LVL Handbook
EUROPE

Finnish Woodworking Industries

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Leading Expert
Wooden Structures
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Finnish Woodworking Industries

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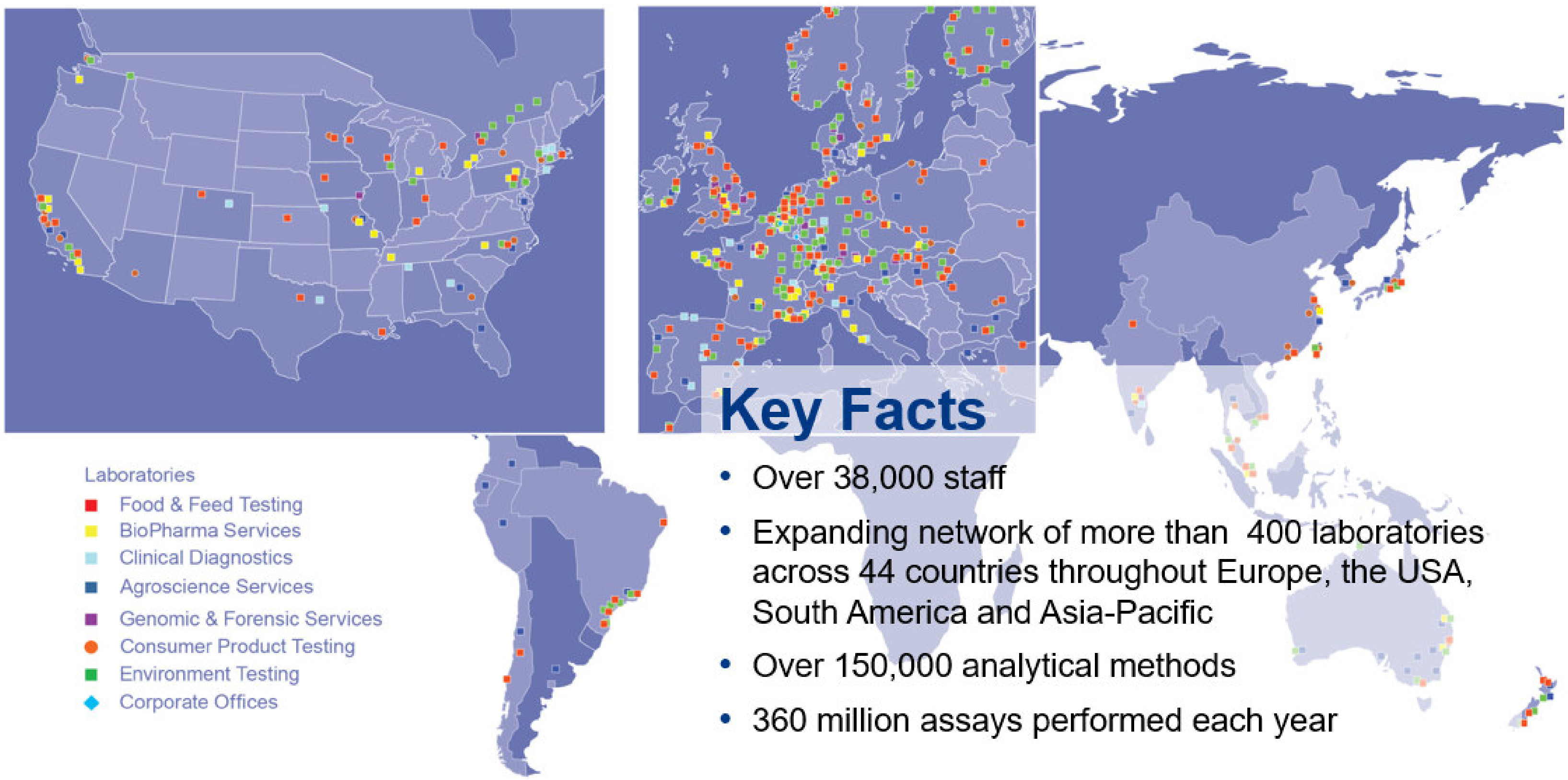

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- Sections 1 – 3 are intended for all users (pages 1 - 111)
- Sections 4 – 9 are intended for designers (pages 112 – 213)

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1 LVL as a construction material

Introduction of LVL-P and LVL-C

Figure 1.3 LVL-P beams.

1.1.1 LVL-P beams and columns – all veneers in the length direction

LVL-P is made of 3 mm veneers laid in the same direction and bonded with weather- and boil-resistant phenolic adhesive. This structure enhances the material's strength properties that have significantly small deviation. LVL-P members can be used both as horizontal beams and vertical posts in various applications in construction systems. Erection and installation can be carried out without heavy machinery, even in confined spaces.

LVL-P beams are produced from the highest strength grade veneers to optimized beam dimensions and a height-to-thickness ratio that provides good material efficiency. LVL-P beams have an excellent strength-to-weight ratio allowing long spans with minimal deflection.

LVL-P studs are perfect for load-bearing or non-load-bearing structures in external and internal walls. LVL-P studs are easy to install, screw, drill, nail and cut. LVL studs are produced from lighter grade veneers, but their dimensional accuracy, structural strength and rigidity, straightness, and lack of twisting make them ideal for wall structures [1, 2].

Table 1.1. Applications of LVL-P.

