	0,22	0,28	0,31	0,34	0,42	0,47	0,51	0,60	0,66	0,73	0,82	0,91	1,00									44,0	75,8	
42	220	0,11	0,11	0,11	0,16	0,17	0,19	0,25	0,27	0,30	0,37	0,41	0,45	0,52	0,58	0,63	0,71	0,79	0,87	0,95								44,1	75,6	
43	220	0,12	0,12	0,12	0,17	0,18	0,20	0,26	0,29	0,32	0,39	0,44	0,48	0,56	0,62	0,68	0,76	0,85	0,93									44,1	75,6	
44	230	0,10	0,10	0,10	0,15	0,16	0,17	0,23	0,25	0,28	0,34	0,37	0,41	0,48	0,53	0,58	0,66	0,73	0,80	0,87	0,97							44,2	75,4	
45	240	0,09	0,09	0,09	0,13	0,14	0,15	0,20	0,22	0,24	0,29	0,32	0,36	0,42	0,46	0,50	0,57	0,63	0,69	0,76	0,84	0,92	0,98					44,2	75,3	
46	200	0,16	0,16	0,16	0,22	0,24	0,27	0,35	0,38	0,42	0,52	0,57	0,63	0,74	0,82	0,90												43,9	75,9	
47	210	0,13	0,13	0,14	0,19	0,21	0,23	0,30	0,34	0,37	0,45	0,50	0,55	0,65	0,72	0,79	0,89	0,98										44,0	75,8	
48	220	0,12	0,12	0,12	0,17	0,19	0,21	0,27	0,30	0,33	0,40	0,44	0,49	0,57	0,63	0,69	0,78	0,87	0,95									44,1	75,6	
49	220	0,12	0,12	0,13	0,18	0,20	0,22	0,28	0,32	0,35	0,42	0,47	0,52	0,60	0,67	0,73	0,83	0,92										44,1	75,6	
50	230	0,11	0,11	0,11	0,16	0,17	0,19	0,25	0,28	0,30	0,37	0,41	0,45	0,53	0,58	0,64	0,72	0,80	0,88	0,96								44,2	75,4	
51	240	0,09	0,09	0,10	0,14	0,15	0,17	0,22	0,24	0,27	0,33	0,36	0,40	0,46	0,51	0,56	0,64	0,70	0,77	0,84	0,93							44,2	75,3	
52	240	0,10	0,10	0,10	0,15	0,16	0,18	0,23	0,26	0,28	0,35	0,39	0,42	0,50	0,55	0,60	0,68	0,75	0,82	0,90	1,00							44,2	75,3	
53	250	0,																												

14 Annex B – 7-layer CLT panel (CLT-7b) with screws as shear connectors

CLT_7b panel configuration: TCC_7b_s_r1_c2																																	
Resistance to fire: R 60, concrete screed depth: 90 mm, self-weight including concrete g_k2: 4,46 kN/m ² , screws as shear connectors																																	
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			R _{sw}	L _{w,eq}			
		dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0	dk = 3,0	dk = 4,0	dk = 5,0					
[-]	[mm]	[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[kN/m ²]			[dB]							
1	140	0,87	0,91	0,96	1,00																							53,3	67,3				
2	150	0,83	0,87	0,91	0,97																								53,5	67,1			
3	160	0,79	0,82	0,86	0,91	0,96																							53,7	66,9			
4	160	0,67	0,72	0,78	0,81	0,89	0,98	0,99																						53,7	66,9		
5	170	0,59	0,65	0,70	0,73	0,80	0,87	0,89	0,98																					53,9	66,7		
6	180	0,53	0,58	0,63	0,66	0,72	0,79	0,80	0,88	0,96	0,97																			54,1	66,4		
7	180	0,55	0,60	0,65	0,68	0,74	0,81	0,82	0,91	0,99	0,99																			54,1	66,4		
8	190	0,49	0,54	0,58	0,61	0,67	0,72	0,74	0,81	0,89	0,89	0,98																		54,3	66,2		
9	200	0,44	0,49	0,53	0,55	0,60	0,65	0,67	0,73	0,80	0,81	0,89	0,96	0,96																54,5	66,0		
10	160	0,68	0,75	0,81	0,84	0,93																								53,7	66,9		
11	170	0,62	0,68	0,74	0,76	0,84	0,91	0,93																							53,9	66,7	
12	180	0,56	0,62	0,67	0,70	0,76	0,83	0,85	0,93																						54,1	66,4	
13	180	0,57	0,63	0,68	0,71	0,78	0,84	0,86	0,95																						54,1	66,4	
14	190	0,52	0,57	0,62	0,64	0,70	0,76	0,78	0,86	0,93	0,94																				54,3	66,2	
15	200	0,48	0,52	0,56	0,59	0,64	0,70	0,71	0,78	0,85	0,86	0,94																			54,5	66,0	
16	200	0,49	0,53	0,58	0,60	0,66	0,71	0,73	0,80	0,87	0,88	0,96																			54,5	66,0	
17	210	0,44	0,48	0,52	0,55	0,60	0,65	0,66	0,73	0,79	0,80	0,87	0,95	0,95																	54,7	65,8	
18	220	0,40	0,45	0,50	0,50	0,54	0,59	0,61	0,66	0,72	0,73	0,80	0,87	0,87	0,95																54,9	65,6	
19	180	0,59	0,64	0,70	0,72	0,79	0,86	0,88	0,97																						54,1	66,4	
20	190	0,54	0,59	0,64	0,66	0,73	0,79	0,81	0,88	0,96	0,97																				54,3	66,2	
21	200	0,50	0,54	0,59	0,61	0,67	0,72	0,74	0,81	0,88	0,89	0,98																			54,5	66,0	
22	200	0,50	0,55	0,60	0,62	0,68	0,74	0,75	0,83	0,90	0,90	0,99																			54,5	66,0	
23	210	0,46	0,50	0,55	0,57	0,62	0,67	0,69	0,76	0,82	0,83	0,91	0,99	0,98																	54,7	65,8	
24	220	0,43	0,46	0,51	0,52	0,57	0,62	0,64	0,69	0,75	0,76	0,83	0,91	0,90	0,99																54,9	65,6	
25	220	0,44	0,48	0,52	0,54	0,59	0,63	0,65	0,71	0,77	0,78	0,85	0,93	0,92																	54,9	65,6	
26	230	0,40	0,45	0,50	0,49	0,54	0,59	0,60	0,65	0,71	0,72	0,78	0,85	0,85	0,93	1,00															55,1	65,4	
27	240	0,39	0,43	0,48	0,46	0,51	0,57	0,55	0,60	0,66	0,66	0,72	0,78	0,78	0,85	0,93	0,92														55,3	65,2	
28	160	0,69	0,70	0,76	0,80	0,86	0,94	0,96																							53,7	66,9	
29	170	0,61	0,63	0,68	0,71	0,78	0,85	0,87	0,95																						53,9	66,7	
30	180	0,54	0,57	0,62	0,64	0,70	0,77	0,78	0,86	0,94	0,95																				54,1	66,4	
31	180	0,56	0,58	0,63	0,65	0,72	0,78	0,80	0,88	0,95	0,96																				54,1	66,4	
32	190	0,49	0,52	0,56	0,59	0,65	0,70	0,72	0,79	0,86	0,87	0,95																			54,3	66,2	
33	200	0,43	0,47	0,51	0,54	0,59	0,64	0,65	0,72	0,78	0,79	0,87	0,94	0,94																	54,5	66,0	
34	200	0,45	0,49	0,53	0,55	0,60	0,65	0,67	0,73	0,80	0,81	0,89	0,96	0,96																	54,5	66,0	
35	210	0,40	0,44	0,48	0,50	0,54	0,59	0,61	0,66	0,72	0,73	0,80	0,87	0,87	0,96																54,7	65,8	
36	220	0,37	0,41	0,46	0,45	0,49	0,55	0,55	0,60	0,65	0,66	0,73	0,79	0,79	0,87	0,94	0,93														54,9	65,6	
37	180	0,55	0,59	0,65	0,67	0,74	0,80	0,82	0,90	0,98	0,99																				54,1	66,4	
38	190	0,50	0,54	0,59	0,61	0,67	0,73	0,75	0,82	0,89	0,90	0,99																			54,3	66,2	
39	200	0,45	0,50	0,54	0,56	0,61	0,67	0,68	0,75	0,81	0,82	0,90	0,98	0,98																	54,5	66,0	
40	200	0,46	0,50	0,55	0,57	0,62	0,68	0,70	0,76	0,83	0,84	0,92	1,00	1,00																	54,5	66,0	
41	210	0,42	0,46	0,50	0,52	0,57	0,62	0,63	0,69	0,75	0,76	0,84	0,91	0,91	1,00																54,7	65,8	
42	220	0,39	0,43	0,48	0,48	0,52	0,57	0,58	0,64	0,69	0,70	0,77	0,83	0,83	0,91	0,99	0,98															54,9	65,6
43	220	0,40	0,44	0,49	0,49	0,53	0,58	0,60	0,65	0,71	0,72	0,78	0,85	0,85	0,93																	54,9	65,6
44	230	0,37	0,42	0,47	0,45	0,50	0,56	0,54	0,59	0,65	0,65	0,72	0,78	0,78	0,85	0,93	0,92															55,1	65,4
45	240	0,36	0,40	0,45	0,42	0,48	0,53	0,50	0,56	0,62	0,60	0,66	0,71	0,71	0,78	0,85	0,84	0,92	0,98													55,3	65,2
46	200	0,47	0,51	0,56	0,58	0,64	0,69	0,71	0,78	0,84	0,85	0,93																			54,5	66,0	
47	210	0,43	0,47	0,51	0,54	0,58	0,63	0,65	0,71	0,77	0,78	0,86	0,93	0,93																	54,7	65,8	
48	220	0,40	0,44	0,49	0,49	0,54	0,58	0,60	0,66	0,71	0,72	0,79	0,86	0,86	0,94																54,9	65,6	
49	220	0,41	0,45	0,50	0,50	0,55	0,59	0,61	0,67	0,73	0,73	0,80	0,87	0,87	0,96																54,9	65,6	
50	230	0,38	0,43	0,48	0,46	0,51	0,57	0,56	0,61	0,67	0,68	0,74	0,80	0,80	0,88	0,96	0,95														55,1	65,4	
51	240	0,37	0,42	0,46	0,44	0,49	0,55	0,52	0,57	0,64	0,62	0,68	0,74	0,74	0,81	0,88	0,87	0,96													55,3	65,2	
52	240	0,38	0,42	0,47	0,44	0,50	0,56	0,53	0,58	0,65	0,64	0,70	0,76	0,76	0,83	0,90	0,89	0,98													55,3	65,2	
53	250	0,36	0,41	0,45	0,43	0,48	0,53	0,50	0,56	0,62	0,59	0,64	0,71	0,70	0,76	0,83	0,82	0,90	0,98	0,96											55,5	65,0	
54	260	0,35	0,39	0,43	0,41	0,46	0,51	0,48	0,54	0,60	0,55	0,62	0,68	0,64	0,70	0,77	0,76	0,83															

14 Annex B – 7-layer CLT panel (CLT-7b) with screws as shear connectors

CLT_7b panel configuration: TCC_7b_s_r2_c2																														
Resistance to fire: R 60, concrete screed depth: 120 mm, self-weight including concrete g_k2: 5,18 kN/m ² , screws as shear connectors																														
Panel Nr.	depth_tot	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			R_w	L_w_eq
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0		
1	140	0,71	0,73	0,76	0,81	0,86	0,93	0,96																				56,6	82,6	
2	150	0,69	0,71	0,73	0,78	0,81	0,85	0,89	0,96																				56,7	82,7
3	160	0,65	0,67	0,69	0,74	0,77	0,79	0,84	0,87	0,95																			56,9	82,9
4	160	0,54	0,59	0,64	0,67	0,73	0,79	0,81	0,88	0,96	0,96																		56,9	82,9
5	170	0,50	0,54	0,58	0,61	0,66	0,72	0,74	0,81	0,87	0,89	0,97																	57,1	83,1
6	180	0,46	0,50	0,53	0,56	0,61	0,66	0,68	0,74	0,80	0,81	0,89	0,96	0,96															57,2	83,2
7	180	0,47	0,51	0,54	0,57	0,62	0,67	0,69	0,75	0,81	0,83	0,90	0,98	0,98															57,2	83,2
8	190	0,43	0,46	0,50	0,52	0,57	0,61	0,63	0,69	0,74	0,76	0,82	0,89	0,90	0,98														57,4	83,4
9	200	0,39	0,42	0,46	0,48	0,52	0,56	0,58	0,63	0,68	0,69	0,75	0,82	0,82	0,90	0,97	0,96												57,6	83,6
10	160	0,56	0,61	0,66	0,68	0,75	0,81	0,83	0,91	0,98	0,99																		56,9	82,9
11	170	0,51	0,56	0,60	0,63	0,69	0,74	0,76	0,83	0,90	0,91	1,00																	57,1	83,1
12	180	0,48	0,52	0,56	0,58	0,63	0,68	0,71	0,77	0,83	0,84	0,92	1,00																57,2	83,2
13	180	0,48	0,52	0,56	0,59	0,64	0,69	0,71	0,78	0,84	0,85	0,93																	57,2	83,2
14	190	0,45	0,48	0,52	0,55	0,59	0,64	0,66	0,72	0,77	0,79	0,86	0,93	0,93															57,4	83,4
15	200	0,41	0,45	0,48	0,50	0,55	0,59	0,61	0,66	0,71	0,73	0,79	0,85	0,86	0,94														57,6	83,6
16	200	0,42	0,45	0,49	0,51	0,56	0,60	0,62	0,67	0,73	0,74	0,80	0,87	0,87	0,95														57,6	83,6
17	210	0,39	0,42	0,45	0,47	0,51	0,55	0,57	0,62	0,67	0,68	0,74	0,80	0,81	0,88	0,95	0,94												57,7	83,7
18	220	0,36	0,39	0,43	0,44	0,47	0,51	0,53	0,57	0,62	0,63	0,68	0,74	0,74	0,81	0,87	0,87	0,95											57,9	83,9
19	180	0,49	0,53	0,57	0,60	0,65	0,70	0,73	0,79	0,85	0,87	0,95																	57,2	83,2
20	190	0,46	0,49	0,53	0,56	0,61	0,65	0,67	0,73	0,79	0,80	0,88	0,95	0,95															57,4	83,4
21	200	0,43	0,46	0,49	0,52	0,56	0,61	0,63	0,68	0,73	0,75	0,81	0,88	0,88	0,96														57,6	83,6
22	200	0,43	0,47	0,50	0,53	0,57	0,61	0,63	0,69	0,74	0,76	0,82	0,89	0,89	0,97														57,6	83,6
23	210	0,40	0,43	0,47	0,49	0,53	0,57	0,59	0,64	0,69	0,70	0,76	0,82	0,83	0,90	0,98	0,97												57,7	83,7
24	220	0,37	0,40	0,44	0,46	0,49	0,53	0,55	0,59	0,64	0,65	0,71	0,76	0,77	0,84	0,90	0,90	0,98											57,9	83,9
25	220	0,38	0,41	0,45	0,46	0,50	0,54	0,56	0,60	0,65	0,66	0,72	0,78	0,78	0,85	0,92	0,92	1,00											57,9	83,9
26	230	0,36	0,39	0,43	0,43	0,47	0,52	0,52	0,56	0,61	0,62	0,67	0,72	0,73	0,79	0,85	0,85	0,92	1,00	0,99									58,0	84,0
27	240	0,34	0,38	0,42	0,41	0,46	0,50	0,48	0,54	0,59	0,57	0,62	0,68	0,68	0,73	0,79	0,79	0,86	0,93	0,92	1,00								58,2	84,2
28	160	0,53	0,58	0,62	0,65	0,71	0,77	0,79	0,86	0,93	0,95																		56,9	82,9
29	170	0,49	0,53	0,57	0,60	0,65	0,70	0,72	0,79	0,85	0,87	0,95																	57,1	83,1
30	180	0,45	0,49	0,52	0,55	0,60	0,64	0,67	0,73	0,78	0,80	0,87	0,94	0,95															57,2	83,2
31	180	0,45	0,49	0,53	0,56	0,60	0,65	0,67	0,73	0,79	0,81	0,88	0,95	0,96															57,2	83,2
32	190	0,42	0,45	0,49	0,51	0,55	0,60	0,62	0,67	0,73	0,74	0,81	0,87	0,88	0,96														57,4	83,4
33	200	0,38	0,41	0,45	0,47	0,51	0,55	0,57	0,62	0,67	0,68	0,74	0,80	0,81	0,88	0,95	0,95												57,6	83,6
34	200	0,39	0,42	0,46	0,48	0,52	0,56	0,58	0,63	0,68	0,69	0,75	0,82	0,82	0,90	0,97	0,96												57,6	83,6
35	210	0,36	0,39	0,42	0,44	0,48	0,51	0,53	0,58	0,62	0,64	0,69	0,75	0,75	0,82	0,89	0,89	0,96											57,7	83,7
36	220	0,33	0,37	0,40	0,41	0,44	0,49	0,49	0,53	0,57	0,59	0,64	0,69	0,69	0,76	0,82	0,81	0,89	0,96	0,95									57,9	83,9
37	180	0,46	0,50	0,54	0,57	0,62	0,67	0,69	0,75	0,81	0,82	0,90	0,97	0,98															57,2	83,2
38	190	0,43	0,46	0,50	0,53	0,57	0,61	0,64	0,69	0,75	0,76	0,83	0,90	0,90	0,98														57,4	83,4
39	200	0,40	0,43	0,46	0,49	0,53	0,57	0,59	0,64	0,69	0,70	0,77	0,83	0,83	0,91	0,98	0,98												57,6	83,6
40	200	0,40	0,44	0,47	0,49	0,54	0,58	0,60	0,65	0,70	0,71	0,78	0,84	0,84	0,92	1,00	0,99												57,6	83,6
41	210	0,37	0,40	0,43	0,46	0,49	0,53	0,55	0,60	0,65	0,66	0,72	0,77	0,78	0,85	0,92	0,91	1,00											57,7	83,7
42	220	0,35	0,38	0,42	0,42	0,46	0,50	0,51	0,55	0,60	0,61	0,66	0,72	0,72	0,79	0,85	0,85	0,92	1,00	0,98									57,9	83,9
43	220	0,35	0,38	0,42	0,43	0,47	0,51	0,52	0,56	0,61	0,62	0,67	0,73	0,73	0,80	0,86	0,86	0,94											57,9	83,9
44	230	0,33	0,37	0,41	0,40	0,45	0,49	0,48	0,52	0,58	0,58	0,62	0,67	0,68	0,74	0,80	0,80	0,87	0,94	0,93									58,0	84,0
45	240	0,32	0,36	0,40	0,39	0,43	0,48	0,45	0,51	0,56	0,53	0,59	0,65	0,63	0,68	0,74	0,74	0,80	0,87	0,86	0,93	0,99							58,2	84,2
46	200	0,41	0,44	0,48	0,50	0,54	0,59	0,61	0,66	0,71	0,72	0,79	0,85	0,85	0,93														57,6	83,6
47	210	0,38	0,41	0,44	0,47	0,50	0,54	0,56	0,61	0,66	0,67	0,73	0,79	0,79	0,86	0,93	0,93												57,7	83,7
48	220	0,36	0,39	0,43	0,43	0,47	0,51	0,52	0,57	0,61	0,63	0,68	0,73	0,74	0,80	0,87	0,87	0,94											57,9	83,9
49	220	0,36	0,39	0,43	0,44	0,48	0,52	0,53	0,58	0,62	0,63	0,69	0,74	0,75	0,81	0,88	0,88	0,96											57,9	83,9
50	230	0,34	0,38	0,42	0,41	0,45	0,50	0,49	0,54	0,59	0,59	0,64	0,69	0,70	0,76	0,82	0,82	0,89	0,96	0,95									58,0	84,0
51	240	0,33	0,37	0,41	0,40	0,44	0,49	0,47	0,52	0,57	0,55	0,60	0,66	0,65	0,70	0,76	0,76	0,83	0,89	0,88	0,96								58,2	84,2
52	240	0,34	0,38	0,41	0,40	0,45	0,50	0,47	0,53	0,58	0,56	0,61	0,67	0,66	0,72	0,77	0,77	0,84	0,91	0,90	0,98								58,2	84,2
53	250	0,33	0,36	0,40	0,39	0,44	0,48	0,46	0,51	0,56	0,53	0,59	0,65	0,61	0,67	0,74	0,72	0,78	0,84	0,83	0,91	0,98								