Beams	Features and benefits
• Headers, main beams, ridge beams • Lintels • Floor joists • Roof rafters • Purlins • Trusses • Frames • Components for roof and floor elements • Sole and top plate • Beam reinforcements **Studs** • Wall studs for internal walls • Wall studs for external walls • Load-bearing and non-load-bearing-applications **Industrial applications** • Support structures and moulds for concrete formwork • Scaffolding • Door- and window frames • Furniture components • Packaging industry	• Strong and rigid: long spans with minimal deflection • Straight and dimensionally stable, does not warp or twist: improves construction quality; ideal for walls, also high constructions • Dry from factory: minimal shrinkage in situ • Customized product dimensions, with minimum waste: Applications in a wide variety of building types; savings in material costs and time • Great workability: easy to install, staple, nail, drill and cut without special tools • Excellent strength-to-weight ratio: Light structures • Light: easy to handle and lift manually or with light cranes • Can be used with any panel material: suitable for a wide variety of structures • Easy to combine with other structures and materials in a wide range of building types

Figure 1.4 LVL-C roof panels.

1.1.2 LVL-C with cross-bonded veneers for robust structural panels

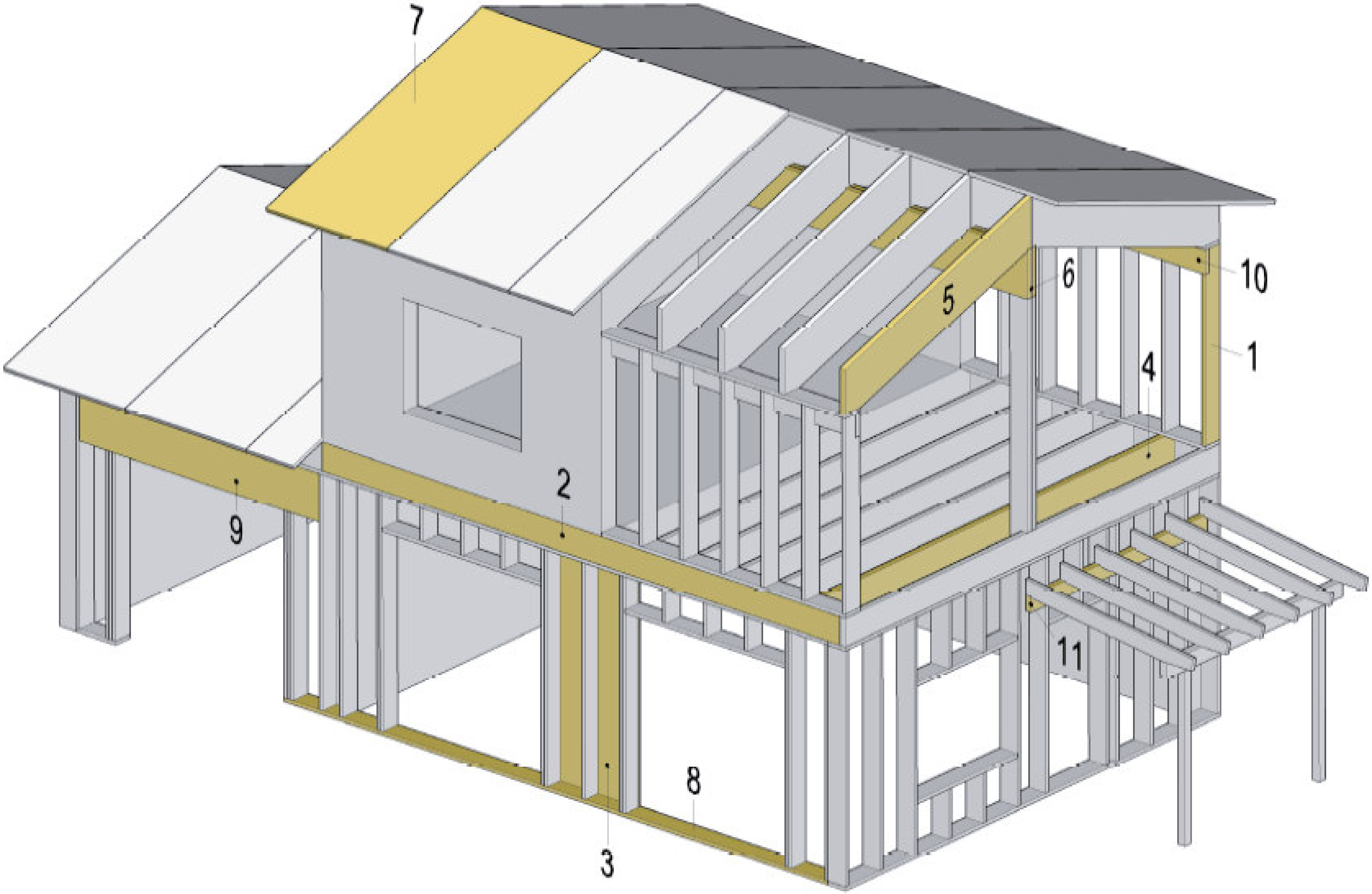
LVL-C panel is a cross-bonded panel product with approximately 20% of the veneers glued in a crosswise direction. This enhances the transverse strength and stiffness and the connection ductility of the panel. It is dimensionally stable, as the cross veneers prevent shrinkage and swelling in the event of moisture changes in the panel width direction. LVL-C panels or beams can be used as both horizontal and vertical bearers in numerous construction applications. It is designed for use as a large-dimension load-bearing panel, as well as for structural bracing and stabilizing. LVL-C panel is an ideal component for floor, wall and roof elements, roof and wall panels, and pre-fabricated houses. The panels can be cut to tailored sizes and special shapes for modern timber structures [1, 2].

Figure 1.5 LVL-C panels.

Table 1.2. Applications for LVL-C.

Panel applications	Features and benefits
• Large panel product for roof, floor and wall constructions • Roof overhangs • Pre-fabricated roof, floor and wall elements and modules • Stresses-skin panel elements • Door panels **Other applications** • Rim boards • High rafter beams • High lintels and header beams • Frames and truss members • Reinforcement of old structures • Curved components, free-form beams and panels (CNC machining) • Concrete formwork	• Strong and rigid: long spans with minimal deflection • Large dimensions: applications in a wide variety of building types • Installation efficiency: large panel for floors, roofs and walls covers vast areas much faster than normal size wood-based panels reducing the amount of lifting required on the construction site. • High and thin beams: energy efficient constructions • Straight and dimensionally stable; does not warp or twist: improves construction quality • Dry from factory: minimal shrinkage in constructions • Customized product dimensions and shapes with minimum waste: applications in a wide variety of building types; savings in material costs and time on construction site • Excellent strength-to-weight ratio: light structures • Great workability: easy to install, staple, nail, drill and cut without special tools • Ductility of connections: improved safety • Strong and rigid in edgewise compression perpendicular to grain direction: better building quality with minimal deformation, suitable for narrow supports • Not sensitive to cracking under tension perpendicular to grain stressed structures: safe connections • Bracing of different size buildings, regardless of frame material: applications in a wide variety of building types; large window openings possible.

1.2 Where can you use LVL



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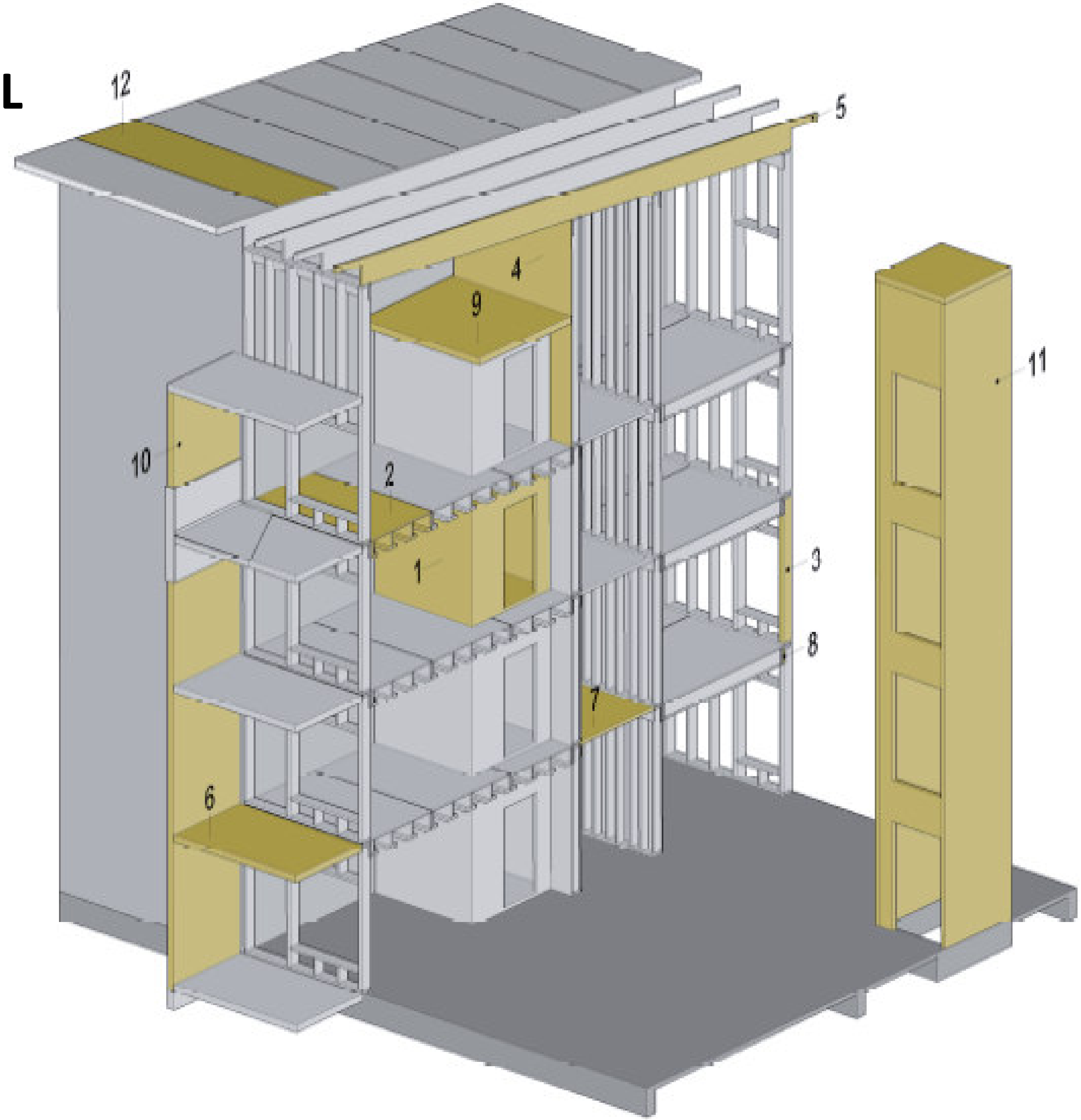
Where can you use LVL