14 Annex B – 7-layer CLT panel (CLT-7b) with screws as shear connectors

CLT_7b panel configuration: TCC_7b_s_r4_c2
Resistance to fire: R 30, concrete screed depth: 120 mm, self-weight including concrete g_k2: 5,18 kN/m², screws as shear connectors

Panel Nr.	depth_tot [mm]	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			R_w [dB]	L_w_eq [dB]
		qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0	qk = 3,0	qk = 4,0	qk = 5,0		
1	140	0,64	0,70	0,75	0,79	0,86	0,93	0,96																					56,6	63,8
2	150	0,59	0,64	0,69	0,72	0,79	0,85	0,87	0,96																				56,7	63,6
3	160	0,54	0,58	0,63	0,66	0,72	0,78	0,80	0,87	0,95	0,96																	56,9	63,4	
4	160	0,54	0,59	0,64	0,67	0,73	0,79	0,81	0,88	0,96	0,97																	56,9	63,4	
5	170	0,50	0,54	0,58	0,61	0,66	0,72	0,74	0,81	0,87	0,89	0,97																57,1	63,3	
6	180	0,46	0,50	0,53	0,56	0,61	0,66	0,68	0,74	0,80	0,81	0,89	0,96	0,96														57,2	63,1	
7	180	0,47	0,51	0,54	0,57	0,62	0,67	0,69	0,75	0,81	0,83	0,90	0,98	0,98														57,2	63,1	
8	190	0,43	0,46	0,50	0,52	0,57	0,61	0,63	0,69	0,74	0,76	0,82	0,89	0,90	0,98													57,4	62,9	
9	200	0,39	0,42	0,46	0,48	0,52	0,56	0,58	0,63	0,68	0,69	0,75	0,82	0,82	0,90	0,97	0,96											57,6	62,7	
10	160	0,56	0,61	0,66	0,68	0,75	0,81	0,83	0,91	0,98	0,99																	56,9	63,4	
11	170	0,51	0,56	0,60	0,63	0,69	0,74	0,76	0,83	0,90	0,91	1,00																57,1	63,3	
12	180	0,48	0,52	0,56	0,58	0,63	0,68	0,71	0,77	0,83	0,84	0,92	1,00															57,2	63,1	
13	180	0,48	0,52	0,56	0,59	0,64	0,69	0,71	0,78	0,84	0,85	0,93																57,2	63,1	
14	190	0,45	0,48	0,52	0,55	0,59	0,64	0,66	0,72	0,77	0,79	0,86	0,93	0,93														57,4	62,9	
15	200	0,41	0,45	0,48	0,50	0,55	0,59	0,61	0,66	0,71	0,73	0,79	0,85	0,86	0,94													57,6	62,7	
16	200	0,42	0,45	0,49	0,51	0,56	0,60	0,62	0,67	0,73	0,74	0,80	0,87	0,87	0,95													57,6	62,7	
17	210	0,39	0,42	0,45	0,47	0,51	0,55	0,57	0,62	0,67	0,68	0,74	0,80	0,81	0,88	0,95	0,94											57,7	62,6	
18	220	0,36	0,39	0,43	0,44	0,47	0,51	0,53	0,57	0,62	0,63	0,68	0,74	0,74	0,81	0,87	0,87	0,95										57,9	62,4	
19	180	0,49	0,53	0,57	0,60	0,65	0,70	0,73	0,79	0,85	0,87	0,95																57,2	63,1	
20	190	0,46	0,49	0,53	0,56	0,61	0,65	0,67	0,73	0,79	0,80	0,88	0,95	0,95														57,4	62,9	
21	200	0,43	0,46	0,49	0,52	0,56	0,61	0,63	0,68	0,73	0,75	0,81	0,88	0,88	0,96													57,6	62,7	
22	200	0,43	0,47	0,50	0,53	0,57	0,61	0,63	0,69	0,74	0,76	0,82	0,89	0,89	0,97													57,6	62,7	
23	210	0,40	0,43	0,47	0,49	0,53	0,57	0,59	0,64	0,69	0,70	0,76	0,82	0,83	0,90	0,98	0,97											57,7	62,6	
24	220	0,37	0,40	0,44	0,46	0,49	0,53	0,55	0,59	0,64	0,65	0,71	0,76	0,77	0,84	0,90	0,90	0,98										57,9	62,4	
25	220	0,38	0,41	0,45	0,46	0,50	0,54	0,56	0,60	0,65	0,66	0,72	0,78	0,78	0,85	0,92	0,92	1,00										57,9	62,4	
26	230	0,36	0,39	0,43	0,43	0,47	0,52	0,52	0,56	0,61	0,62	0,67	0,72	0,73	0,79	0,85	0,85	0,92	1,00	0,99								58,0	62,2	
27	240	0,34	0,38	0,42	0,41	0,46	0,50	0,48	0,54	0,59	0,57	0,62	0,68	0,68	0,73	0,79	0,79	0,86	0,93	0,92	1,00							58,2	62,1	
28	160	0,53	0,58	0,62	0,65	0,71	0,77	0,79	0,86	0,93	0,95																	56,9	63,4	
29	170	0,49	0,53	0,57	0,60	0,65	0,70	0,72	0,79	0,85	0,87	0,95																57,1	63,3	
30	180	0,45	0,49	0,52	0,55	0,60	0,64	0,67	0,73	0,78	0,80	0,87	0,94	0,95														57,2	63,1	
31	180	0,45	0,49	0,53	0,56	0,60	0,65	0,67	0,73	0,79	0,81	0,88	0,95	0,96														57,2	63,1	
32	190	0,42	0,45	0,49	0,51	0,55	0,60	0,62	0,67	0,73	0,74	0,81	0,87	0,88	0,96													57,4	62,9	
33	200	0,38	0,41	0,45	0,47	0,51	0,55	0,57	0,62	0,67	0,68	0,74	0,80	0,81	0,88	0,95	0,95											57,6	62,7	
34	200	0,39	0,42	0,46	0,48	0,52	0,56	0,58	0,63	0,68	0,69	0,75	0,82	0,82	0,90	0,97	0,96											57,6	62,7	
35	210	0,36	0,39	0,42	0,44	0,48	0,51	0,53	0,58	0,62	0,64	0,69	0,75	0,75	0,82	0,89	0,89	0,96										57,7	62,6	
36	220	0,33	0,37	0,40	0,41	0,44	0,49	0,49	0,53	0,57	0,59	0,64	0,69	0,69	0,76	0,82	0,81	0,89	0,96	0,95								57,9	62,4	
37	180	0,46	0,50	0,54	0,57	0,62	0,67	0,69	0,75	0,81	0,82	0,90	0,97	0,98														57,2	63,1	
38	190	0,43	0,46	0,50	0,53	0,57	0,61	0,64	0,69	0,75	0,76	0,83	0,90	0,90	0,98													57,4	62,9	
39	200	0,40	0,43	0,46	0,49	0,53	0,57	0,59	0,64	0,69	0,70	0,77	0,83	0,83	0,91	0,98	0,98											57,6	62,7	
40	200	0,40	0,44	0,47	0,49	0,54	0,58	0,60	0,65	0,70	0,71	0,78	0,84	0,84	0,92	1,00	0,99											57,6	62,7	
41	210	0,37	0,40	0,43	0,46	0,49	0,53	0,55	0,60	0,65	0,66	0,72	0,77	0,78	0,85	0,92	0,91	1,00										57,7	62,6	
42	220	0,35	0,38	0,42	0,42	0,46	0,50	0,51	0,55	0,60	0,61	0,66	0,72	0,72	0,79	0,85	0,85	0,92	1,00	0,98								57,9	62,4	
43	220	0,35	0,38	0,42	0,43	0,47	0,51	0,52	0,56	0,61	0,62	0,67	0,73	0,73	0,80	0,86	0,86	0,94										57,9	62,4	
44	230	0,33	0,37	0,41	0,40	0,45	0,49	0,48	0,52	0,58	0,58	0,62	0,67	0,68	0,74	0,80	0,80	0,87	0,94	0,93								58,0	62,2	
45	240	0,32	0,36	0,40	0,39	0,43	0,48	0,45	0,51	0,56	0,53	0,59	0,65	0,63	0,68	0,74	0,74	0,80	0,87	0,86	0,93	0,99						58,2	62,1	
46	200	0,41	0,44	0,48	0,50	0,54	0,59	0,61	0,66	0,71	0,72	0,79	0,85	0,85	0,93													57,6	62,7	
47	210	0,38	0,41	0,44	0,47	0,50	0,54	0,56	0,61	0,66	0,67	0,73	0,79	0,79	0,86	0,93	0,93											57,7	62,6	
48	220	0,36	0,39	0,43	0,43	0,47	0,51	0,52	0,57	0,61	0,63	0,68	0,73	0,74	0,80	0,87	0,87	0,94										57,9	62,4	
49	220	0,36	0,39	0,43	0,44	0,48	0,52	0,53	0,58	0,62	0,63	0,69	0,74	0,75	0,81	0,88	0,88	0,96										57,9	62,4	
50	230	0,34	0,38	0,42	0,41	0,45	0,50	0,49	0,54	0,59	0,59	0,64	0,69	0,70	0,76	0,82	0,82	0,89	0,96	0,95								58,0	62,2	
51	240	0,33	0,37	0,41	0,40	0,44	0,49	0,47	0,52	0,57	0,55	0,60	0,66	0,65	0,70	0,76	0,76	0,83	0,89	0,88	0,96							58,2	62,1	
52	240	0,34	0,38	0,41	0,40	0,45	0,50	0,47	0,53	0,58	0,56	0,61	0,67	0,66	0,72	0,77	0,77	0,84	0,91	0,90	0,98							58,2	62,1	
53	250	0,33	0,36	0,40	0,39	0,44	0,48	0,46	0,51	0,56	0,53	0,59	0,65	0,61	0,67	0,74	0,72	0,78	0,84	0,83	0,91	0,98	0,96					58,3	61,9	
54	260	0,32	0,35	0,39	0,38	0,42	0,47	0,44	0,50	0,55	0,51	0,57	0,63	0,59	0,65	0,72	0													