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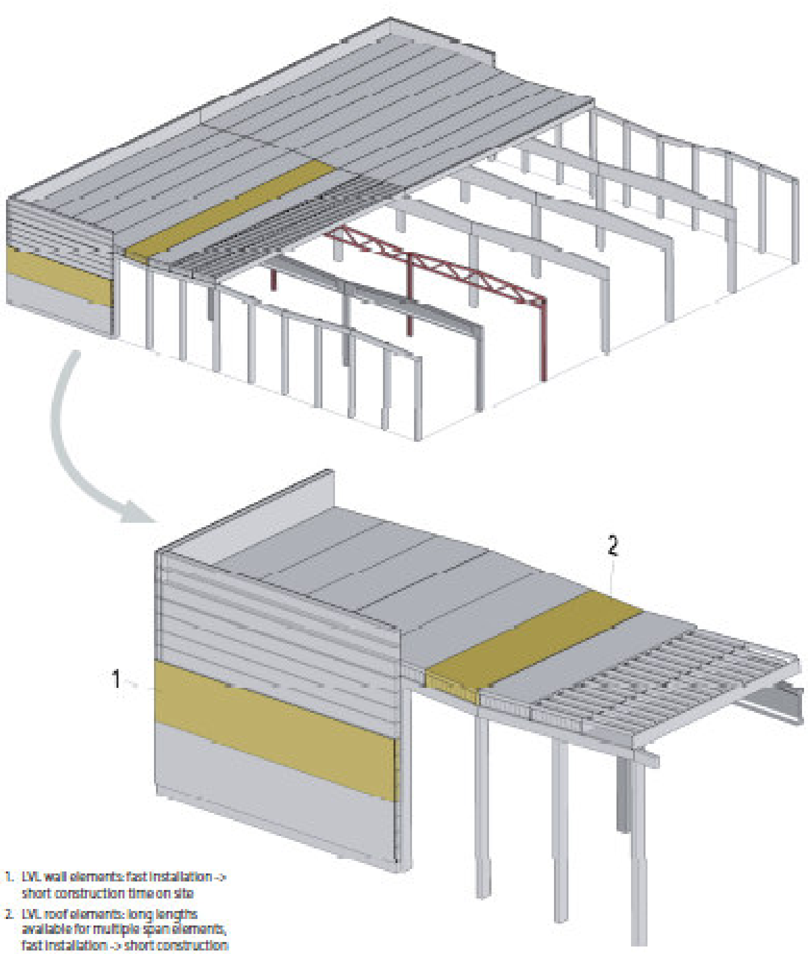
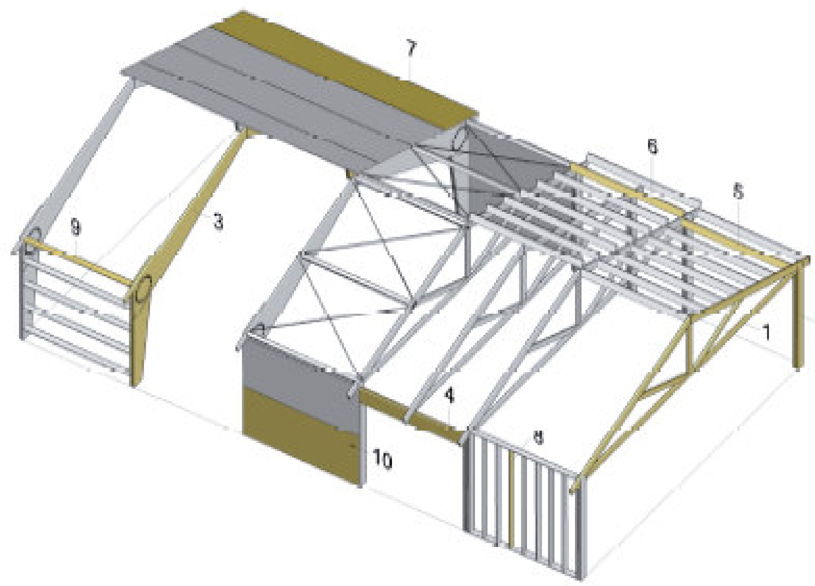
Where can you use LVL

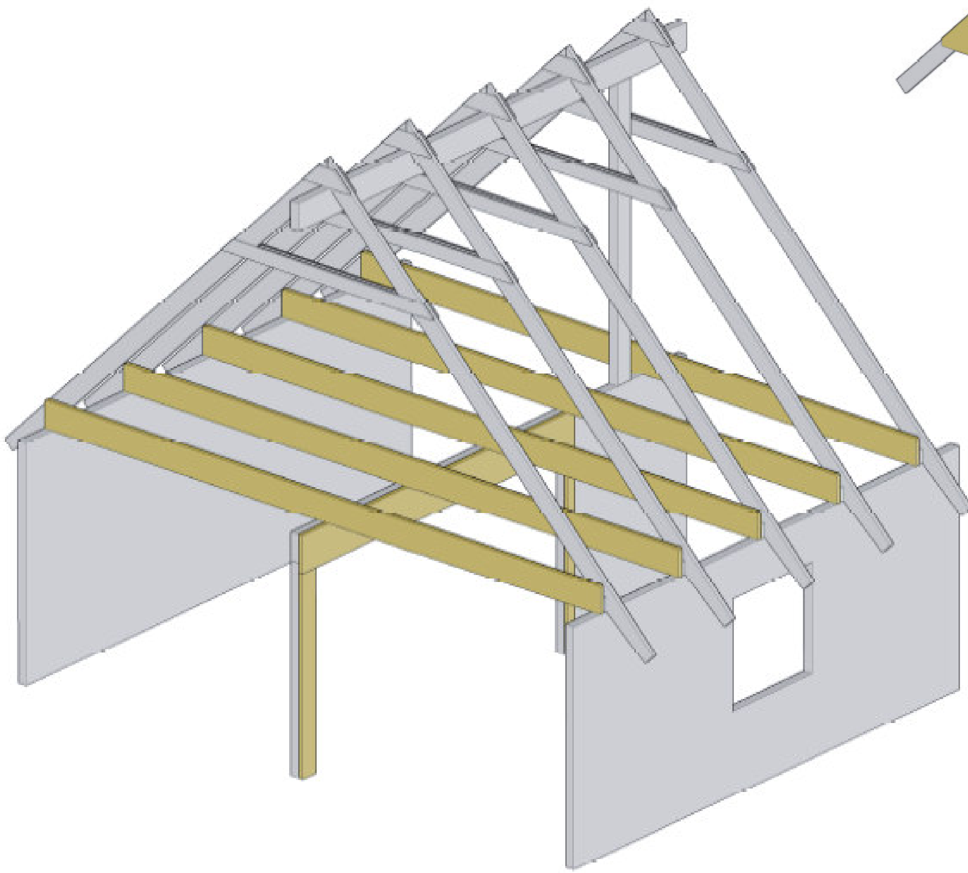


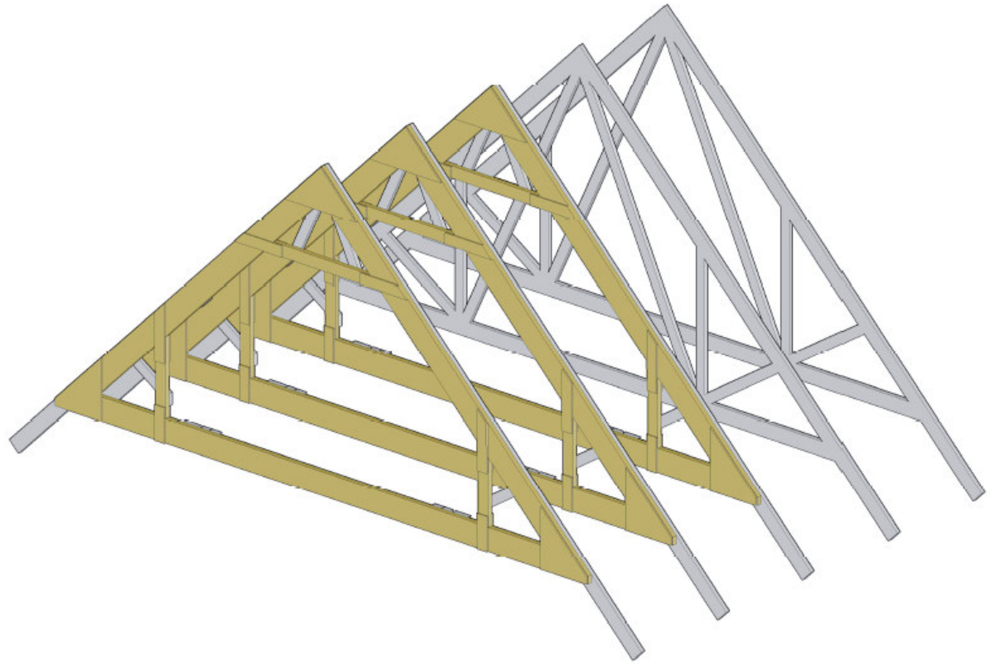
1. LVL wall elements: fast installation -> short construction time on site
2. LVL roof elements: long lengths available for multiple span elements, fast installation -> short construction time on site. Glued box slab elements for long spans.



1. LVL king post or queen post roof trusses: impressive appearance.
2. LVL columns: fit together with LVL roof trusses.
3. LVL-P and LVL-C portal frames: large clear height.
4. LVL lintels for door and window openings: strong and rigid.
5. LVL-P purlins, single-span: strong and rigid.
6. LVL-P purlins, multiple span: long lengths available.
7. LVL-C bracing panels for roofs: simple and robust.
8. LVL-P studs for high walls: straight and precise.
9. LVL-P horizontal beams for walls: large spacing between main frames.
10. LVL-C bracing panels for walls: simple and robust structure.

Where can you use LVL





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History, volumes and raw material efficiency of LVL

1.4 HISTORY, VOLUMES AND RAW MATERIALS OF LVL

1.4.1 History of the globally used engineered wood product LVL

Parallel oriented plywood products have been used in the furniture industry since the beginning of the 20th century. The history of LVL in its present form dates back to 1970s North America and the research and development of veneer-based wooden beams by Peter Koch and the USDA Forest Products Laboratory. The first commercial solution for manufacturing LVL was created by Al Troutner of the company Trus-Joist (Weyerhaeuser). In 1975, Finnish company Metsäliiton Teollisuus Oy (Metsä Wood) developed the first commercial LVL production line in Europe. Metsäliitto went on to develop its own manufacturing concept, which was further developed by another Finnish company, Raute Oyj, which is today the leading LVL machinery supplier worldwide. LVL production has since grown continuously and today LVL is manufactured in ten countries on four continents with a total production capacity of around 4 million cubic metres per year across 30 locations. In addition, a number of small plants produce LVL that does not meet the requirements of structural LVL [4].

Figure 1.13 LVL-P beam and LVL-C panels.

Table 1.3. Global LVL production. Active manufacturers of structural LVL produce about 3.9 million cubic metres per year [4,5].

Europe			North America			Asia & Oceania		
Manufacturer	Mills	Capacity 1000 m³/year	Manufacturer	Mills	Capacity 1000 m³/year	Manufacturer	Mills	Capacity 1000 m³/year
Metsä Wood	2	300	Boise Cascade	3	890	JNL	2	140
Steico	1	160	Weyerhaeuser	4	530	Carter Holt Harvey	1	100
Stora Enso	1	100	Louisiana Pacific	2	260	Nelson Pine	1	100
MLT	1	100	Pacific Woodtech	1	220	First plywood	1	100
Pollmeier	1	80	Roseburg	1	200	Wesbeam	1	60
LVL Ugra	1	40	Forex Amos Inc.	1	140	Keyteck	1	60
			Murphy	1	120	Shin Yang	1	20
			West Fraser	1	90			
			RedBuilt	1	70			
			Global LVL	1	20			
Total	7	780		16	2540		8	580