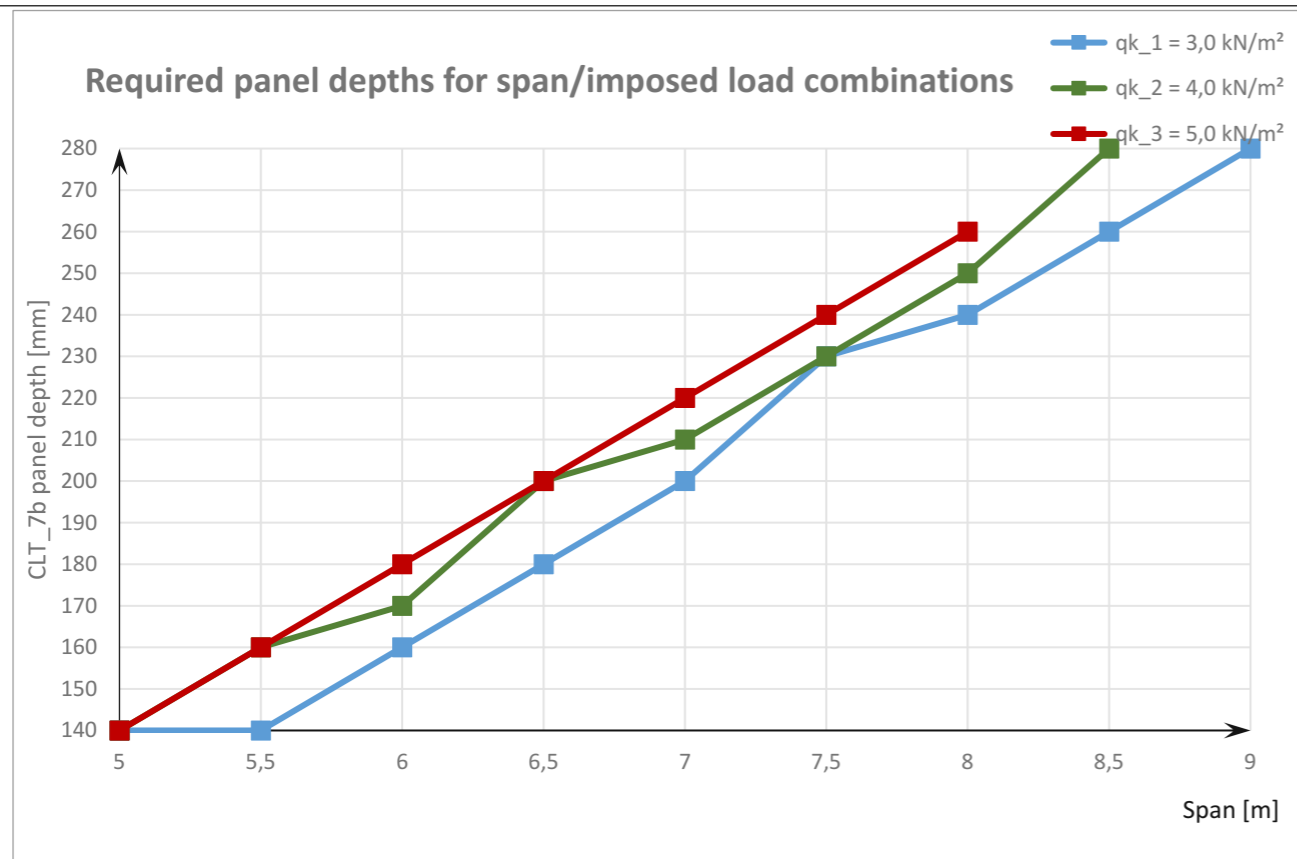


Figure 14-5: Minimum panel depths in regard to span for TCC_7b_s_r1_c2

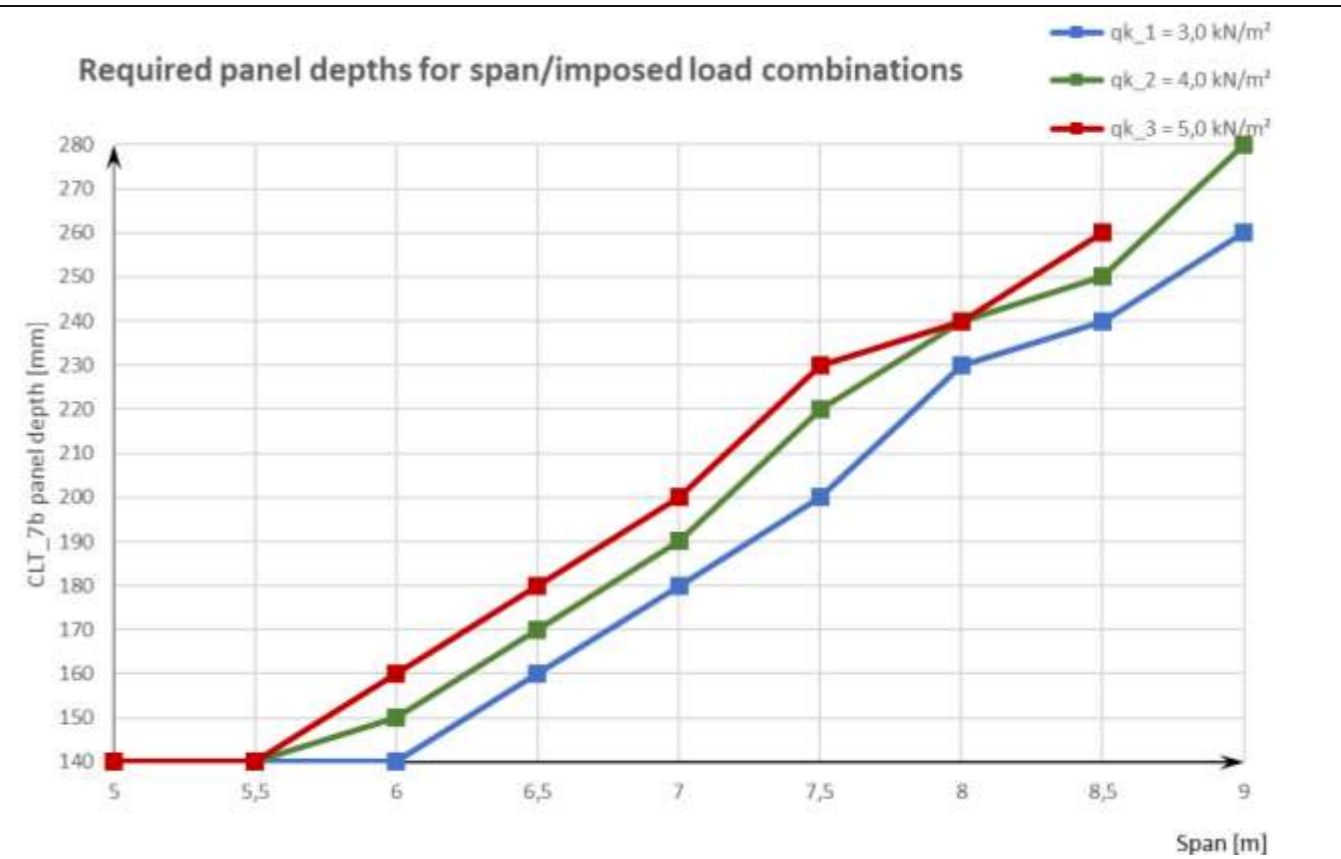


Figure 14-6: Minimum panel depths in regard to span for TCC_7b_s_r2_c2

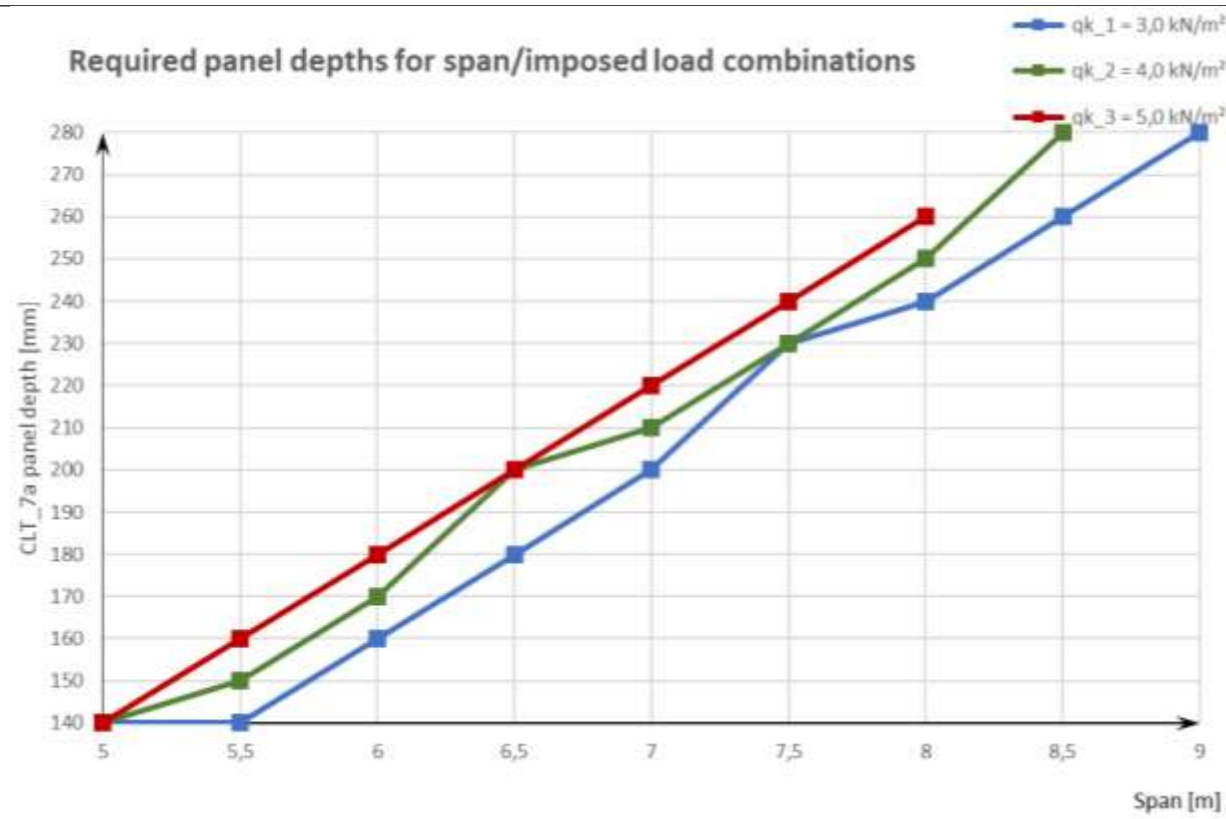


Figure 14-7: Minimum panel depths in regard to span for TCC_7b_s_r3_c2

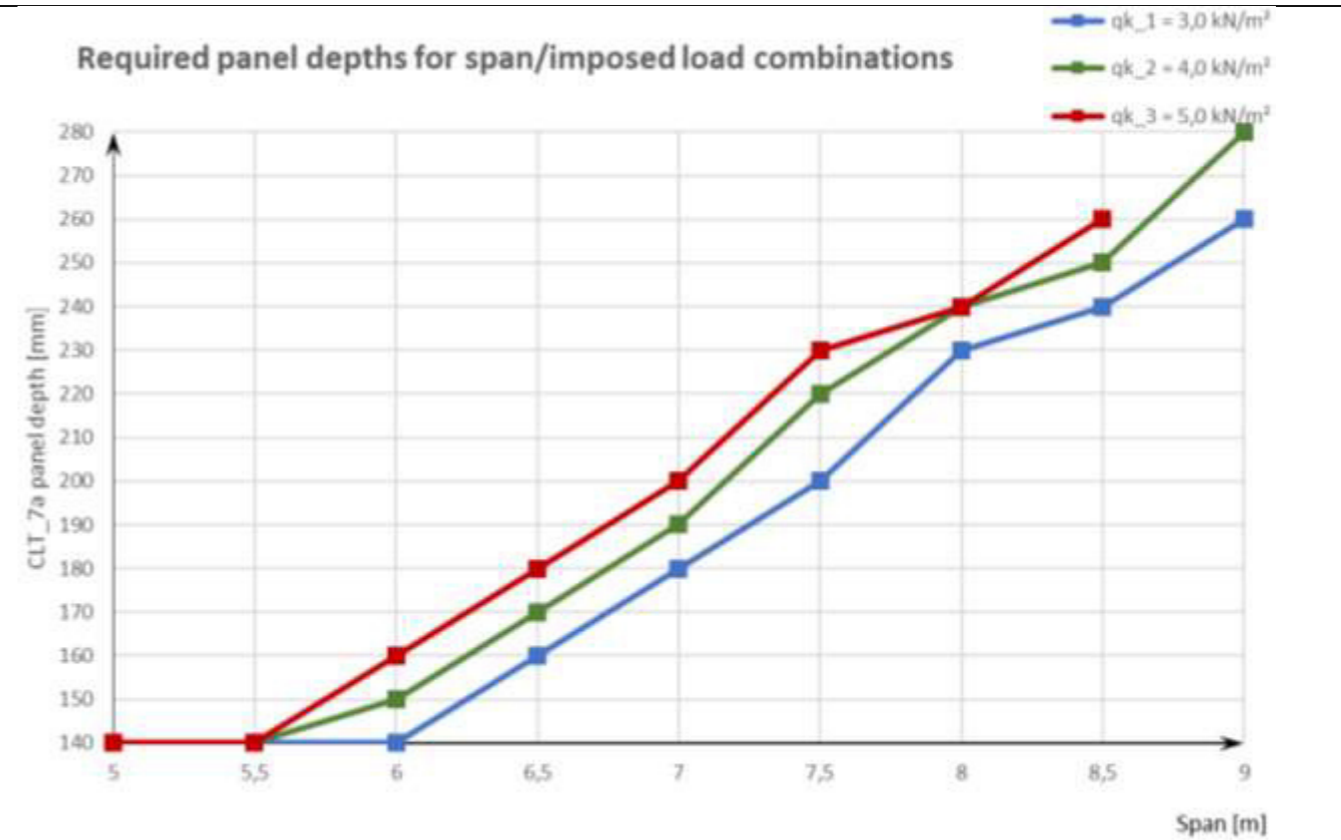


Figure 14-8: Minimum panel depths in regard to span for TCC_7b_s_r4_c2

15 Annex C – 7-layer CLT panel (CLT-7b) with notches as shear connectors

CLT_7b panel configuration: TCC_7b_n_r2_c2																														
Resistance to fire: R 60, concrete screed depth: 120 mm, self-weight including concrete g_k2: 5,18 kN/m ² , notches as shear connectors																														
Panel Nr.	depth_tot [mm]	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			R_w	L_w_eiq
		q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0	q_k = 3,0	q_k = 4,0	q_k = 5,0		
1	140	0,64	0,68	0,74	0,79	0,86	0,93	0,97																					56,6	63,8
2	150	0,61	0,64	0,68	0,75	0,78	0,85	0,91	0,97																				56,7	63,6
3	160	0,59	0,62	0,64	0,73	0,76	0,79	0,89	0,93	0,97	0,94																		56,9	63,4
4	160	0,53	0,58	0,63	0,67	0,73	0,79	0,82	0,90	0,97	0,95																		56,9	63,4
5	170	0,49	0,53	0,57	0,61	0,66	0,72	0,75	0,82	0,89	0,87	0,95																	57,1	63,3
6	180	0,45	0,49	0,52	0,56	0,61	0,66	0,69	0,75	0,81	0,80	0,87	0,94	0,96															57,2	63,1
7	180	0,46	0,50	0,53	0,57	0,62	0,67	0,70	0,76	0,83	0,81	0,88	0,96	0,97															57,2	63,1
8	190	0,42	0,45	0,49	0,52	0,57	0,61	0,64	0,70	0,75	0,74	0,81	0,87	0,89	0,97														57,4	62,9
9	200	0,39	0,42	0,45	0,48	0,52	0,56	0,59	0,64	0,69	0,68	0,74	0,80	0,82	0,89	0,96	0,97												57,6	62,7
10	160	0,55	0,60	0,64	0,68	0,74	0,81	0,84	0,92	1,00	0,97																		56,9	63,4
11	170	0,51	0,55	0,59	0,63	0,69	0,74	0,77	0,84	0,91	0,90	0,98																	57,1	63,3
12	180	0,47	0,51	0,55	0,58	0,63	0,68	0,73	0,78	0,84	0,83	0,90	0,98	0,99															57,2	63,1
13	180	0,47	0,51	0,55	0,59	0,64	0,69	0,72	0,79	0,85	0,84	0,91	0,99																57,2	63,1
14	190	0,44	0,47	0,51	0,54	0,59	0,64	0,67	0,73	0,78	0,77	0,84	0,91	0,92															57,4	62,9
15	200	0,41	0,44	0,47	0,50	0,55	0,59	0,62	0,67	0,72	0,71	0,77	0,84	0,85	0,93														57,6	62,7
16	200	0,41	0,45	0,48	0,51	0,56	0,60	0,63	0,68	0,74	0,72	0,79	0,85	0,87	0,94														57,6	62,7
17	210	0,38	0,41	0,45	0,47	0,51	0,56	0,58	0,63	0,69	0,67	0,73	0,78	0,80	0,87	0,94	0,95												57,7	62,6
18	220	0,35	0,39	0,43	0,44	0,49	0,55	0,54	0,61	0,67	0,62	0,67	0,72	0,74	0,80	0,87	0,87	0,95	0,99										57,9	62,4
19	180	0,48	0,52	0,56	0,60	0,65	0,70	0,74	0,80	0,87	0,85	0,93																	57,2	63,1
20	190	0,45	0,49	0,52	0,56	0,60	0,65	0,68	0,74	0,80	0,79	0,86	0,93	0,94															57,4	62,9
21	200	0,42	0,45	0,49	0,52	0,56	0,61	0,63	0,69	0,74	0,73	0,80	0,86	0,88	0,95														57,6	62,7
22	200	0,42	0,46	0,49	0,53	0,57	0,61	0,64	0,70	0,75	0,74	0,81	0,87	0,89	0,97														57,6	62,7
23	210	0,39	0,43	0,46	0,49	0,53	0,57	0,60	0,65	0,71	0,69	0,75	0,81	0,82	0,89	0,97	0,97												57,7	62,6
24	220	0,37	0,40	0,44	0,45	0,50	0,56	0,56	0,62	0,69	0,64	0,69	0,75	0,76	0,83	0,90	0,90	0,98											57,9	62,4
25	220	0,37	0,41	0,45	0,46	0,51	0,56	0,57	0,63	0,69	0,65	0,71	0,76	0,78	0,84	0,91	0,92	1,00											57,9	62,4
26	230	0,35	0,39	0,44	0,44	0,50	0,55	0,55	0,61	0,67	0,60	0,66	0,71	0,72	0,78	0,84	0,85	0,93	0,97										58,0	62,2
27	240	0,34	0,38	0,42	0,43	0,48	0,53	0,53	0,59	0,65	0,56	0,61	0,66	0,67	0,73	0,78	0,79	0,86	0,93	0,90	0,98								58,2	62,1
28	160	0,52	0,57	0,61	0,65	0,71	0,77	0,80	0,87	0,95	0,93																		56,9	63,4
29	170	0,48	0,52	0,56	0,60	0,65	0,70	0,73	0,80	0,87	0,85	0,93																	57,1	63,3
30	180	0,44	0,48	0,51	0,55	0,60	0,64	0,67	0,73	0,79	0,78	0,85	0,92	0,94															57,2	63,1
31	180	0,45	0,48	0,52	0,56	0,60	0,65	0,68	0,74	0,80	0,79	0,86	0,94	0,95															57,2	63,1
32	190	0,41	0,44	0,48	0,51	0,55	0,60	0,63	0,68	0,74	0,73	0,79	0,86	0,87	0,95														57,4	62,9
33	200	0,38	0,41	0,44	0,47	0,51	0,55	0,58	0,63	0,68	0,67	0,73	0,79	0,80	0,87	0,94	0,95												57,6	62,7
34	200	0,39	0,42	0,45	0,48	0,52	0,56	0,59	0,64	0,69	0,68	0,74	0,80	0,82	0,89	0,96	0,97												57,6	62,7
35	210	0,35	0,39	0,43	0,44	0,49	0,54	0,54	0,60	0,66	0,63	0,68	0,73	0,75	0,81	0,88	0,89	0,97											57,7	62,6
36	220	0,33	0,37	0,41	0,42	0,47	0,52	0,52	0,58	0,64	0,58	0,63	0,67	0,69	0,75	0,81	0,82	0,89	0,96	0,93									57,9	62,4
37	180	0,46	0,49	0,53	0,57	0,62	0,67	0,70	0,76	0,82	0,81	0,88	0,95	0,97															57,2	63,1
38	190	0,42	0,46	0,49	0,52	0,57	0,61	0,64	0,70	0,76	0,75	0,81	0,88	0,89	0,97														57,4	62,9
39	200	0,39	0,42	0,45	0,49	0,53	0,57	0,60	0,65	0,70	0,69	0,75	0,81	0,83	0,90	0,97	0,98												57,6	62,7
40	200	0,40	0,43	0,46	0,49	0,53	0,58	0,60	0,66	0,71	0,70	0,76	0,82	0,84	0,91	0,99	0,99												57,6	62,7
41	210	0,37	0,40	0,44	0,46	0,50	0,55	0,56	0,61	0,68	0,65	0,70	0,76	0,77	0,84	0,91	0,92	1,00											57,7	62,6
42	220	0,34	0,38	0,42	0,43	0,48	0,53	0,53	0,60	0,66	0,60	0,65	0,70	0,72	0,78	0,84	0,85	0,92	1,00	0,97									57,9	62,4
43	220	0,35	0,39	0,43	0,44	0,49	0,54	0,54	0,60	0,67	0,61	0,66	0,71	0,73	0,79	0,86	0,86	0,94	0,98										57,9	62,4
44	230	0,34	0,38	0,42	0,42	0,47	0,52	0,52	0,58	0,64	0,56	0,61	0,66	0,67	0,73	0,79	0,80	0,87	0,94	0,91	0,99								58,0	62,2
45	240	0,33	0,36	0,40	0,41	0,46	0,51	0,51	0,57	0,62	0,52	0,57	0,63	0,63	0,68	0,75	0,74	0,80	0,88	0,84	0,92	0,99	0,98					58,2	62,1	
46	200	0,40	0,44	0,47	0,50	0,54	0,58	0,61	0,67	0,72	0,71	0,77	0,83	0,85	0,92	1,00													57,6	62,7
47	210	0,38	0,40	0,44	0,47	0,50	0,56	0,58	0,62	0,69	0,66	0,72	0,77	0,79	0,86	0,93	0,93												57,7	62,6
48	220	0,35	0,39	0,43	0,45	0,49	0,54	0,57	0,61	0,67	0,61	0,67	0,72	0,73	0,80	0,86	0,87	0,95	0,99										57,9	62,4
49	220	0,36	0,39	0,44	0,44	0,50	0,55	0,55	0,61	0,67	0,62	0,68	0,73	0,74	0,81	0,87	0,88	0,96											57,9	62,4
50	230	0,34	0,38	0,42	0,43	0,48	0,53	0,53	0,59	0,66	0,58	0,63	0,68	0,69	0,75	0,81	0,82	0,89	0,96	0,93									58,0	62,2
51	240	0,33	0,37	0,41	0,42	0,47	0,52	0,52	0,58	0,64	0,54	0,58	0,64	0,64	0,70	0,77	0,76	0,83	0,90	0,87	0,94								58,2	62,1
52	240	0,34	0,38	0,42	0,42	0,47	0,52	0,52	0,58	0,64	0,55	0,60	0,65	0,66	0,71	0,77	0,77	0,84	0,91	0,88	0,96								58,2	62,1
53	250	0,33	0,37	0,40	0,41	0,46	0,51	0,51	0,57	0,62	0,51	0,57	0,63	0,61	0,68	0,75	0,72													

15 Annex C – 7-layer CLT panel (CLT-7b) with notches as shear connectors

CLT_7b panel configuration: TCC_7b_n_r4_c2
Resistance to fire: R 30, concrete screed depth: 120 mm, self-weight including concrete g_k2: 5,18 kN/m², notches as shear connectors