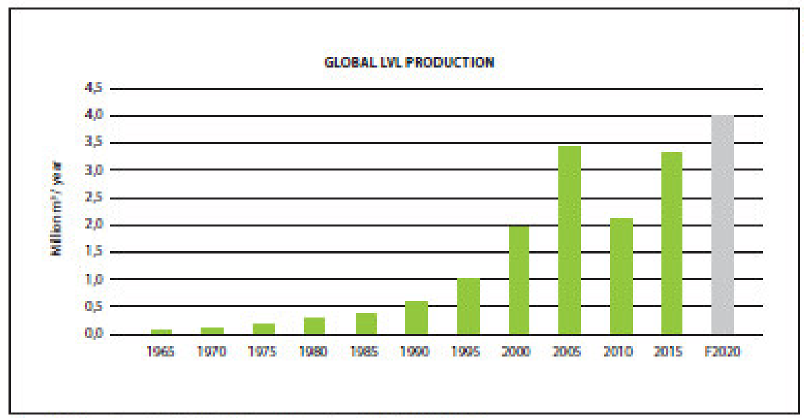


Figure 1.14 Development of structural LVL production volume globally 1965 – 2020 [5].

1.5 Sustainable building with LVL

1.5.2 Sustainable over the life cycle

Wood products offer renewable and sustainable solutions for construction. Wood as a renewable material has a lower global warming impact compared to alternative, non-renewable building materials. The infinite carbon cycle between the atmosphere, growing trees and wood products distinguishes renewable wood from non-renewable materials.

Life cycle assessment (LCA) is a holistic approach for assessing environmental impacts throughout a product's or system's life cycle, from extraction of raw materials to disposal of the product. The principles of LCA have been internationally agreed and standardized with the ISO 14040 and ISO 14044 standards, which enables third-party verification of life cycle calculations. LCA compiles and evaluates the inputs, outputs and potential environmental impacts of a product or system throughout its life cycle. LCA helps manufacturers to identify opportunities to improve the environmental and climate performance of a product and to inform customers and stakeholders. LCA includes four steps; defining of the goal and scope, inventory of material and energy flows, assessment of impacts, and interpretation of results.

Environmental performance of buildings and building products

The European standard series 'Sustainability of Construction Works' (CEN/TC 350) guides the assessment of the sustainability of buildings and building products. The standard series aims to enhance the supply and demand of products and buildings that have as low environmental impact as possible. Environmental assessment of a building is based on the life cycle approach, in which each of the different stages of the building's life cycle are included and assessed (Figure 1.17).

At the product and service level, the environmental product declaration (EPD) applies the life cycle assessment approach and presents quantified environmental information over a product's life cycle. EPDs enable comparison between different products with the same functional purpose at the building level. In the case of LVL, the comparison is most appropriately done at the structure type level, e.g. structures with the same load carrying capacity and stiffness. The EN 15804 standard provides product category rules (PCR) for an environmental product declaration for any construction product or construction service (Table 1.4). Biogenic carbon content calculation rules are provided in the EN 16485 standard.

The most used environmental indicator of EPDs is global warming potential (GWP), also known as carbon footprint. The GWP reflects the amount of greenhouse gas emissions in each stage of a product's life cycle and is mainly the outcome of fossil fuel use in the raw material supply stage and energy use in the production stage (A1–3).

At the building level, the EN 15978 standard provides systematic calculation rules for the assessment of the environmental performance of new and existing buildings. The environmental performance of wooden buildings derives from their light weight (compared to other building materials), energy efficiency of materials and buildings, life-time carbon storage in wood, and their renewable and sustainable origin. Wooden buildings typically achieve the same service time as other buildings, typically 50–100 years. Up to 100 years or longer service time is achievable with proper design and optimized maintenance.

Table 1.4. Life cycle stages of building environmental assessment based on EN 15978.

	Life cycle stages	Module	
Building life cycle information	Product stage	A1	Raw material supply
		A2	Transport
		A3	Manufacturing
	Construction process stage	A4	Transport
		A5	Construction installation process
	Use stage	B1	Use
		B2	Maintenance
		B3	Repair
		B4	Replacement
		B5	Refurbishment
		B6	Operational energy use
		B7	Operational water use
	End of life stage	C1	De-construction, demolition
		C2	Transport
		C3	Waste processing
		C4	Disposal
Additional information outside the system boundary	Potential benefits and loads	D	Reuse, recovery, recycling potential

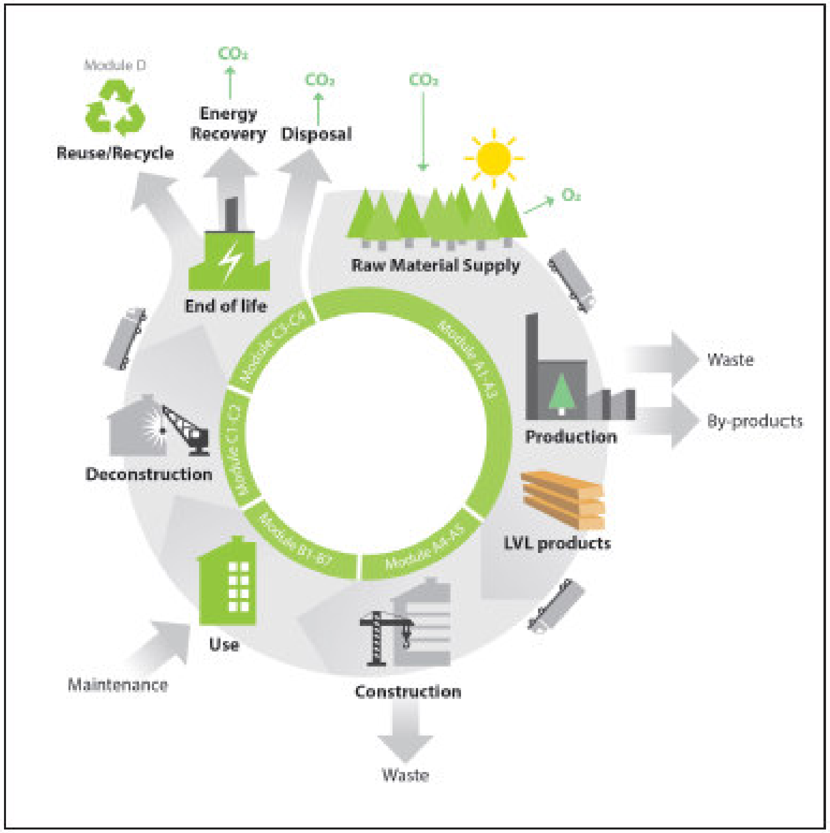


Figure 1.17 Life cycle approach of building product assessment.