Panel Nr.	depth_tot [mm]	SPAN 1 = 5,0 m			SPAN 2 = 5,5 m			SPAN 3 = 6,0 m			SPAN 4 = 6,5 m			SPAN 5 = 7,0 m			SPAN 6 = 7,5 m			SPAN 7 = 8,0 m			SPAN 8 = 8,5 m			SPAN 9 = 9,0 m			R_w	L_w_eq
		dk=3.0	dk=4.0	dk=5.0	dk=3.0	dk=4.0	dk=5.0	dk=3.0	dk=4.0	dk=5.0	dk=3.0	dk=4.0	dk=5.0	dk=3.0	dk=4.0	dk=5.0	dk=3.0	dk=4.0	dk=5.0	dk=3.0	dk=4.0	dk=5.0	dk=3.0	dk=4.0	dk=5.0	dk=3.0	dk=4.0	dk=5.0		
1	140	0,63	0,68	0,74	0,79	0,86	0,93	0,97																				56,6	63,8	
2	150	0,57	0,63	0,68	0,72	0,78	0,85	0,89	0,97																			56,7	63,6	
3	160	0,53	0,57	0,62	0,66	0,72	0,78	0,81	0,89	0,96	0,94																	56,9	63,4	
4	160	0,53	0,58	0,63	0,67	0,73	0,79	0,82	0,90	0,97	0,95																	56,9	63,4	
5	170	0,49	0,53	0,57	0,61	0,66	0,72	0,75	0,82	0,89	0,87	0,95																57,1	63,3	
6	180	0,45	0,49	0,52	0,56	0,61	0,66	0,69	0,75	0,81	0,80	0,87	0,94	0,96														57,2	63,1	
7	180	0,46	0,50	0,53	0,57	0,62	0,67	0,70	0,76	0,83	0,81	0,88	0,96	0,97														57,2	63,1	
8	190	0,42	0,45	0,49	0,52	0,57	0,61	0,64	0,70	0,75	0,74	0,81	0,87	0,89	0,97													57,4	62,9	
9	200	0,39	0,42	0,45	0,48	0,52	0,56	0,59	0,64	0,69	0,68	0,74	0,80	0,82	0,89	0,96	0,97											57,6	62,7	
10	160	0,55	0,60	0,64	0,68	0,74	0,81	0,84	0,92	1,00	0,97																	56,9	63,4	
11	170	0,51	0,55	0,59	0,63	0,69	0,74	0,77	0,84	0,91	0,90	0,98																57,1	63,3	
12	180	0,47	0,51	0,55	0,58	0,63	0,68	0,71	0,78	0,84	0,83	0,90	0,98	0,99														57,2	63,1	
13	180	0,47	0,51	0,55	0,59	0,64	0,69	0,72	0,79	0,85	0,84	0,91	0,99															57,2	63,1	
14	190	0,44	0,47	0,51	0,54	0,59	0,64	0,67	0,73	0,78	0,77	0,84	0,91	0,92														57,4	62,9	
15	200	0,41	0,44	0,47	0,50	0,55	0,59	0,62	0,67	0,72	0,71	0,77	0,84	0,85	0,93													57,6	62,7	
16	200	0,41	0,45	0,48	0,51	0,56	0,60	0,63	0,68	0,74	0,72	0,79	0,85	0,87	0,94													57,6	62,7	
17	210	0,38	0,41	0,45	0,47	0,51	0,56	0,58	0,63	0,69	0,67	0,73	0,78	0,80	0,87	0,94	0,95											57,7	62,6	
18	220	0,35	0,39	0,43	0,44	0,49	0,55	0,54	0,61	0,67	0,62	0,67	0,72	0,74	0,80	0,87	0,87	0,95	0,99									57,9	62,4	
19	180	0,48	0,52	0,56	0,60	0,65	0,70	0,74	0,80	0,87	0,85	0,93																57,2	63,1	
20	190	0,45	0,49	0,52	0,56	0,60	0,65	0,68	0,74	0,80	0,79	0,86	0,93	0,94														57,4	62,9	
21	200	0,42	0,45	0,49	0,52	0,56	0,61	0,63	0,69	0,74	0,73	0,80	0,86	0,88	0,95													57,6	62,7	
22	200	0,42	0,46	0,49	0,53	0,57	0,61	0,64	0,70	0,75	0,74	0,81	0,87	0,89	0,97													57,6	62,7	
23	210	0,39	0,43	0,46	0,49	0,53	0,57	0,60	0,65	0,71	0,69	0,75	0,81	0,82	0,89	0,97	0,97											57,7	62,6	
24	220	0,37	0,40	0,44	0,45	0,50	0,56	0,56	0,62	0,69	0,64	0,69	0,75	0,76	0,83	0,90	0,90	0,98										57,9	62,4	
25	220	0,37	0,41	0,45	0,46	0,51	0,56	0,57	0,63	0,69	0,65	0,71	0,76	0,78	0,84	0,91	0,92	1,00										57,9	62,4	
26	230	0,35	0,39	0,44	0,44	0,50	0,55	0,55	0,61	0,67	0,60	0,66	0,71	0,72	0,78	0,84	0,85	0,93	0,97									58,0	62,2	
27	240	0,34	0,38	0,42	0,43	0,48	0,53	0,53	0,59	0,65	0,56	0,61	0,66	0,67	0,73	0,78	0,79	0,86	0,93	0,90	0,98							58,2	62,1	
28	160	0,52	0,57	0,61	0,65	0,71	0,77	0,80	0,87	0,95	0,93																	56,9	63,4	
29	170	0,48	0,52	0,56	0,60	0,65	0,70	0,73	0,80	0,87	0,85	0,93																57,1	63,3	
30	180	0,44	0,48	0,51	0,55	0,60	0,64	0,67	0,73	0,79	0,78	0,85	0,92	0,94														57,2	63,1	
31	180	0,45	0,48	0,52	0,56	0,60	0,65	0,68	0,74	0,80	0,79	0,86	0,94	0,95														57,2	63,1	
32	190	0,41	0,44	0,48	0,51	0,55	0,60	0,63	0,68	0,74	0,73	0,79	0,86	0,87	0,95													57,4	62,9	
33	200	0,38	0,41	0,44	0,47	0,51	0,55	0,58	0,63	0,68	0,67	0,73	0,79	0,80	0,87	0,94	0,95											57,6	62,7	
34	200	0,39	0,42	0,45	0,48	0,52	0,56	0,59	0,64	0,69	0,68	0,74	0,80	0,82	0,89	0,96	0,97											57,6	62,7	
35	210	0,35	0,39	0,43	0,44	0,49	0,54	0,54	0,60	0,66	0,63	0,68	0,73	0,75	0,81	0,88	0,89	0,97										57,7	62,6	
36	220	0,33	0,37	0,41	0,42	0,47	0,52	0,52	0,58	0,64	0,58	0,63	0,67	0,69	0,75	0,81	0,82	0,89	0,96	0,93								57,9	62,4	
37	180	0,46	0,49	0,53	0,57	0,62	0,67	0,70	0,76	0,82	0,81	0,88	0,95	0,97														57,2	63,1	
38	190	0,42	0,46	0,49	0,52	0,57	0,61	0,64	0,70	0,76	0,75	0,81	0,88	0,89	0,97													57,4	62,9	
39	200	0,39	0,42	0,45	0,49	0,53	0,57	0,60	0,65	0,70	0,69	0,75	0,81	0,83	0,90	0,97	0,98											57,6	62,7	
40	200	0,40	0,43	0,46	0,49	0,53	0,58	0,60	0,66	0,71	0,70	0,76	0,82	0,84	0,91	0,99	0,99											57,6	62,7	
41	210	0,37	0,40	0,44	0,46	0,50	0,55	0,56	0,61	0,68	0,65	0,70	0,76	0,77	0,84	0,91	0,92	1,00										57,7	62,6	
42	220	0,34	0,38	0,42	0,43	0,48	0,53	0,53	0,60	0,66	0,60	0,65	0,70	0,72	0,78	0,84	0,85	0,92	1,00	0,97								57,9	62,4	
43	220	0,35	0,39	0,43	0,44	0,49	0,54	0,54	0,60	0,67	0,61	0,66	0,71	0,73	0,79	0,86	0,86	0,94	0,98									57,9	62,4	
44	230	0,34	0,38	0,42	0,42	0,47	0,52	0,52	0,58	0,64	0,56	0,61	0,66	0,67	0,73	0,79	0,80	0,87	0,94	0,91	0,99							58,0	62,2	
45	240	0,33	0,36	0,40	0,41	0,46	0,51	0,51	0,57	0,62	0,52	0,57	0,63	0,63	0,68	0,75	0,74	0,80	0,88	0,84	0,92	0,99	0,98					58,2	62,1	
46	200	0,40	0,44	0,47	0,50	0,54	0,58	0,57	0,62	0,67	0,71	0,77	0,83	0,85	0,92	1,00												57,6	62,7	
47	210	0,38	0,40	0,44	0,47	0,50	0,56	0,58	0,62	0,69	0,66	0,72	0,77	0,79	0,86	0,93	0,93											57,7	62,6	
48	220	0,36	0,39	0,43	0,46	0,49	0,54	0,57	0,61	0,67	0,61	0,67	0,72	0,73	0,80	0,86	0,87	0,95	0,99									57,9	62,4	
49	220	0,36	0,39	0,44	0,44	0,50	0,55	0,55	0,61	0,67	0,62	0,68	0,73	0,74	0,81	0,87	0,88	0,96										57,9	62,4	
50	230	0,34	0,38	0,42	0,43	0,48	0,53	0,53	0,59	0,66	0,58	0,63	0,68	0,69	0,75	0,81	0,82	0,89	0,96	0,93								58,0	62,2	
51	240	0,33	0,37	0,41	0,42	0,47	0,52	0,52	0,58	0,64	0,54	0,58	0,64	0,64	0,70	0,77	0,76	0,83	0,90	0,87	0,94							58,2	62,1	
52	240	0,34	0,38	0,42	0,42	0,47	0,52	0,52	0,58	0,64	0,55	0,60	0,65	0,66	0,71	0,77	0,77	0,84	0,91	0,88	0,96							58,2	62,1	
53	250	0,33	0,37	0,40	0,41	0,46	0,51	0,51	0,57	0,62	0,51	0,57	0,63	0,61	0,68	0,75	0,72	0,80	0,88	0,82	0,89	0,96	0,95					58,3	61,9	
54	260	0,32	0,35	0,39	0,40	0,45	0,49	0,49	0,55	0,61	0,50	0,55	0,61	0,59	0,66	0,73	0,69	0,77	0,85	0,76	0,83									

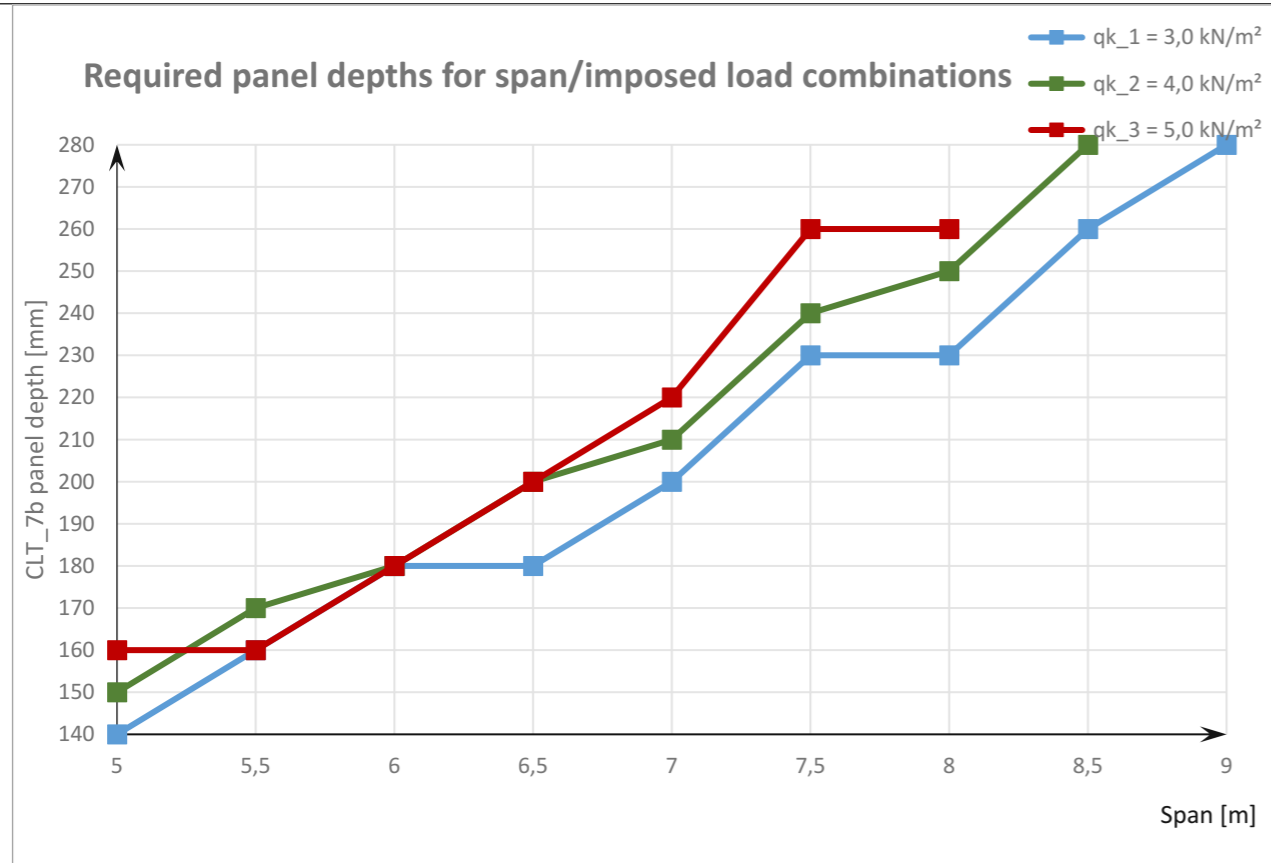


Figure 15-5: Minimum panel depths in regard to span for TCC_7b_n_r1_c2

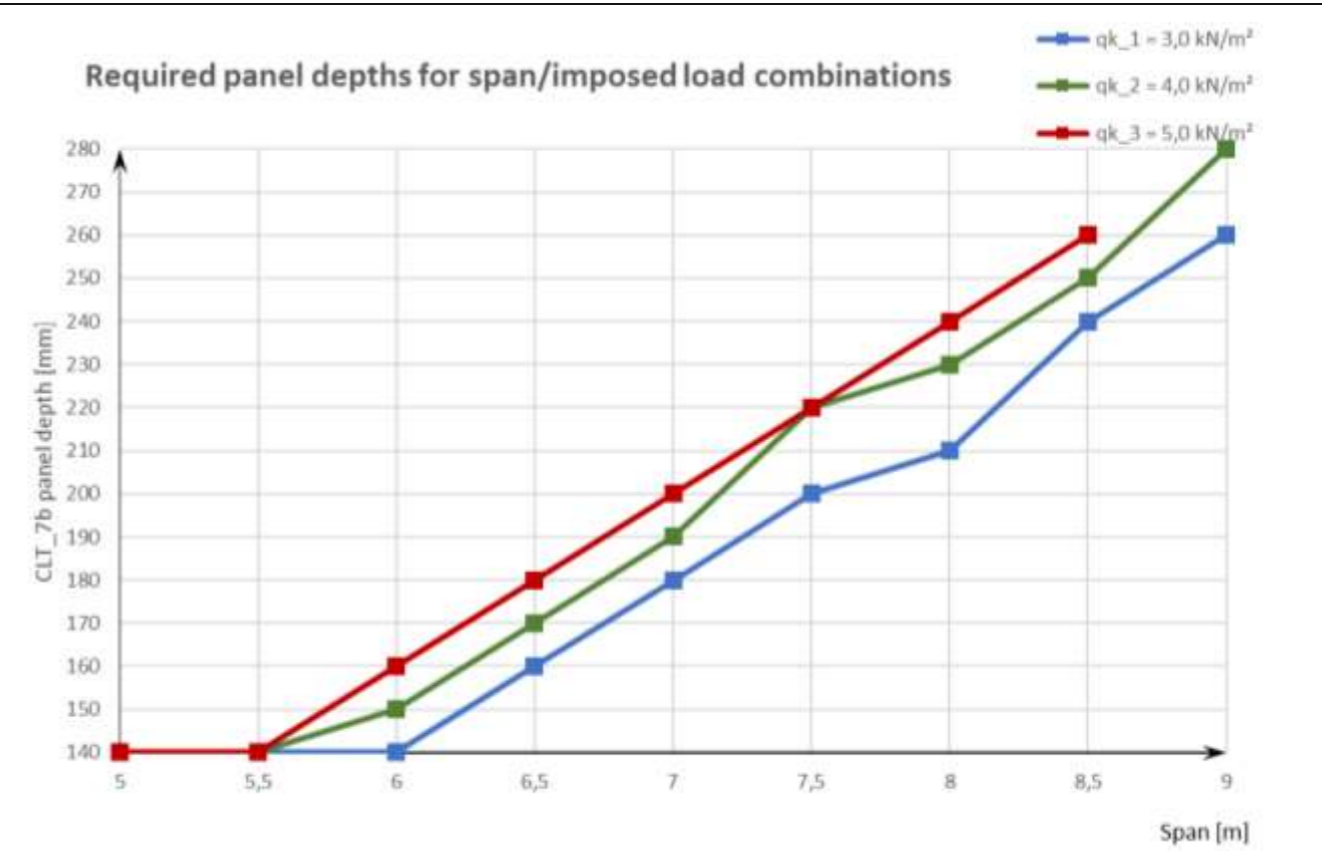


Figure 15-6: Minimum panel depths in regard to span for TCC_7b_n_r2_c2

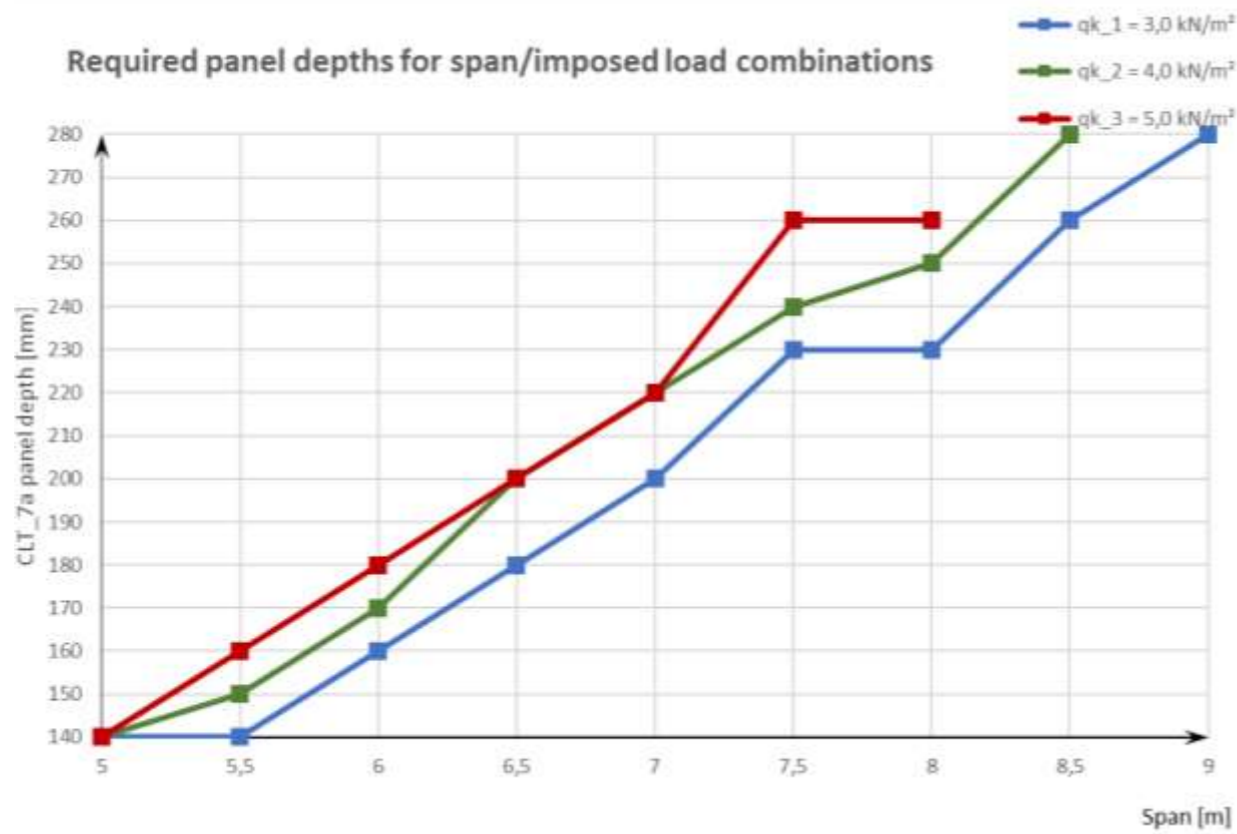


Figure 15-7: Minimum panel depths in regard to span for TCC_7b_n_r3_c2

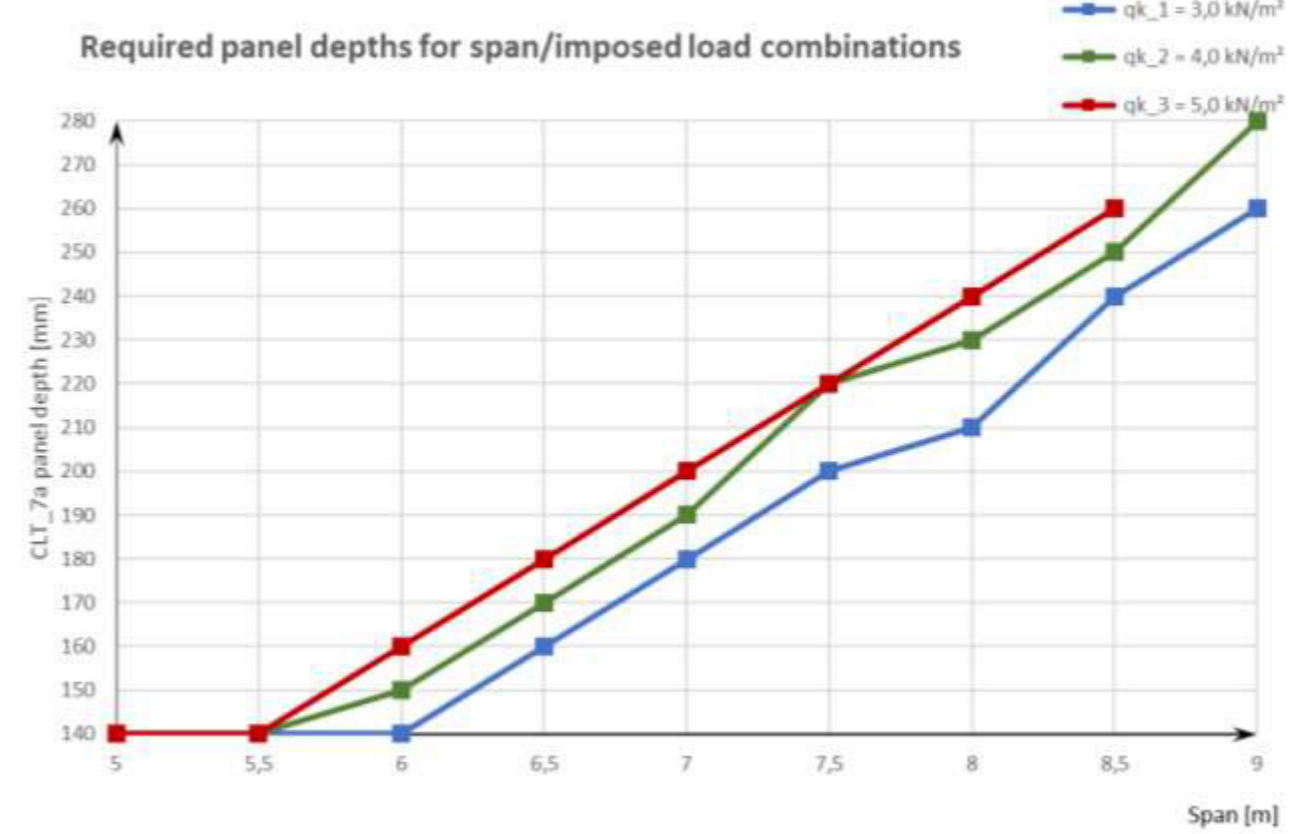
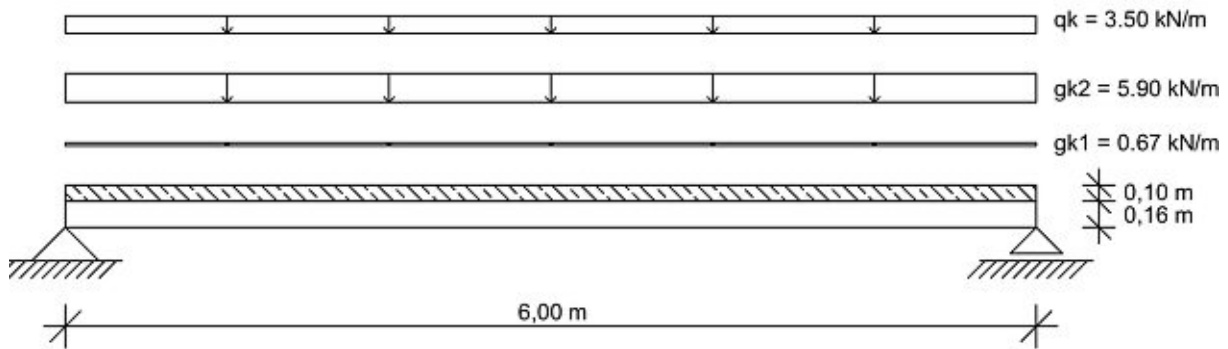