1.5 Sustainable building with LVL

1.5.3 Global Warming impact of LVL

In the manufacture of LVL, a large share of renewable energy is used (see Figure 1.18), resulting in lower fossil greenhouse gas emissions and global warming potential compared to other building materials. In addition, LVL stores biogenic carbon, which constitutes about one half of the dry weight of the wood. The biogenic carbon remains in the LVL throughout its lifetime until it is released back to the atmosphere to be absorbed by the next generation of growing trees.

The global warming potential of LVL when used in a load-bearing structure of a building has been determined by LVL producers as follows:

- Raw materials extraction and energy use are similar in different production units, but different energy mixes are used depending on the unit and country. Energy mix affects the greenhouse gas emissions of the production stage (modules A1–3). Biogenic carbon content is given separately.
- Construction stage (A4–5) covers transportation to the Central European market and normal construction works.
- Use stage (B1–7) is considered negligible.
- End of life stage C1–4 scenarios consider utilization of LVL as a source of energy.
- Module D, other benefits, originate mainly from the bio-energy substitution effect, compared to typical local energy mix, when LVL is used for bioenergy at end of life.

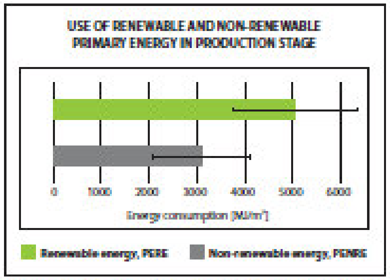


Figure 1.18 Primary energy (renewable and non-renewable) use in the manufacturing stage (A1–A3) of LVL [3,7,8].

Biogenic Global Warming Potential is the sum of stored biogenic carbon in the production stage and release of biogenic carbon in the end of life stage. The sum is close to zero for the whole life cycle.

Consolidated results for fossil global warming potential show that the production stage (A1–3) constitutes 90% of the result (Figure 1.19). The construction stage (A4–5) constitutes 10%, and end of life stage (C1–4) constitutes 2.5% of the fossil GWP. In module D the GWP benefits are shown as the amount of fossil fuels substituted by biomass energy.

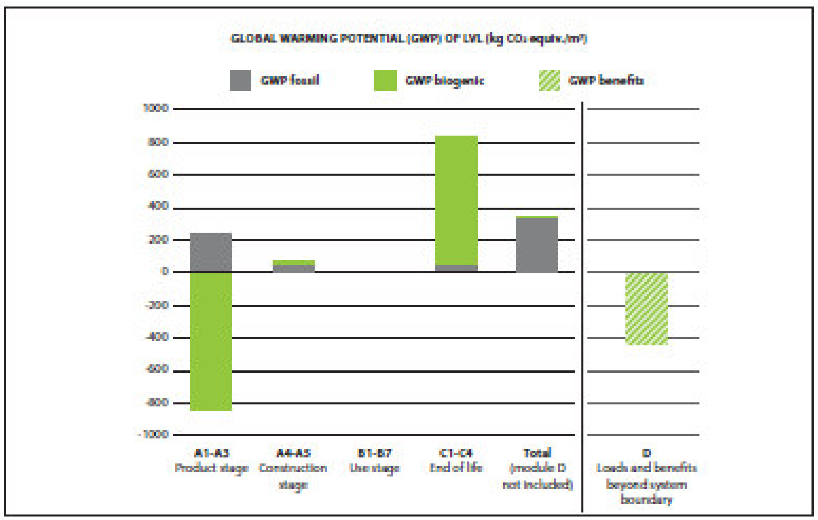


Figure 1.19. Example global warming potential of different life cycle stages [3,7,8].

1.5.4 Global warming impact of buildings

The life cycle of a building covers all life cycle stages from 'cradle to grave' as well as, optionally, also the benefits and loads beyond the building's life cycle. These life cycles stages are presented as modules A1–C4 + D (Figure 1.17). The environmental performance of a wood-frame building, and a concrete-frame building were assessed based on a generic Finnish building type (a 4-storey residential building) [9,10]. The assessment was done according to the EN 15978 standard, with the specific assumptions presented in Table 1.5.

The global warming potential of the whole life cycle and beyond is 798 kg CO_2e/m^2 for a wood-frame building and 1022 kg CO_2e/m^2 for a concrete-frame building (Figure 1.20).

Table 1.5. Scenarios of a wooden frame building and a concrete frame building [9,10].