Figure 15-8: Minimum panel depths in regard to span for TCC_7b_n_r4_c2

1. System specifications and material strenghts



Material timber

$$E_0 := 11.55 \frac{\text{kN}}{\text{mm}^2}$$

$$G_0 := 0.69 \frac{\text{kN}}{\text{mm}^2}$$

Modulus of elasticity and shear modulus

$$f_{t.0.k} := 14.5 \frac{\text{N}}{\text{mm}^2}$$

$$f_{m.k} := 21 \frac{\text{N}}{\text{mm}^2}$$

Tensile and normal strength of timber

$$f_{v.k} := 4 \frac{\text{N}}{\text{mm}^2}$$

$$k_{def} := 0.6$$

$$\gamma_M := 1.25$$

Deformation factor and timber safety factor

$$k_{mod.1} := 0.8$$

$$k_{mod.2} := 0.6$$

Modification factor for imposed and permanent loads

$$k_{mod.fi} := 1$$

$$\gamma_{M.fi} := 1$$

$$\rho_k := 4.20 \frac{\text{kN}}{\text{m}^3}$$

$$k_{fi} := 1.15$$

Timber density

$$k_{mod} := \sqrt{k_{mod.1} \cdot k_{mod.2}} = 0.693$$

$$E_0 := \frac{E_0}{\gamma_M} = 9.24 \frac{\text{kN}}{\text{mm}^2}$$

Material concrete C50/60

$$E_{rc} := 37 \frac{\text{kN}}{\text{mm}^2}$$

$$G_{rc} := \frac{1}{2 \cdot (1 + 0.1)} \cdot E_{rc} = 16.818 \frac{\text{kN}}{\text{mm}^2}$$

Modulus of elasticity and shear modulus

$$f_{ck} := 50 \frac{\text{N}}{\text{mm}^2}$$

$$f_{ct.k} := 2.9 \frac{\text{N}}{\text{mm}^2}$$

Tensile and compression strength of concrete

$$f_{cm} := 58 \frac{\text{N}}{\text{mm}^2}$$

$$f_{cm.0} := 10 \frac{\text{N}}{\text{mm}^2}$$

$$\gamma_c := 1.5$$

$$\alpha_{cc} := 1$$

Concrete safety factor

$$\varphi_{rc} := 2.5$$

Creep number concrete

$$\rho_{rc} := 24 \frac{\text{kN}}{\text{m}^3}$$

System dimensions

$$sp := 6.5 \text{ m}$$

$$width := 1 \text{ m}$$

System span and analyzed width

$$depth_{rc} := 12 \text{ cm}$$

$$depth_{CLT} := 17 \text{ cm}$$

Concrete layer and CLT panel depths

Loads

$$g_{k1} := \rho_k \cdot depth_{CLT} \cdot width = 0.714 \frac{\text{kN}}{\text{m}}$$

$$g_{k2} := 5.18 \frac{\text{kN}}{\text{m}}$$

self weight loads

$$q_k := 5.0 \frac{\text{kN}}{\text{m}}$$

Imposed loads

$$\gamma_G := 1.35$$

$$\gamma_Q := 1.5$$

$$\psi := 0.3$$

Safety factor for self-weight, imposed load and combination factor

Shear connectors (here screws)

$$d_{screw} := 10 \text{ mm}$$

Screw diameter

$$K_{ser} := 20000 \frac{\text{N}}{\text{mm}}$$

Displacement modulus acc. to ETA 13/0029

$$s_{min} := 100 \text{ mm}$$

$$s_{max} := 250 \text{ mm}$$

Minimum/Maximum spacing between screws

$$n_{vbm} := 8$$

rows of shear connectors per meter width

$$\delta_{screw} := 45^\circ$$

$$l_{ef} := 200 \text{ mm}$$

Screw angle and drilling length

$$f_{ax.k} := 10 \frac{\text{N}}{\text{mm}^2}$$

$$f_{tens.k} := 32 \text{ kN}$$

Withdrawal parameter and tensile strength acc. to ETA 13/0029

Other specifications

$$\gamma_{f.shrink.u} := 1.5$$

$$\gamma_{f.shrink.ser} := 1$$

Safety factor for forces due to shrinkage (ULS and SLS)

$$\alpha_{ds1} := 3$$

$$\alpha_{ds2} := 0.13$$

Coefficients for cement type S

$$RH := 50$$

Assumed interior relative humidity

Time points for concrete shrinkage over structure life

$$t_0 := 7$$

$$t_{mid} := 2555$$

Day 0 and Day 2555 (after 5 years)

$$t_s := 7$$

$$t_{fin} := 18250$$

Reference Day and Day 18250
(after 50 years)

Areas, Moments of Inertia

$$W_{CLT} := 4.333 \cdot 10^5 \text{ mm}^3$$

$$I_{CLT} := 5.833 \cdot 10^6 \text{ mm}^4$$

$$a_x := 0.5 \cdot (\text{depth}_{CLT} + \text{depth}_{rc}) = 0.145 \text{ m}$$

Location center of gravity

$$a_{i.c} := \left(a_x - \frac{\text{depth}_{rc}}{2} \right) = 0.085 \text{ m}$$

$$A_{CLT} := \text{width} \cdot \text{depth}_{CLT} = (1.7 \cdot 10^5) \text{ mm}^2$$

$$A_{rc} := \text{width} \cdot \text{depth}_{rc} = (1.2 \cdot 10^5) \text{ mm}^2$$

$$W_{rc} := \text{width} \cdot \frac{\text{depth}_{rc}^2}{6} = (2.4 \cdot 10^3) \text{ cm}^3$$

$$I_{rc} := \text{width} \cdot \frac{\text{depth}_{rc}^3}{12} = (1.44 \cdot 10^8) \text{ mm}^4$$

$$U_{rc} := \text{width} = 1 \text{ m}$$

exposed to drying

Moments and Shear forces

$$p_{Ed.perm} := (g_{k1} + g_{k2}) \cdot \gamma_G + \psi \cdot q_k \cdot \gamma_Q = 10.207 \frac{\text{kN}}{\text{m}}$$

$$p_{Ed.short} := (1 - \psi) \cdot q_k \cdot \gamma_Q = 5.25 \frac{\text{kN}}{\text{m}}$$

$$M_{ed.perm} := \frac{sp^2}{8} \cdot p_{Ed.perm} = 53.905 \text{ kN} \cdot \text{m}$$

$$M_{ed.short} := \frac{sp^2}{8} \cdot p_{Ed.short} = 27.727 \text{ kN} \cdot \text{m}$$

$$V_{ed.perm} := \frac{sp}{2} \cdot p_{Ed.perm} = 33.172 \text{ kN}$$

$$V_{ed.short} := \frac{sp}{2} \cdot p_{Ed.short} = 17.063 \text{ kN}$$

$$p_{SLS.perm} := (g_{k1} + g_{k2}) + \psi \cdot q_k = 7.394 \frac{\text{kN}}{\text{m}}$$

$$p_{SLS.short} := (1 - \psi) \cdot q_k = 3.5 \frac{\text{kN}}{\text{m}}$$

$$M_{SLS.perm} := \frac{sp^2}{8} \cdot p_{SLS.perm} = 39.05 \text{ kN} \cdot \text{m}$$

$$V_{SLS.perm} := \frac{sp}{2} \cdot p_{SLS.perm} = 24.031 \text{ kN}$$

$$M_{SLS.short} := \frac{sp^2}{8} \cdot p_{SLS.short} = 18.484 \text{ kN} \cdot \text{m}$$

$$V_{SLS.short} := \frac{sp}{2} \cdot p_{SLS.short} = 11.375 \text{ kN}$$

2. Calculation of effective bending stiffness for $t=0$

$$K_u := \frac{2}{3} \cdot K_{ser} = (1.333 \cdot 10^4) \frac{N}{mm}$$

$$s_{eff} := 0.75 \cdot s_{min} + 0.25 \cdot s_{max} = 137.5 \text{ mm}$$

$$c_{i.ser} := K_{ser} \cdot \frac{n_{vbm}}{s_{eff}} = 1.164 \frac{kN}{mm^2} \quad c_{i.u} := K_u \cdot \frac{n_{vbm}}{s_{eff}} = 0.776 \frac{kN}{mm^2}$$

$$\gamma_{1.ser.t0} := \frac{1}{1 + \frac{E_{rc} \cdot A_{rc} \cdot \pi^2}{c_{i.ser} \cdot s^2}} = 0.529 \quad \gamma_{1.u.t0} := \frac{1}{1 + \frac{E_{rc} \cdot A_{rc} \cdot \pi^2}{c_{i.u} \cdot s^2}} = 0.428 \quad \gamma_2 := 1$$

$$a_{2.ser.t0} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_{1.ser.t0} \cdot E_{rc} \cdot A_{rc}}{\gamma_{1.ser.t0} \cdot E_{rc} \cdot A_{rc} + \gamma_2 \cdot E_0 \cdot A_{CLT}} = 86.872 \text{ mm}$$

$$a_{1.ser.t0} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_2 \cdot E_0 \cdot A_{CLT}}{\gamma_{1.ser.t0} \cdot E_{rc} \cdot A_{rc} + \gamma_2 \cdot E_0 \cdot A_{CLT}} = 58.128 \text{ mm}$$

$$a_{2.u.t0} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_{1.u.t0} \cdot E_{rc} \cdot A_{rc}}{\gamma_{1.u.t0} \cdot E_{rc} \cdot A_{rc} + \gamma_2 \cdot E_0 \cdot A_{CLT}} = 79.374 \text{ mm}$$

$$a_{1.u.t0} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_2 \cdot E_0 \cdot A_{CLT}}{\gamma_{1.u.t0} \cdot E_{rc} \cdot A_{rc} + \gamma_2 \cdot E_0 \cdot A_{CLT}} = 65.626 \text{ mm}$$

$$EI_{eff.CLt} := 2781.2 \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.CLt.c} := 1222.2 \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.u.eig} := E_{rc} \cdot I_{rc} + EI_{eff.CLt} = (8.109 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.u.st} := \gamma_{1.u.t0} \cdot E_{rc} \cdot A_{rc} \cdot a_{1.u.t0}^2 + \gamma_2 \cdot E_0 \cdot A_{CLT} \cdot a_{2.u.t0}^2 = (1.808 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.u} := EI_{eff.t0.u.eig} + EI_{eff.t0.u.st} = (2.619 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.ser.eig} := E_{rc} \cdot I_{rc} + EI_{eff.CLt} = (8.109 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.ser.st} := \gamma_{1.ser.t0} \cdot E_{rc} \cdot A_{rc} \cdot a_{1.ser.t0}^2 + \gamma_2 \cdot E_0 \cdot A_{CLT} \cdot a_{2.ser.t0}^2 = (1.979 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.ser} := EI_{eff.t0.ser.eig} + EI_{eff.t0.ser.st} = (2.79 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

3. Calculation of effective bending stiffness for t=final (50 years)

$$k_{def.str} := 2 \cdot k_{def} = 1.2$$

$$\psi_{rc.fin.u} := 1.8 - 0.3 \cdot \gamma_{1.u.t0}^{2.5} = 1.764$$

$$\psi_{t.fin} := 1$$

$$\psi_{rc.fin.ser} := 1.8 - 0.3 \cdot \gamma_{1.ser.t0}^{2.5} = 1.739$$

$$\psi_{conn.fin} := 1$$

$$E_{rc.u.fin} := \frac{E_{rc}}{1 + \psi_{rc.fin.u} \cdot \varphi_{rc}} = 6.839 \frac{kN}{mm^2}$$

$$E_{0.fin} := \frac{E_0}{1 + \psi_{t.fin} \cdot k_{def}} = 5.775 \frac{kN}{mm^2}$$

$$E_{rc.ser.fin} := \frac{E_{rc}}{1 + \psi_{rc.fin.ser} \cdot \varphi_{rc}} = 6.919 \frac{kN}{mm^2}$$

$$G_{0.fin} := \frac{G_0}{1 + \psi_{t.fin} \cdot k_{def}} = 0.431 \frac{kN}{mm^2}$$

$$K_{ser.fin} := \frac{K_{ser}}{1 + \psi_{conn.fin} \cdot k_{def.str}} = (9.091 \cdot 10^3) \frac{N}{mm}$$

$$K_{u.fin} := \frac{K_u}{1 + \psi_{conn.fin} \cdot k_{def.str}} = (6.061 \cdot 10^3) \frac{N}{mm}$$

$$c_{i.ser.fin} := K_{ser.fin} \cdot \frac{n_{vbm}}{s_{eff}} = 0.529 \frac{kN}{mm^2}$$

$$c_{i.u.fin} := K_{u.fin} \cdot \frac{n_{vbm}}{s_{eff}} = 0.353 \frac{kN}{mm^2}$$

$$\gamma_{1.ser.fin} := \frac{1}{1 + \frac{E_{rc.ser.fin} \cdot A_{rc} \cdot \pi^2}{c_{i.ser.fin} \cdot s p^2}} = 0.732$$

$$\gamma_{1.u.fin} := \frac{1}{1 + \frac{E_{rc.u.fin} \cdot A_{rc} \cdot \pi^2}{c_{i.u.fin} \cdot s p^2}} = 0.648 \quad \gamma_2 := 1$$

$$a_{2.ser.fin} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_{1.ser.fin} \cdot E_{rc.ser.fin} \cdot A_{rc}}{\gamma_{1.ser.fin} \cdot E_{rc.ser.fin} \cdot A_{rc} + \gamma_2 \cdot E_{0.fin} \cdot A_{CLT}} = 55.428 \text{ mm}$$

$$a_{1.ser.fin} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_2 \cdot E_{0.fin} \cdot A_{CLT}}{\gamma_{1.ser.fin} \cdot E_{rc.ser.fin} \cdot A_{rc} + \gamma_2 \cdot E_{0.fin} \cdot A_{CLT}} = 89.572 \text{ mm}$$

$$a_{2.u.fin} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_{1.u.fin} \cdot E_{rc.u.fin} \cdot A_{rc}}{\gamma_{1.u.fin} \cdot E_{rc.u.fin} \cdot A_{rc} + \gamma_2 \cdot E_{0.fin} \cdot A_{CLT}} = 50.937 \text{ mm}$$

$$a_{1.u.fin} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_2 \cdot E_{0.fin} \cdot A_{CLT}}{\gamma_{1.u.fin} \cdot E_{rc.u.fin} \cdot A_{rc} + \gamma_2 \cdot E_{0.fin} \cdot A_{CLT}} = 94.063 \text{ mm}$$

$$EI_{eff.CLT.fin} := 1739.5 \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.CLT.c.fin} := 764.10 \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.fin.u.eig} := E_{rc.u.fin} \cdot I_{rc} + EI_{eff.CLT.fin} = (2.724 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.fin.u.st} := \gamma_{1.u.fin} \cdot E_{rc.u.fin} \cdot A_{rc} \cdot a_{1.u.fin}^2 + \gamma_2 \cdot E_{0.fin} \cdot A_{CLT} \cdot a_{2.u.fin}^2 = (7.251 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.fin.u} := EI_{eff.fin.u.eig} + EI_{eff.fin.u.st} = (9.975 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.fin.ser.eig} := E_{rc.ser.fin} \cdot I_{rc} + EI_{eff.CLT.fin} = (2.736 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.fin.ser.st} := \gamma_{1.ser.fin} \cdot E_{rc.ser.fin} \cdot A_{rc} \cdot a_{1.ser.fin}^2 + \gamma_2 \cdot E_{0.fin} \cdot A_{CLT} \cdot a_{2.ser.fin}^2 = (7.89 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.fin.ser} := EI_{eff.fin.ser.eig} + EI_{eff.fin.ser.st} = (1.063 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

4. Calculation of effective bending stiffness for t=mid (3-7 years)

$$\psi_{rc.mid.u} := 1.7 - 0.5 \cdot \gamma_{1.u.t0}^{1.1} = 1.503$$

$$\psi_{t.mid} := 0.5$$

$$\psi_{rc.mid.ser} := 1.7 - 0.5 \cdot \gamma_{1.ser.t0}^{1.1} = 1.452$$

$$\psi_{conn.mid} := 0.65$$

$$E_{rc.u.mid} := \frac{E_{rc}}{1 + \psi_{rc.mid.u} \cdot \varphi_{rc}} = 7.775 \frac{kN}{mm^2}$$

$$E_{0.mid} := \frac{E_0}{1 + \psi_{t.mid} \cdot k_{def}} = 7.108 \frac{kN}{mm^2}$$

$$E_{rc.ser.mid} := \frac{E_{rc}}{1 + \psi_{rc.mid.ser} \cdot \varphi_{rc}} = 7.992 \frac{kN}{mm^2}$$

$$G_{0.mid} := \frac{G_0}{1 + \psi_{t.mid} \cdot k_{def}} = 0.531 \frac{kN}{mm^2}$$

$$K_{ser.mid} := \frac{K_{ser}}{1 + \psi_{conn.mid} \cdot k_{def.str}} = (1.124 \cdot 10^4) \frac{N}{mm}$$

$$K_{u.mid} := \frac{K_u}{1 + \psi_{conn.mid} \cdot k_{def.str}} = (7.491 \cdot 10^3) \frac{N}{mm}$$

$$c_{i.ser.mid} := K_{ser.mid} \cdot \frac{n_{vbm}}{s_{eff}} = 0.654 \frac{kN}{mm^2}$$

$$c_{i.u.mid} := K_{u.mid} \cdot \frac{n_{vbm}}{s_{eff}} = 0.436 \frac{kN}{mm^2}$$

$$\gamma_{1.ser.mid} := \frac{1}{1 + \frac{E_{rc.ser.mid} \cdot A_{rc} \cdot \pi^2}{c_{i.ser.mid} \cdot sp^2}} = 0.745$$

$$\gamma_{1.u.mid} := \frac{1}{1 + \frac{E_{rc.u.mid} \cdot A_{rc} \cdot \pi^2}{c_{i.u.mid} \cdot sp^2}} = 0.667 \quad \gamma_2 := 1$$

$$a_{2.ser.mid} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_{1.ser.mid} \cdot E_{rc.ser.mid} \cdot A_{rc}}{\gamma_{1.ser.mid} \cdot E_{rc.ser.mid} \cdot A_{rc} + \gamma_2 \cdot E_{0.mid} \cdot A_{CLT}} = 53.868 \text{ mm}$$

$$a_{1.ser.mid} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_2 \cdot E_{0.mid} \cdot A_{CLT}}{\gamma_{1.ser.mid} \cdot E_{rc.ser.mid} \cdot A_{rc} + \gamma_2 \cdot E_{0.mid} \cdot A_{CLT}} = 91.132 \text{ mm}$$

$$a_{2.u.mid} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_{1.u.mid} \cdot E_{rc.u.mid} \cdot A_{rc}}{\gamma_{1.u.mid} \cdot E_{rc.u.mid} \cdot A_{rc} + \gamma_2 \cdot E_{0.mid} \cdot A_{CLT}} = 49.275 \text{ mm}$$

$$a_{1.u.mid} := \frac{1}{2} \cdot (depth_{rc} + depth_{CLT}) \cdot \frac{\gamma_2 \cdot E_{0.mid} \cdot A_{CLT}}{\gamma_{1.u.mid} \cdot E_{rc.u.mid} \cdot A_{rc} + \gamma_2 \cdot E_{0.mid} \cdot A_{CLT}} = 95.725 \text{ mm}$$

$$EI_{eff.CLT.mid} := 2140.9 \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.CLT.c.mid} := 940.43 \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.mid.u.eig} := E_{rc.u.mid} \cdot I_{rc} + EI_{eff.CLT.mid} = (3.261 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.mid.u.st} := \gamma_{1.u.mid} \cdot E_{rc.u.mid} \cdot A_{rc} \cdot a_{1.u.mid}^2 + \gamma_2 \cdot E_{0.mid} \cdot A_{CLT} \cdot a_{2.u.mid}^2 = (8.633 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.mid.u} := EI_{eff.mid.u.eig} + EI_{eff.mid.u.st} = (1.189 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.mid.ser.eig} := E_{rc.ser.mid} \cdot I_{rc} + EI_{eff.CLT.mid} = (3.292 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.mid.ser.st} := \gamma_{1.ser.mid} \cdot E_{rc.ser.mid} \cdot A_{rc} \cdot a_{1.ser.mid}^2 + \gamma_2 \cdot E_{0.mid} \cdot A_{CLT} \cdot a_{2.ser.mid}^2 = (9.438 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.mid.ser} := EI_{eff.mid.ser.eig} + EI_{eff.mid.ser.st} = (1.273 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

5. Calculation of effective bending stiffness under fire conditions (R 60) for t=0 and t=final for R60

Determination of new section after fire exposition

$$\beta_1 := 0.65 \frac{\text{mm}}{\text{min}}$$

$$\beta_2 := 2 \cdot \beta_1 = 1.3 \frac{\text{mm}}{\text{min}}$$

$$\beta_3 := 0.65 \frac{\text{mm}}{\text{min}}$$

$$k_{0;d_0} := 7 \text{ mm}$$

$$d_0 := 60 \text{ min}$$

Wanted fire resistance!

$$d_{ef} := k_{0;d_0} + \beta_1 \cdot d_0 = 46 \text{ mm}$$

Total section depth that is lost after 60min fire exposition

$$EI_{eff,CLT,t_0,fi} := 1033.8 \text{ kN} \cdot \text{m}^2$$

$$EI_{eff,CLT,fin,fi} := 646.3 \text{ kN} \cdot \text{m}^2$$

$$I_{CLT,fi} := 3.5833 \cdot 10^6 \text{ mm}^4$$

$$A_{CLT,fi} := 5.480 \cdot 10^4 \text{ mm}^2$$

$$\text{depth}_{CLT,fi} := \text{depth}_{CLT} - d_{ef} = 124 \text{ mm}$$

$$a_{2,ser,fin,fi} := \frac{1}{2} \cdot (\text{depth}_{rc} + \text{depth}_{CLT,fi}) \cdot \frac{\gamma_{1,ser,fin} \cdot E_{rc,ser,fin} \cdot A_{rc}}{\gamma_{1,ser,fin} \cdot E_{rc,ser,fin} \cdot A_{rc} + \gamma_2 \cdot E_{0,fin} \cdot A_{CLT,fi}} = 80.214 \text{ mm}$$

$$a_{1,ser,fin,fi} := \frac{1}{2} \cdot (\text{depth}_{rc} + \text{depth}_{CLT,fi}) \cdot \frac{\gamma_2 \cdot E_{0,fin} \cdot A_{CLT,fi}}{\gamma_{1,ser,fin} \cdot E_{rc,ser,fin} \cdot A_{rc} + \gamma_2 \cdot E_{0,fin} \cdot A_{CLT,fi}} = 41.786 \text{ mm}$$

$$a_{2,u,fin,fi} := \frac{1}{2} \cdot (\text{depth}_{rc} + \text{depth}_{CLT,fi}) \cdot \frac{\gamma_{1,u,fin} \cdot E_{rc,u,fin} \cdot A_{rc}}{\gamma_{1,u,fin} \cdot E_{rc,u,fin} \cdot A_{rc} + \gamma_2 \cdot E_{0,fin} \cdot A_{CLT,fi}} = 76.476 \text{ mm}$$

$$a_{1,u,fin,fi} := \frac{1}{2} \cdot (\text{depth}_{rc} + \text{depth}_{CLT,fi}) \cdot \frac{\gamma_2 \cdot E_{0,fin} \cdot A_{CLT,fi}}{\gamma_{1,u,fin} \cdot E_{rc,u,fin} \cdot A_{rc} + \gamma_2 \cdot E_{0,fin} \cdot A_{CLT,fi}} = 45.524 \text{ mm}$$

$$a_{2,ser,t_0,fi} := \frac{1}{2} \cdot (\text{depth}_{rc} + \text{depth}_{CLT,fi}) \cdot \frac{\gamma_{1,ser,t_0} \cdot E_{rc} \cdot A_{rc}}{\gamma_{1,ser,t_0} \cdot E_{rc} \cdot A_{rc} + \gamma_2 \cdot E_0 \cdot A_{CLT,fi}} = 100.354 \text{ mm}$$

$$a_{1,ser,t_0,fi} := \frac{1}{2} \cdot (\text{depth}_{rc} + \text{depth}_{CLT,fi}) \cdot \frac{\gamma_2 \cdot E_0 \cdot A_{CLT,fi}}{\gamma_{1,ser,t_0} \cdot E_{rc} \cdot A_{rc} + \gamma_2 \cdot E_0 \cdot A_{CLT,fi}} = 21.646 \text{ mm}$$

$$a_{2,u,t_0,fi} := \frac{1}{2} \cdot (\text{depth}_{rc} + \text{depth}_{CLT,fi}) \cdot \frac{\gamma_{1,u,t_0} \cdot E_{rc} \cdot A_{rc}}{\gamma_{1,u,t_0} \cdot E_{rc} \cdot A_{rc} + \gamma_2 \cdot E_0 \cdot A_{CLT,fi}} = 96.327 \text{ mm}$$

$$a_{1,u,t_0,fi} := \frac{1}{2} \cdot (\text{depth}_{rc} + \text{depth}_{CLT,fi}) \cdot \frac{\gamma_2 \cdot E_0 \cdot A_{CLT,fi}}{\gamma_{1,u,t_0} \cdot E_{rc} \cdot A_{rc} + \gamma_2 \cdot E_0 \cdot A_{CLT,fi}} = 25.673 \text{ mm}$$

$$EI_{eff.fin.u.eig.fi} := E_{rc.u.fin} \cdot I_{rc} + E_{0.fin} \cdot I_{CLT.fi} + EI_{eff.CLt.fin.fi} = (1.652 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.fin.u.st.fi} := \gamma_{1.u.fin} \cdot E_{rc.u.fin} \cdot A_{rc} \cdot a_{1.u.fin.fi}^2 + \gamma_2 \cdot E_{0.fin} \cdot A_{CLT.fi} \cdot a_{2.u.fin.fi}^2 = (2.953 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.fin.u.fi} := EI_{eff.fin.u.eig.fi} + EI_{eff.fin.u.st.fi} = (4.604 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.fin.ser.eig.fi} := E_{rc.ser.fin} \cdot I_{rc} + E_{0.fin} \cdot I_{CLT.fi} + EI_{eff.CLt.fin} = (2.757 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.fin.ser.st.fi} := \gamma_{1.ser.fin} \cdot E_{rc.ser.fin} \cdot A_{rc} \cdot a_{1.ser.fin.fi}^2 + \gamma_2 \cdot E_{0.fin} \cdot A_{CLT.fi} \cdot a_{2.ser.fin.fi}^2 = (3.097 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.fin.ser.fi} := EI_{eff.fin.ser.eig.fi} + EI_{eff.fin.ser.st.fi} = (5.854 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.u.eig.fi} := E_{rc} \cdot I_{rc} + E_0 \cdot I_{CLT.fi} + EI_{eff.CLt.t0.fi} = (6.395 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.u.st.fi} := \gamma_{1.u.t0} \cdot E_{rc} \cdot A_{rc} \cdot a_{1.u.t0.fi}^2 + \gamma_2 \cdot E_0 \cdot A_{CLT.fi} \cdot a_{2.u.t0.fi}^2 = (5.951 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.u.fi} := EI_{eff.t0.u.eig.fi} + EI_{eff.t0.u.st.fi} = (1.235 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.ser.eig.fi} := E_{rc} \cdot I_{rc} + E_0 \cdot I_{CLT.fi} + EI_{eff.CLt.t0.fi} = (6.395 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.ser.st.fi} := \gamma_{1.ser.t0} \cdot E_{rc} \cdot A_{rc} \cdot a_{1.ser.t0.fi}^2 + \gamma_2 \cdot E_0 \cdot A_{CLT.fi} \cdot a_{2.ser.t0.fi}^2 = (6.199 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$EI_{eff.t0.ser.fi} := EI_{eff.t0.ser.eig.fi} + EI_{eff.t0.ser.st.fi} = (1.259 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

$$a_x fi := 0.5 \cdot (depth_{CLT} - d_{ef} + depth_{rc}) = 0.122 \text{ m}$$

6. Calculation of concrete shrinkage acc. to EN 1995-1-1

$$\beta_{RH} := 1.55 \cdot \left(1 - \left(\frac{RH}{100} \right)^3 \right) = 1.356 \quad h_0 := 2 \cdot \frac{A_{rc}}{U_{rc}} = 240 \text{ mm} \quad k_h := 0.85$$

$$\varepsilon_{cd.0} := 0.85 \cdot \left((220 + 110 \cdot \alpha_{ds1}) \cdot \exp \left(\frac{f_{cm}}{f_{cm.0}} \cdot -\alpha_{ds2} \right) \right) \cdot 10^{-6} \cdot \beta_{RH} = 2.983 \cdot 10^{-4} \quad (\text{Tab 3.3 in EN 1992-1-1})$$

$$\beta_{ds.fin} := \frac{t_{fin} - t_s}{(t_{fin} - t_s) + 0.04 \cdot \sqrt{\left(\frac{h_0}{\text{mm}} \right)^3}} = 0.992 \quad (\text{Formula 3.10 in EN 1992-1-1})$$

$$\varepsilon_{cd.fin} := \beta_{ds.fin} \cdot k_h \cdot \varepsilon_{cd.0} = 2.515 \cdot 10^{-4} \quad (\text{Formula 3.9 in EN 1992-1-1})$$

$$\beta_{as.fin} := 1 - \exp(-0.2 \cdot t_{fin}^{0.5}) = 1 \quad (\text{Formula 3.13 in EN 1992-1-1})$$

$$\varepsilon_{ca} := 2.5 \cdot \left(\frac{f_{ck}}{\text{N}} - 10 \right) \cdot 10^{-6} = 1 \cdot 10^{-4} \quad (\text{Formula 3.12 in EN 1992-1-1})$$

$$\varepsilon_{ca.fin} := \beta_{as.fin} \cdot \varepsilon_{ca} = 10 \cdot 10^{-5} \quad (\text{Formula 3.11 in EN 1992-1-1})$$

$$\varepsilon_{cs.fin} := \varepsilon_{ca.fin} + \varepsilon_{cd.fin} = 3.515 \cdot 10^{-4} \quad (\text{Formula 3.8 in EN 1992-1-1})$$

$$\varepsilon_{shrink.timber} := 0 \quad \text{Timber shrinkage} = 0 \text{ because temperature is constant}$$

7. ULS and SLS Calculation for t=0 acc. to EN 1995-1-1

Calculation of shrinkage for t=0

$$K_{s,t0} := 0 \quad \text{effective shrinkage for t=0}$$

$$f_{-\varepsilon_{ef.conc.t0}} := 0$$

see formula (7.3) in draft norm

$$\Delta\varepsilon_{sls.t0} := K_{s,t0} \cdot (\varepsilon_{shrink.timb} - f_{-\varepsilon_{ef.conc.t0}} \cdot \varepsilon_{cs.fin}) = 0$$

see formula (B.3) in draft norm

$$C_{p.sls.t0.u} := \pi^2 \cdot \frac{E_{rc} \cdot A_{rc} \cdot E_0 \cdot A_{CLT} \cdot a_x \cdot \gamma_{1.u.t0}}{(E_{rc} \cdot A_{rc} + E_0 \cdot A_{CLT}) \cdot sp^2} = 16.817 \frac{kN}{mm}$$

see formula (B.2) in draft norm

$$C_{p.sls.t0.ser} := \pi^2 \cdot \frac{E_{rc} \cdot A_{rc} \cdot E_0 \cdot A_{CLT} \cdot a_x \cdot \gamma_{1.ser.t0}}{(E_{rc} \cdot A_{rc} + E_0 \cdot A_{CLT}) \cdot sp^2} = 20.78 \frac{kN}{mm}$$

$$p_{sls.t0.u} := C_{p.sls.t0.u} \cdot \gamma_{f.shrink.u} \cdot \Delta\varepsilon_{sls.t0} = 0 \frac{kN}{m}$$

see formula (B.1) in draft norm

$$p_{sls.t0.ser} := C_{p.sls.t0.ser} \cdot \gamma_{f.shrink.ser} \cdot \Delta\varepsilon_{sls.t0} = 0 \frac{kN}{m}$$

$$C_{j.sls.t0.u} := \frac{p_{sls.t0.u} + p_{Ed.perm}}{\frac{E_{rc} \cdot A_{rc} + E_0 \cdot A_{CLT}}{\gamma_{1.u.t0} \cdot E_{rc} \cdot A_{rc} + E_0 \cdot A_{CLT}} \cdot p_{sls.t0.u} + p_{Ed.perm}} = 1$$

see formula (B.7) in draft norm

$$C_{j.sls.t0.ser} := \frac{p_{sls.t0.ser} + p_{Ed.perm}}{\frac{E_{rc} \cdot A_{rc} + E_0 \cdot A_{CLT}}{\gamma_{1.ser.t0} \cdot E_{rc} \cdot A_{rc} + E_0 \cdot A_{CLT}} \cdot p_{sls.t0.ser} + p_{Ed.perm}} = 1$$

$$EI_{sls.t0.u} := EI_{eff.t0.u} \cdot C_{j.sls.t0.u} = (2.619 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

see formula (B.6) in draft norm

$$EI_{sls.t0.ser} := EI_{eff.t0.ser} \cdot C_{j.sls.t0.ser} = (2.79 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

$$M_{perm.d.t0} := M_{ed.perm} + 0.8 \cdot p_{sls.t0.u} \cdot \frac{sp^2}{8} = 53.905 \text{ kN} \cdot \text{m}$$

see formula (B.9) in draft norm

$$M_{short.d.t0} := M_{ed.short} = 27.727 \text{ kN} \cdot \text{m}$$

$$V_{sls.t0.u} := -\pi \cdot E_0 \cdot A_{CLT} \cdot \frac{E_{rc} \cdot I_{rc} + E_0 \cdot I_{CLT}}{(\gamma_{1.u.t0} \cdot E_{rc} \cdot A_{rc} + E_0 \cdot A_{CLT}) \cdot sp \cdot a_{i,c}} \cdot \Delta\varepsilon_{sls.t0} = 0 \text{ kN}$$

see formula (B.12) in draft norm

$$V_{perm.t0.u} := V_{sls.t0.u} + V_{ed.perm} = 33.172 \text{ kN}$$

$$M_{c.t0.perm} := \frac{E_{rc} \cdot I_{rc}}{EI_{sls.t0.u}} \cdot M_{perm.d.t0} = 10.967 \text{ kN} \cdot \text{m}$$

see formula (B.9) in draft norm

$$M_{c.t0.short} := \frac{E_{rc} \cdot I_{rc}}{EI_{sls.t0.u}} \cdot M_{ed.short} = 5.641 \text{ kN} \cdot \text{m}$$

$$M_{t.t0.perm} := \frac{E_0 \cdot I_{CLT}}{EI_{sls.t0.u}} \cdot M_{perm.d.t0} = 0.111 \text{ kN} \cdot \text{m}$$

$$M_{t.t0.short} := \frac{E_0 \cdot I_{CLT}}{EI_{sls.t0.u}} \cdot M_{ed.short} = 0.057 \text{ kN} \cdot \text{m}$$

$$N_{perm.d.t0} := \frac{(M_{perm.d.t0} - M_{t.t0.perm} - M_{c.t0.perm})}{a_x} = 295.359 \text{ kN}$$

see formula (B.10) in draft norm

$$N_{short.d.t0} := \frac{(M_{short.d.t0} - M_{t.t0.short} - M_{c.t0.short})}{a_x} = 151.92 \text{ kN}$$

Calculation of normal stresses in concrete

$$\sigma_{N.c.t0} := \frac{-N_{perm.d.t0}}{A_{rc}} - \frac{N_{short.d.t0}}{A_{rc}} = -3.727 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{M.c.t0} := \frac{M_{c.t0.perm}}{W_{rc}} + \frac{M_{c.t0.short}}{W_{rc}} = 6.92 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{c.t0.min} := \sigma_{N.c.t0} - \sigma_{M.c.t0} = -10.647 \frac{\text{N}}{\text{mm}^2}$$

Compression stress on top of concrete layer

$$\sigma_{c.t0.max} := \sigma_{N.c.t0} + \sigma_{M.c.t0} = 3.193 \frac{\text{N}}{\text{mm}^2}$$

Tensional stress on bottom of concrete layer

$$\mu_{comp} := \frac{-(\sigma_{c.t0.min})}{\frac{f_{ck} \cdot \alpha_{cc}}{\gamma_c}} = 0.319$$

$$\mu_{tens} := \frac{(\sigma_{c.t0.max})}{\frac{f_{ct,k} \cdot \alpha_{cc}}{\gamma_c}} = 1.651$$

Dimensioning of reinforcement for concrete

$$d_1 := 15 \text{ mm}$$

concrete covering

$$d_{rc} := \text{depth}_{rc} - d_1 = 105 \text{ mm}$$

Depth of concrete for reinforcement

$$f_{yd} := \frac{550 \frac{\text{N}}{\text{mm}^2}}{1.15} = 478.261 \frac{\text{N}}{\text{mm}^2}$$

$$M_{rc.t0} := M_{c.t0.perm} + M_{c.t0.short} = 16.608 \text{ kN} \cdot \text{m}$$

$$N_{rc.t0} := N_{perm.d.t0} + N_{short.d.t0} = 447.28 \text{ kN}$$

$$M_{s1.t0} := M_{rc.t0} + N_{rc.t0} \cdot (\text{depth}_{rc} \cdot 0.5 - d_1) = 36.736 \text{ kN} \cdot \text{m}$$

$$x_{b.lim} := \frac{560 \frac{\text{N}}{\text{mm}^2} \cdot d_{rc}}{f_{yd} + 700 \frac{\text{N}}{\text{mm}^2}} = 49.904 \text{ mm}$$

$$x_{b.rc.t0} := d_{rc} - \sqrt{d_{rc}^2 - \left(\frac{2 \cdot M_{s1.t0}}{\text{width} \cdot \frac{f_{ck}}{\gamma_c}} \right)} = 11.081 \text{ mm}$$

$$F_{cd.rc.t0} := x_{b.rc.t0} \cdot \text{width} \cdot \frac{f_{ck}}{\gamma_c} = 369.353 \text{ kN}$$

$$A_{s.rc.t0} := \frac{N_{rc.t0} - F_{cd.rc.t0}}{f_{yd}} = 162.937 \text{ mm}^2$$

$$A_{s.rc.t0.d} := A_{s.rc.t0} + 1 \text{ cm}^2 = 262.937 \text{ mm}^2$$

$$M_{rd.t0} := x_{b.rc.t0} \cdot \text{width} \cdot \frac{f_{ck}}{\gamma_c} \cdot (d_{rc} - 0.5 \cdot x_{b.rc.t0}) = 36.736 \text{ kN} \cdot \text{m}$$

$$N_{rd.t0} := x_{b.rc.t0} \cdot \text{width} \cdot \frac{f_{ck}}{\gamma_c} + A_{s.rc.t0.d} \cdot f_{yd} = 495.106 \text{ kN}$$

$$\sigma_{c.t0.max.rd} := \frac{N_{rd.t0}}{A_{rc}} + \frac{M_{rd.t0}}{W_{rc}} = 19.432 \frac{\text{N}}{\text{mm}^2}$$

$$\mu_{tens} := \frac{(\sigma_{c.t0.max})}{\sigma_{c.t0.max.rd}} = 0.164$$

Calculation of normal stresses in timber

$$\sigma_{N.t.t0} := \frac{-N_{perm.d.t0}}{A_{CLT}} - \frac{N_{short.d.t0}}{A_{CLT}} = -2.631 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{M.t.t0} := \frac{M_{t.t0.perm}}{W_{CLT}} + \frac{M_{t.t0.short}}{W_{CLT}} = 0.388 \frac{\text{N}}{\text{mm}^2}$$

$$\mu_{tot} := \frac{-(\sigma_{N.t.t0})}{\frac{f_{t.0.k} \cdot k_{mod}}{\gamma_M}} + \frac{(\sigma_{M.t.t0})}{\frac{f_{m.k} \cdot k_{mod}}{\gamma_M}} = 0.361$$

Shear stresses in the shear connection due to concrete shrinkage

see formula (B.11) in draft norm

$$F_{max.t0} := \frac{\gamma_{1.u.t0} \cdot E_{rc} \cdot A_{rc} \cdot \left(a_x - \frac{depth_{rc}}{2} \right) \cdot s_{eff}}{EI_{sls.t0.u}} \cdot (V_{perm.t0.u} + V_{ed.short}) = 42.594 \text{ kN}$$

$$F_{ax.\alpha.Rk} := \frac{f_{ax.k} \cdot d_{screw} \cdot l_{ef}}{1.2 \cdot \cos(\delta_{screw})^2 + \sin(\delta_{screw})^2} \cdot \left(\frac{\rho_k}{3.5 \frac{kN}{m^3}} \right)^{0.8} = 21.037 \text{ kN}$$

$$F_{rd} := n_{vbm} \cdot (\cos(\delta_{screw}) + 0.25 \cdot \sin(\delta_{screw})) \cdot \min \left(F_{ax.\alpha.Rk} \cdot \frac{k_{mod}}{\gamma_M}, f_{tens.k} \right) = 82.448 \text{ kN}$$

$$\mu_{screw} := \frac{F_{max.t0}}{F_{rd}} = 0.517$$

Shear stresses in timber due to external force

$$h := a_{2.u.t0} + \frac{depth_{CLT}}{2} = 164.374 \text{ mm}$$

$$\tau_{t.t0} := \frac{0.5 \cdot E_0 \cdot h^2}{EI_{sls.t0.u}} \cdot (V_{ed.short} + V_{ed.perm}) = 0.239 \frac{N}{mm^2}$$

see formula (B.10) in EN 1995-1-1

$$\mu_{tot.t0} := \frac{\tau_{t.t0}}{\frac{f_{v.k} \cdot k_{mod}}{\gamma_M}} = 0.108$$

Deflections for t=0

$$w_{t0.tot} := \frac{5}{384} \cdot \frac{(p_{SLS.perm} + p_{SLS.short} + p_{sls.t0.ser}) \cdot sp^4}{EI_{sls.t0.ser}} = 9.077 \text{ mm}$$

$$w_{lim} := \frac{1}{300} \cdot sp = 21.667 \text{ mm}$$

$$\mu_{w.t0} := \frac{w_{t0.tot}}{w_{lim}} = 0.419$$

Verifications of vibrations

$$q_{t0} := \frac{EI_{eff.CLTC} + E_{rc} \cdot I_{rc}}{EI_{sls.t0.ser}} = 0.235$$

$$f_{lim} := 8 \text{ Hz}$$

$$lim_{val} := 0.05$$

For "floor class 1"

$$f_{1,t0} := \begin{cases} \text{if } q_{t0} > \text{lim}_{val} \\ \frac{\pi}{2 \cdot sp^2} \cdot \sqrt{\frac{EI_{eff,t0,ser}}{(g_{k1} + g_{k2})}} \cdot \sqrt{1 + \left(\frac{sp}{width}\right)^4} \cdot \frac{EI_{eff,CLT,c} + E_{rc} \cdot I_{rc}}{EI_{sls,t0,ser}} \\ \text{else} \\ \frac{\pi}{2 \cdot sp^2} \cdot \sqrt{\frac{EI_{eff,t0,ser}}{(g_{k1} + g_{k2})}} \end{cases} = 164.208 \text{ Hz}$$

$9.81 \frac{m}{s^2}$

$$\mu_{vib,t0} := \left(\frac{f_{1,t0}}{f_{lim}}\right)^{-1} = 0.049 \quad \text{Verification of vibration acceleration is not necessary because } f_{1,t0} \text{ is greater than } f_{lim}$$

Stiffness criterium

$$w_{stat,lim} := 0.50 \text{ mm}$$

$$b_{f,t0} := \min\left(width \cdot 10^3, \frac{sp}{1.1} \cdot \sqrt[4]{\frac{EI_{eff,CLT,c} + E_{rc} \cdot I_{rc}}{EI_{sls,t0,ser}}}\right) = 4.113 \text{ m}$$

$$w_{stat,t0} := \frac{1 \text{ kN} \cdot sp^3}{48 \cdot EI_{sls,t0,ser} \cdot b_{f,t0}} \cdot m = 0.05 \text{ mm}$$

$$\mu_{stiff} := \frac{w_{stat,t0}}{w_{stat,lim}} = 0.1$$

8. ULS and SLS Calculation for t=mid acc. to EN 1995-1-1

Calculation of shrinkage for t=mid

$$K_{s.mid} := 0.8 \quad \text{effective shrinkage for } t=0$$

$$f_{-\varepsilon_{ef.conc.mid}} := 0.6 \quad \text{see formula (7.4) in draft norm}$$

$$\Delta\varepsilon_{sls.mid} := K_{s.mid} \cdot (\varepsilon_{shrink.timb} - f_{-\varepsilon_{ef.conc.mid}} \cdot \varepsilon_{cs.fin}) = -1.687 \cdot 10^{-4} \quad \text{see formula (B.3) in draft norm}$$

$$C_{p.sls.mid.u} := \pi^2 \cdot \frac{E_{rc.u.mid} \cdot A_{rc} \cdot E_{0.mid} \cdot A_{CLT} \cdot a_x \cdot \gamma_{1.u.mid}}{(E_{rc.u.mid} \cdot A_{rc} + E_{0.mid} \cdot A_{CLT}) \cdot sp^2} = 11.888 \frac{kN}{mm} \quad \text{(B.2) in draft norm}$$

$$C_{p.sls.mid.ser} := \pi^2 \cdot \frac{E_{rc.ser.mid} \cdot A_{rc} \cdot E_{0.mid} \cdot A_{CLT} \cdot a_x \cdot \gamma_{1.ser.mid}}{(E_{rc.ser.mid} \cdot A_{rc} + E_{0.mid} \cdot A_{CLT}) \cdot sp^2} = 13.488 \frac{kN}{mm}$$

$$p_{sls.mid.u} := -C_{p.sls.mid.u} \cdot \gamma_{f.shrink.u} \cdot \Delta\varepsilon_{sls.mid} = 3.009 \frac{kN}{m} \quad \text{see formula (B.1) in draft norm}$$

$$p_{sls.mid.ser} := -C_{p.sls.mid.ser} \cdot \gamma_{f.shrink.ser} \cdot \Delta\varepsilon_{sls.mid} = 2.276 \frac{kN}{m}$$

$$C_{j.sls.mid.u} := \frac{p_{sls.mid.u} + p_{Ed.perm}}{\frac{E_{rc.u.mid} \cdot A_{rc} + E_{0.mid} \cdot A_{CLT}}{\gamma_{1.u.mid} \cdot E_{rc.u.mid} \cdot A_{rc} + E_{0.mid} \cdot A_{CLT}} \cdot p_{sls.mid.u} + p_{Ed.perm}} = 0.963 \quad \text{see formula (B.7) in draft norm}$$

$$C_{j.sls.mid.ser} := \frac{p_{sls.mid.ser} + p_{Ed.perm}}{\frac{E_{rc.ser.mid} \cdot A_{rc} + E_{0.mid} \cdot A_{CLT}}{\gamma_{1.ser.mid} \cdot E_{rc.ser.mid} \cdot A_{rc} + E_{0.mid} \cdot A_{CLT}} \cdot p_{sls.mid.ser} + p_{Ed.perm}} = 0.977$$

$$EI_{sls.mid.u} := EI_{eff.mid.u} \cdot C_{j.sls.mid.u} = (1.145 \cdot 10^4) \text{ kN} \cdot \text{m}^2 \quad \text{see formula (B.6) in draft norm}$$

$$EI_{sls.mid.ser} := EI_{eff.mid.ser} \cdot C_{j.sls.mid.ser} = (1.244 \cdot 10^4) \text{ kN} \cdot \text{m}^2$$

$$M_{perm.d.mid} := M_{ed.perm} + 0.8 \cdot (p_{sls.mid.u}) \cdot \frac{sp^2}{8} = 66.617 \text{ kN} \cdot \text{m} \quad \text{see formula (B.9) in draft norm}$$

$$M_{short.d.mid} := M_{ed.short} = 27.727 \text{ kN} \cdot \text{m}$$

see formula (B.12) in draft norm

$$V_{sls.mid.u} := -\pi \cdot E_{0.mid} \cdot A_{CLT} \cdot \frac{E_{rc.u.mid} \cdot I_{rc} + E_{0.mid} \cdot I_{CLT}}{(\gamma_{1.u.mid} \cdot E_{rc.u.mid} \cdot A_{rc} + E_{0.mid} \cdot A_{CLT}) \cdot sp \cdot a_{i,c}} \cdot \Delta\varepsilon_{sls.mid} = 0.735 \text{ kN}$$

$$V_{perm.mid.u} := V_{sls.mid.u} + V_{ed.perm} = 33.908 \text{ kN}$$

$$M_{c.mid.perm} := \frac{E_{rc.u.mid} \cdot I_{rc}}{EI_{sls.mid.u}} \cdot M_{perm.d.mid} = 6.514 \text{ kN} \cdot \text{m}$$

see formula (B.9) in draft norm

$$M_{c.mid.short} := \frac{E_{rc.u.mid} \cdot I_{rc}}{EI_{sls.mid.u}} \cdot M_{ed.short} = 2.711 \text{ kN} \cdot \text{m}$$

$$M_{t.mid.perm} := \frac{E_{0.mid} \cdot I_{CLT}}{EI_{sls.mid.u}} \cdot M_{perm.d.mid} = 0.241 \text{ kN} \cdot \text{m}$$

$$M_{t.mid.short} := \frac{E_{0.mid} \cdot I_{CLT}}{EI_{sls.mid.u}} \cdot M_{ed.short} = 0.1 \text{ kN} \cdot \text{m}$$

$$N_{perm.d.mid} := \frac{(M_{perm.d.mid} - M_{t.mid.perm} - M_{c.mid.perm})}{a_x} = 412.841 \text{ kN} \quad \text{see formula (B.10) in draft norm}$$

$$N_{short.d.mid} := \frac{(M_{short.d.mid} - M_{t.mid.short} - M_{c.mid.short})}{a_x} = 171.828 \text{ kN}$$

Calculation of normal stresses in concrete

$$\sigma_{N.c.mid} := \frac{-N_{perm.d.mid}}{A_{rc}} - \frac{N_{short.d.mid}}{A_{rc}} = -4.872 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{M.c.mid} := \frac{M_{c.mid.perm}}{W_{rc}} + \frac{M_{c.mid.short}}{W_{rc}} = 3.844 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{c.mid.min} := \sigma_{N.c.mid} - \sigma_{M.c.mid} = -8.716 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{c.mid.max} := \sigma_{N.c.mid} + \sigma_{M.c.mid} = -1.029 \frac{\text{N}}{\text{mm}^2}$$

$$\mu_{comp} := \frac{-(\sigma_{c.mid.min})}{\frac{f_{ck} \cdot \alpha_{cc}}{\gamma_c}} = 0.261$$

$$\mu_{tens} := \frac{-(\sigma_{c.mid.max})}{\frac{f_{ck} \cdot \alpha_{cc}}{\gamma_c}} = 0.031$$

Calculation of normal stresses in timber

$$\sigma_{N.t.mid} := \frac{-N_{perm.d.mid}}{A_{CLT}} - \frac{N_{short.d.mid}}{A_{CLT}} = -3.439 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{M.t.mid} := \frac{M_{t.mid.perm}}{W_{CLT}} + \frac{M_{t.mid.short}}{W_{CLT}} = 0.788 \frac{\text{N}}{\text{mm}^2}$$

$$\mu_{tot} := \frac{-(\sigma_{N.t.mid})}{\frac{f_{t.0.k} \cdot k_{mod}}{\gamma_M}} + \frac{(\sigma_{M.t.mid})}{\frac{f_{m.k} \cdot k_{mod}}{\gamma_M}} = 0.496$$

Shear stresses in the shear connection due to concrete shrinkage

see formula (B.11) in draft norm

$$F_{max.mid} := \frac{\gamma_{1.u.mid} \cdot E_{rc.u.mid} \cdot A_{rc} \cdot \left(a_x - \frac{depth_{rc}}{2} \right) \cdot s_{eff}}{EI_{sls.mid.u}} \cdot (V_{perm.mid.u} + V_{ed.short}) = 32.358 \text{ kN}$$

$$F_{ax.\alpha.Rk} := \frac{f_{ax.k} \cdot d_{screw} \cdot l_{ef}}{1.2 \cdot \cos(\delta_{screw})^2 + \sin(\delta_{screw})^2} \cdot \left(\frac{\rho_k}{3.50 \frac{kN}{m^3}} \right)^{0.8} = 21.037 \text{ kN}$$

$$F_{rd} := n_{vbm} \cdot (\cos(\delta_{screw}) + 0.25 \cdot \sin(\delta_{screw})) \cdot \min \left(F_{ax.\alpha.Rk} \cdot \frac{k_{mod}}{\gamma_M}, f_{tens.k} \right) = 82.448 \text{ kN}$$

$$\mu_{screw} := \frac{F_{max.mid}}{F_{rd}} = 0.392$$

$$h = 0.164 \text{ m}$$

Shear stresses in timber due to external force

$$h := a_{2.u.mid} + \frac{depth_{CLT}}{2} = 134.275 \text{ mm}$$

$$\tau_{t.mid} := \frac{0.5 \cdot E_{0.mid} \cdot h^2}{EI_{sls.mid.u}} \cdot (V_{ed.short} + V_{ed.perm}) = 0.281 \frac{N}{mm^2} \quad \text{see formula (B.10) in EN 1995-1-1}$$

$$\mu_{tot.mid} := \frac{\tau_{t.mid}}{\frac{f_{v.k} \cdot k_{mod}}{\gamma_M}} = 0.127$$

Deflections for t=mid

$$w_{mid.tot} := \frac{5}{384} \cdot \frac{(p_{SLS.perm} + p_{SLS.short} + p_{sls.mid.ser}) \cdot sp^4}{EI_{sls.mid.ser}} = 24.605 \text{ mm}$$

$$w_{lim} := \frac{1}{300} \cdot sp = 21.667 \text{ mm}$$

$$\mu_{w.mid} := \frac{w_{mid.tot}}{w_{lim}} = 1.136$$

Verifications of vibrations

$$q_{mid} := \frac{EI_{eff.CLT.c.mid} + E_{rc.ser.mid} \cdot I_{rc}}{EI_{sls.mid.ser}} = 0.168$$

$$f_{lim} := 8 \text{ Hz}$$

$$lim_{val} := 0.05$$

$$f_{1,mid} := \begin{cases} \text{if } q_{mid} > \text{lim}_{val} \\ \frac{\pi}{2 \cdot sp^2} \cdot \sqrt{\frac{EI_{eff,mid,ser}}{(g_{k1} + g_{k2})}} \cdot \sqrt{1 + \left(\frac{sp}{width}\right)^4} \cdot \frac{EI_{eff,CLT,c,mid} + E_{rc,ser,mid} \cdot I_{rc}}{EI_{sls,mid,ser}} \\ \text{else} \\ \frac{\pi}{2 \cdot sp^2} \cdot \sqrt{\frac{EI_{eff,mid,ser}}{(g_{k1} + g_{k2})}} \cdot \sqrt{9.81 \frac{m}{s^2}} \end{cases} = 93.897 \text{ Hz}$$

$$\mu_{vib,mid} := \frac{f_{1,mid}}{f_{lim}} = 11.737 \quad \text{Verification of vibration acceleration is not necessary because } f_{1,t0} \text{ is greater than } f_{lim}$$

Stiffness criterium

$$w_{stat,lim} := 0.50 \text{ mm}$$

$$b_{f,mid} := \min \left(width \cdot 10^3, \frac{sp}{1.1} \cdot \sqrt[4]{\frac{EI_{eff,CLT,c,mid} + E_{rc,ser,mid} \cdot I_{rc}}{EI_{sls,mid,ser}}} \right) = 3.784 \text{ m}$$

$$w_{stat,mid} := \frac{1 \text{ kN} \cdot sp^3}{48 \cdot EI_{sls,mid,ser} \cdot b_{f,mid}} \cdot m = 0.122 \text{ mm}$$

$$\mu_{stiff,mid} := \frac{w_{stat,mid}}{w_{stat,lim}} = 0.243$$

9. ULS and SLS Calculation for t=fin acc. to EN 1995-1-1

Calculation of shrinkage for t=mid

$$K_{s,fin} := 0.8 \quad \text{effective shrinkage for t=fin}$$

$$f_{-\varepsilon_{ef.conc.fin}} := 0.9 \quad \text{see formula (7.4) in draft norm}$$

$$\Delta\varepsilon_{sls.fin} := K_{s,fin} \cdot (\varepsilon_{shrink.timb} - f_{-\varepsilon_{ef.conc.fin}} \cdot \varepsilon_{cs.fin}) = -2.531 \cdot 10^{-4} \quad \text{see formula (B.3) in draft norm}$$

$$C_{p,sls.fin.u} := \pi^2 \cdot \frac{E_{rc.u.fin} \cdot A_{rc} \cdot E_{0.fin} \cdot A_{CLT} \cdot a_x \cdot \gamma_{1.u.fin}}{(E_{rc.u.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT}) \cdot sp^2} = 9.808 \frac{kN}{mm} \quad \text{(B.2) in draft norm}$$

$$C_{p,sls.fin.ser} := \pi^2 \cdot \frac{E_{rc.ser.fin} \cdot A_{rc} \cdot E_{0.fin} \cdot A_{CLT} \cdot a_x \cdot \gamma_{1.ser.fin}}{(E_{rc.ser.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT}) \cdot sp^2} = 11.149 \frac{kN}{mm}$$

$$p_{sls.fin.u} := -C_{p,sls.fin.u} \cdot \gamma_{f.shrink.u} \cdot \Delta\varepsilon_{sls.fin} = 3.724 \frac{kN}{m} \quad \text{see formula (B.1) in draft norm}$$

$$p_{sls.fin.ser} := -C_{p,sls.fin.ser} \cdot \gamma_{f.shrink.ser} \cdot \Delta\varepsilon_{sls.fin} = 2.822 \frac{kN}{m}$$

$$C_{j,sls.fin.u} := \frac{p_{sls.fin.u} + p_{Ed.perm}}{\frac{E_{rc.u.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT}}{\gamma_{1.u.fin} \cdot E_{rc.u.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT}} \cdot p_{sls.fin.u} + p_{Ed.perm}} = 0.951 \quad \text{see formula (B.7) in draft norm}$$

$$C_{j,sls.fin.ser} := \frac{p_{sls.fin.ser} + p_{Ed.perm}}{\frac{E_{rc.ser.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT}}{\gamma_{1.ser.fin} \cdot E_{rc.ser.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT}} \cdot p_{sls.fin.ser} + p_{Ed.perm}} = 0.971$$

$$EI_{sls.fin.u} := EI_{eff.fin.u} \cdot C_{j,sls.fin.u} = (9.491 \cdot 10^3) kN \cdot m^2 \quad \text{see formula (B.6) in draft norm}$$

$$EI_{sls.fin.ser} := EI_{eff.fin.ser} \cdot C_{j,sls.fin.ser} = (1.031 \cdot 10^4) kN \cdot m^2$$

$$M_{perm.d.fin} := M_{ed.perm} + 0.8 \cdot (p_{sls.fin.u}) \cdot \frac{sp^2}{8} = 69.637 kN \cdot m \quad \text{see formula (B.9) in draft norm}$$

$$M_{short.d.fin} := M_{ed.short} = 27.727 kN \cdot m$$

see formula (B.12) in draft norm

$$V_{sls.fin.u} := -\pi \cdot E_{0.fin} \cdot A_{CLT} \cdot \frac{E_{rc.u.fin} \cdot I_{rc} + E_{0.fin} \cdot I_{CLT}}{(\gamma_{1.u.fin} \cdot E_{rc.u.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT}) \cdot sp \cdot a_{i.c}} \cdot \Delta\varepsilon_{sls.fin} = 0.951 kN$$

$$V_{perm.fin.u} := V_{sls.fin.u} + V_{ed.perm} = 34.123 kN$$

$$M_{c.fin.perm} := \frac{E_{rc.u.fin} \cdot I_{rc}}{EI_{sls.fin.u}} \cdot M_{perm.d.fin} = 7.226 \text{ kN} \cdot \text{m}$$

see formula (B.9) in draft norm

$$M_{c.fin.short} := \frac{E_{rc.u.fin} \cdot I_{rc}}{EI_{sls.fin.u}} \cdot M_{ed.short} = 2.877 \text{ kN} \cdot \text{m}$$

$$M_{t.fin.perm} := \frac{E_{0.fin} \cdot I_{CLT}}{EI_{sls.fin.u}} \cdot M_{perm.d.fin} = 0.247 \text{ kN} \cdot \text{m}$$

$$M_{perm.d.fin} = 69.637 \text{ kN} \cdot \text{m}$$

$$M_{t.fin.short} := \frac{E_{0.fin} \cdot I_{CLT}}{EI_{sls.fin.u}} \cdot M_{ed.short} = 0.098 \text{ kN} \cdot \text{m}$$

$$N_{perm.d.fin} := \frac{(M_{perm.d.fin} - M_{t.fin.perm} - M_{c.fin.perm})}{a_x} = 428.72 \text{ kN}$$

see formula (B.10) in draft norm

$$N_{short.d.fin} := \frac{(M_{short.d.fin} - M_{t.fin.short} - M_{c.fin.short})}{a_x} = 170.697 \text{ kN}$$

Calculation of normal stresses in concrete

$$\sigma_{N.c.fin} := \frac{-N_{perm.d.fin}}{A_{rc}} - \frac{N_{short.d.fin}}{A_{rc}} = -4.995 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{M.c.fin} := \frac{M_{c.fin.perm}}{W_{rc}} + \frac{M_{c.fin.short}}{W_{rc}} = 4.21 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{c.fin.min} := \sigma_{N.c.fin} - \sigma_{M.c.fin} = -9.205 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{c.fin.max} := \sigma_{N.c.fin} + \sigma_{M.c.fin} = -0.786 \frac{\text{N}}{\text{mm}^2}$$

$$\mu_{comp.fin} := \frac{-(\sigma_{c.fin.min})}{f_{ck} \cdot \alpha_{cc}} = 0.276$$

$$\mu_{tens.fin} := \frac{-(\sigma_{c.fin.max})}{f_{ck} \cdot \alpha_{cc}} = 0.024$$

Calculation of normal stresses in timber

$$\sigma_{N.t.fin} := \frac{-N_{perm.d.fin}}{A_{CLT}} - \frac{N_{short.d.fin}}{A_{CLT}} = -3.526 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{M.t.fin} := \frac{M_{t.fin.perm}}{W_{CLT}} + \frac{M_{t.fin.short}}{W_{CLT}} = 0.798 \frac{\text{N}}{\text{mm}^2}$$

$$\mu_{tot.fin} := \frac{-(\sigma_{N.t.fin})}{f_{t.0.k} \cdot k_{mod}} + \frac{(\sigma_{M.t.fin})}{f_{m.k} \cdot k_{mod}} = 0.507$$

Shear stresses in the shear connection due to concrete shrinkage

see formula (B.11) in draft norm

$$F_{max.fin} := \frac{\gamma_{1.u.fin} \cdot E_{rc.u.fin} \cdot A_{rc} \cdot \left(a_x - \frac{depth_{rc}}{2} \right) \cdot s_{eff}}{EI_{sls.fin.u}} \cdot (V_{perm.fin.u} + V_{ed.short}) = 33.51 \text{ kN}$$

$$F_{ax.\alpha.Rk} := \frac{f_{ax.k} \cdot d_{screw} \cdot l_{ef}}{1.2 \cdot \cos(\delta_{screw})^2 + \sin(\delta_{screw})^2} \cdot \left(\frac{\rho_k}{3.50 \frac{kN}{m^3}} \right)^{0.8} = 21.037 \text{ kN}$$

$$F_{rd} := n_{vbm} \cdot (\cos(\delta_{screw}) + 0.25 \cdot \sin(\delta_{screw})) \cdot \min \left(F_{ax.\alpha.Rk} \cdot \frac{k_{mod}}{\gamma_M}, f_{tens.k} \right) = 82.448 \text{ kN}$$

$$\mu_{screw} := \frac{F_{max.fin}}{F_{rd}} = 0.406$$

$$h = 0.134 \text{ m}$$

Shear stresses in timber due to external force

$$h := a_{2.u.fin} + \frac{depth_{CLT}}{2} = 135.937 \text{ mm}$$

$$\tau_{t.fin} := \frac{0.5 \cdot E_{0.fin} \cdot h^2}{EI_{sls.fin.u}} \cdot (V_{ed.short} + V_{ed.perm}) = 0.282 \frac{N}{mm^2} \quad \text{see formula (B.10) in EN 1995-1-1}$$

$$\mu_{tot.mid} := \frac{\tau_{t.fin}}{\frac{f_{v.k} \cdot k_{mod}}{\gamma_M}} = 0.127$$

Deflections for t=mid

$$w_{fin.tot} := \frac{5}{384} \cdot \frac{(p_{SLS.perm} + p_{SLS.short} + p_{sls.fin.ser}) \cdot sp^4}{EI_{sls.fin.ser}} = 30.911 \text{ mm}$$

$$w_{lim} := \frac{1}{250} \cdot sp = 26 \text{ mm} \quad p_{sls.fin.ser} = 2.822 \frac{kN}{m}$$

$$\mu_{w.fin} := \frac{w_{fin.tot}}{w_{lim}} = 1.189$$

Verifications of vibrations

$$q_{fin} := \frac{EI_{eff.CLT.c.fin} + E_{rc.ser.fin} \cdot I_{rc}}{EI_{sls.fin.ser}} = 0.171$$

$$f_{lim} := 8 \text{ Hz}$$

$$lim_{val} := 0.05$$

$$f_{1,fin} := \begin{cases} \text{if } q_{fin} > \text{lim}_{val} \\ \frac{\pi}{2 \cdot sp^2} \cdot \sqrt{\frac{EI_{eff,fin.ser}}{(g_{k1} + g_{k2})}} \cdot \sqrt{1 + \left(\frac{sp}{width}\right)^4} \cdot \frac{EI_{eff,CLT.c.fin} + E_{rc.ser,fin} \cdot I_{rc}}{EI_{sls,fin.ser}} \\ \text{else} \\ \frac{\pi}{2 \cdot sp^2} \cdot \sqrt{\frac{EI_{eff,fin.ser}}{(g_{k1} + g_{k2})}} \cdot \sqrt{9.81 \frac{m}{s^2}} \end{cases} = 86.45 \text{ Hz}$$

$$\mu_{vib,fin} := \frac{f_{1,fin}}{f_{lim}} = 10.806 \quad \text{Verification of vibration acceleration is not necessary because } f_{1,t0} \text{ is greater than } f_{lim}$$

Stiffness criterium

$$w_{stat,lim} := 0.25 \text{ mm}$$

$$b_{f,fin} := \min\left(width \cdot 10^3, \frac{sp}{1.1} \cdot \sqrt[4]{\frac{EI_{eff,CLT.c.fin} + E_{rc.ser,fin} \cdot I_{rc}}{EI_{sls,fin.ser}}}\right) = 3.798 \text{ m}$$

$$w_{stat,fin} := \frac{1 \text{ kN} \cdot sp^3}{48 \cdot EI_{sls,fin.ser} \cdot b_{f,fin}} \cdot m = 0.146 \text{ mm}$$

$$\mu_{stiff,fin} := \frac{w_{stat,fin}}{w_{stat,lim}} = 0.584$$

10. ULS for t=fin under fire conditions acc. to EN 1995-1-1

Loads under fire conditions

$$q_{fi} := g_{k1} + g_{k2} + \psi \cdot q_k = 7.394 \text{ m} \cdot \frac{\text{kN}}{\text{m}^2}$$

$$M_{fi} := q_{fi} \cdot \frac{sp^2}{8} = 39.05 \text{ kN} \cdot \text{m} \quad V_{fi} := q_{fi} \cdot \frac{sp}{2} = 24.031 \text{ kN}$$

$$C_{p.sls.fin.u.fi} := \pi^2 \cdot \frac{E_{rc.u.fin} \cdot A_{rc} \cdot E_{0.fin} \cdot A_{CLT.fi} \cdot a_x \cdot \gamma_{1.u.fin}}{(E_{rc.u.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT.fi}) \cdot sp^2} = 5.012 \frac{\text{kN}}{\text{mm}} \quad (\text{B.2) in draft norm}$$

$$C_{p.sls.fin.ser.fi} := \pi^2 \cdot \frac{E_{rc.ser.fin} \cdot A_{rc} \cdot E_{0.fin} \cdot A_{CLT.fi} \cdot a_x \cdot \gamma_{1.ser.fin}}{(E_{rc.ser.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT.fi}) \cdot sp^2} = 5.679 \frac{\text{kN}}{\text{mm}}$$

$$p_{sls.fin.u.fi} := -C_{p.sls.fin.u.fi} \cdot \gamma_{f.shrink.u} \cdot \Delta \varepsilon_{sls.fin} = 1.903 \frac{\text{kN}}{\text{m}} \quad \text{see formula (B.1) in draft norm}$$

$$p_{sls.fin.ser.fi} := -C_{p.sls.fin.ser.fi} \cdot \gamma_{f.shrink.ser} \cdot \Delta \varepsilon_{sls.fin} = 1.437 \frac{\text{kN}}{\text{m}}$$

$$C_{j.sls.fin.u.fi} := \frac{p_{sls.fin.u.fi} + q_{fi}}{\frac{E_{rc.u.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT.fi}}{\gamma_{1.u.fin} \cdot E_{rc.u.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT.fi}} \cdot p_{sls.fin.u.fi} + q_{fi}} = 0.935 \quad \text{see formula (B.7) in draft norm}$$

$$C_{j.sls.fin.ser.fi} := \frac{p_{sls.fin.ser.fi} + q_{fi}}{\frac{E_{rc.ser.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT.fi}}{\gamma_{1.ser.fin} \cdot E_{rc.ser.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT.fi}} \cdot p_{sls.fin.ser.fi} + q_{fi}} = 0.962$$

$$EI_{sls.fin.u.fi} := EI_{eff.fin.u.fi} \cdot C_{j.sls.fin.u.fi} = (4.304 \cdot 10^3) \text{ kN} \cdot \text{m}^2 \quad \text{see formula (B.6) in draft norm}$$

$$EI_{sls.fin.ser} := EI_{eff.fin.ser.fi} \cdot C_{j.sls.fin.ser.fi} = (5.633 \cdot 10^3) \text{ kN} \cdot \text{m}^2$$

$$M_{d.fin.fi} := M_{fi} + 0.8 \cdot (p_{sls.fin.u}) \cdot \frac{sp^2}{8} = 54.782 \text{ kN} \cdot \text{m} \quad \text{see formula (B.9) in draft norm}$$

see formula (B.12) in draft norm

$$V_{sls.fin.u.fi} := -\pi \cdot E_{0.fin} \cdot A_{CLT.fi} \cdot \frac{E_{rc.u.fin} \cdot I_{rc} + E_{0.fin} \cdot I_{CLT.fi}}{(\gamma_{1.u.fin} \cdot E_{rc.u.fin} \cdot A_{rc} + E_{0.fin} \cdot A_{CLT.fi}) \cdot sp \cdot a_{i,c}} \cdot \Delta \varepsilon_{sls.fin} = 0.54 \text{ kN}$$

$$V_{fin.u.fi} := V_{sls.fin.u.fi} + V_{fi} = 24.57 \text{ kN}$$

$$M_{c.fin.fi} := \frac{E_{rc.u.fin} \cdot I_{rc}}{EI_{sls.fin.u.fi}} \cdot M_{d.fin.fi} = 12.534 \text{ kN} \cdot \text{m} \quad \text{see formula (B.9) in draft norm}$$

$$M_{t.fin.fi} := \frac{E_{0.fin} \cdot I_{CLT.fi}}{EI_{sls.fin.u.fi}} \cdot M_{d.fin.fi} = 0.263 \text{ kN} \cdot \text{m}$$

$$N_{d.fin.fi} := \frac{(M_{d.fin.fi} - M_{t.fin.fi} - M_{c.fin.fi})}{a_{x_{fi}}} = 344.134 \text{ kN}$$

see formula (B.10) in draft norm

Calculation of normal stresses in concrete

$$\sigma_{N.c.fin.fi} := \frac{-N_{d.fin.fi}}{A_{rc}} = -2.868 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{M.c.fin.fi} := \frac{M_{c.fin.fi}}{W_{rc}} = 5.222 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{c.fin.min.fi} := \sigma_{N.c.fin.fi} - \sigma_{M.c.fin.fi} = -8.09 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{c.fin.max.fi} := \sigma_{N.c.fin.fi} + \sigma_{M.c.fin.fi} = 2.355 \frac{\text{N}}{\text{mm}^2}$$

$$\mu_{comp.fin.fi} := \frac{-(\sigma_{c.fin.min.fi})}{\frac{f_{ck} \cdot \alpha_{cc}}{\gamma_c}} = 0.243$$

$$\mu_{tens.fin.fi} := \frac{(\sigma_{c.fin.max.fi})}{\frac{f_{ct,k} \cdot \alpha_{cc}}{\gamma_c}} = 1.218$$

Calculation of normal stresses in timber

$$\sigma_{N.t.fin.fi} := \frac{-N_{d.fin.fi}}{A_{CLT.fi}} = -6.28 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_{M.t.fin.fi} := \frac{M_{t.fin.fi}}{I_{CLT.fi}} \cdot a_{x_{fi}} = 8.967 \frac{\text{N}}{\text{mm}^2}$$

$$\mu_{tot.fin} := \frac{-(\sigma_{N.t.fin.fi})}{\frac{k_{fi} \cdot f_{t.0,k} \cdot k_{mod.fi}}{\gamma_{M.fi}}} + \frac{(\sigma_{M.t.fin.fi})}{\frac{k_{fi} \cdot f_{m,k} \cdot k_{mod.fi}}{\gamma_{M.fi}}} = 0.748$$

Shear stresses in the shear connection due to concrete shrinkage

see formula (B.11) in draft norm

$$F_{max.fin.fi} := \frac{\gamma_{1.u.fin} \cdot E_{rc.u.fin} \cdot A_{rc} \cdot \left(a_{x_{fi}} - \frac{depth_{rc}}{2} \right) \cdot s_{eff}}{EI_{sls.fin.u.fi}} \cdot (V_{fin.u.fi}) = 25.872 \text{ kN}$$

$$F_{ax.\alpha.Rk} := \frac{f_{ax,k} \cdot d_{screw} \cdot l_{ef}}{1.2 \cdot \cos(\delta_{screw})^2 + \sin(\delta_{screw})^2} \cdot \left(\frac{\rho_k}{3.50 \frac{\text{kN}}{\text{m}^3}} \right)^{0.8} = 21.037 \text{ kN}$$

$$F_{rd} := n_{vbm} \cdot (\cos(\delta_{screw}) + 0.25 \cdot \sin(\delta_{screw})) \cdot \min\left(F_{ax.\alpha.Rk} \cdot \frac{k_{mod}}{\gamma_M}, f_{tens.k}\right) = 82.448 \text{ kN}$$

$$\mu_{screw.fi} := \frac{F_{max.fin.fi}}{F_{rd}} = 0.314$$

Shear stresses in timber due to external force

$$h_{fi} := a_{2.u.fin.fi} + \frac{depth_{CLT} - d_{ef}}{2} = 138.476 \text{ mm}$$

$$\tau_{t.fin.fi} := \frac{0.5 \cdot E_{0.fin} \cdot h_{fi}^2}{EI_{sls.fin.u.fi}} \cdot (V_{fin.u.fi}) = 0.316 \frac{\text{N}}{\text{mm}^2}$$

see formula (B.10) in EN 1995-1-1

$$\mu_{tot.fin.fi} := \frac{\tau_{t.fin.fi}}{\frac{k_{fi} \cdot f_{v.k} \cdot k_{mod.fi}}{\gamma_{M.fi}}} = 0.069$$

11. Estimation of sound insulation properties of TCC floor

$$m_{CLT} := depth_{CLT} \cdot \rho_k \cdot \frac{1}{g} \cdot \frac{m^2}{kg} = 72.808$$

$$m_{rc} := depth_{rc} \cdot \rho_{rc} \cdot \frac{1}{g} \cdot \frac{m^2}{kg} = 293.678$$

Airborne sound insulation

$$R_{w,tot.rc} := \min(32.4 \cdot \log(m_{rc}) - 26, 37.5 \cdot \log(m_{rc}) - 42) = 50.545$$

$$R_{w,tot.CLT} := \min(20.3 \cdot \log(m_{CLT}), 12.2 \cdot \log(m_{CLT}) + 15) = 37.719$$

$$R_{w,tot} := R_{w,tot.rc} + R_{w,tot.CLT} = 88.264$$

Footfall sound insulation (equivalent normalized impact sound pressure level)

$$L_{n,w.eq} := (164 - 35 \cdot \log(m_{rc})) + (128 - 22 \cdot \log(m_{CLT})) = 164.657$$