	Concrete-frame	Wood-frame
System boundary	4-storey residential building, gross floor area 1922 brm², concrete structure, wooden roof structure, all technical installation included (HVAC, piping, electricity), energy supply based on average Finnish heat and electricity	4-storey residential building, gross floor area 1922 brm², first floor concrete structure, other floors wood structures, all technical installation included (HVAC, piping, electricity), energy supply based on average Finnish heat and electricity
Reference period	50 years	50 years
Service life	Windows replaced once	Windows replaced once, external cladding (wood) painting every 10th year
End of life	Concrete: crushing and recycling for ground construction Wood: chipping and energy recovery	Concrete: crushing and recycling for ground construction Wood: chipping and energy recovery
Benefits and loads beyond system boundary (module D)	Concrete: carbonization Wood: bioenergy carbon emissions compared to natural gas emissions	Concrete: carbonization Wood: bioenergy carbon emissions compared to natural gas emissions

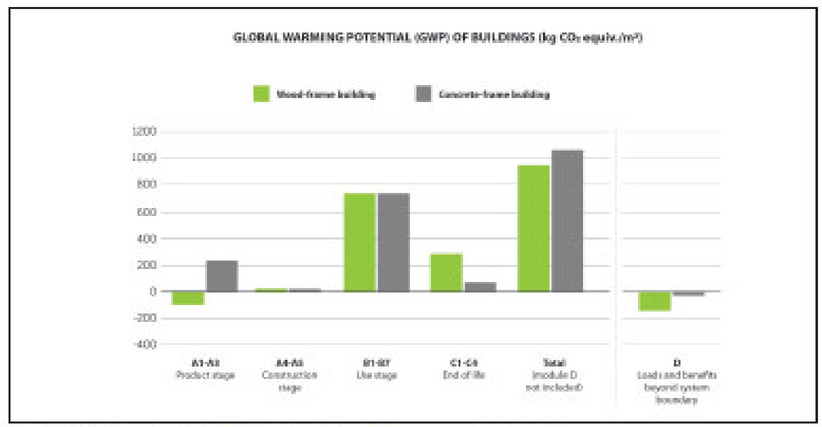


Figure 1.20. Global warming potential (GWP) of a wood-frame building vs. a concrete-frame building [10].

1.6 Production of LVL

The LVL production process is subject to strict quality standards and audited by inspectors to ensure the final product is safe to use and meets the specified end use requirements. LVL is made by gluing and layering wood veneers to produce a homogenous wood panel. The process distributes any natural defects in the wood raw material evenly throughout the product, eliminating any individual points of weakness. The following simplified production diagram illustrates the LVL production process inside the mill.

Veneer logs are delivered from the forest to the mill at a specified length. The logs are debarked, conditioned, and cut to blocks. On the peeling line, the veneer block is turned to produce a veneer mat. The green veneer is clipped to size and then dried, graded and composed when necessary. Glue is then applied on the top side of each veneer and the veneers are staggered to form a LVL billet. In hot-pressing, the glue cures and binds the veneers together. Finally, the formed LVL panel is edge trimmed or cut to size (e.g. to a specific beam width) before stacking and packaging.

For every cubic metre of LVL about 2,5 m^3 of logs (measured over bark) are processed, which is a similar raw material yield to plywood production. The LVL production process thus delivers more by-products than final product. None of these by-products go to waste. They are sold and used in pulp, fibreboard and other wood-based products, for energy production, and for decorative purposes. Glue residues are reused inside the mill.

Figure 1.21. Composition of LVL, from veneer mat to cut-to-size panel.

1.6.1 Logs to blocks

To maintain high raw material quality, veneer logs are transported to the LVL mill immediately after harvesting. At the mill site, the log piles are sprayed with water to avoid drying and cracking and attack by pests.

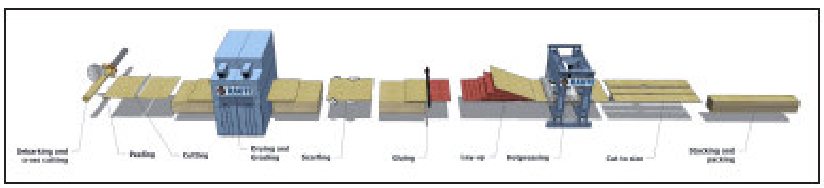


Figure 1.22. The LVL production process.

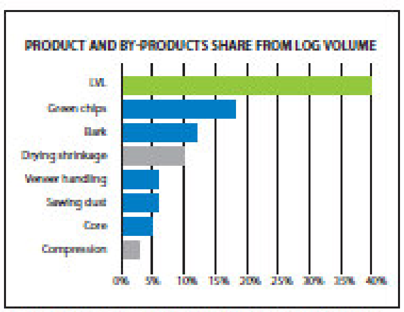


Figure 1.23. Log use distribution by volume: LVL and by-products (incl. shrinkage and compression losses).

Figure 1.24. Harvesting of logs.

automatic saw line and transferred to the debarker. The debarker removes the bark down to the cambium so that the blocks are free of bark. During debarking, damage to the peeler block surface is carefully avoided, as the most valuable veneer qualities are obtained from the outermost layers of the wood during peeling.

The conditioning increases the internal temperature of the blocks and makes the wood softer for peeling. In northern winter conditions the logs are thawed by soaking them in covered and heated conditioning chambers.

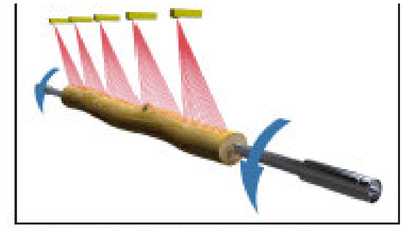


Figure 1.26. XY centring device with laser scanning

1.6.2 Blocks to veneer

A jack-ladder lifts the blocks one by one to the charger for XY centering. The block charger plays a key role in optimizing raw material utilization and the value of the veneer yield. To recover the maximum amount of veneer from the block, the block is optimally aligned between the lathe spindles using high precision laser measurement.

In the lathe, the peeler block is rotated between the spindles at a constant speed while the knife carriage moves toward the block core. For LVL production, the typical nominal thickness for softwood veneer is 3 mm. According to EN14374, the maximum thickness of veneers in structural LVL is 6 mm. The veneer is peeled through the gap between the peeler knife and the overhead nose bar. The knife gap is smaller than the veneer thickness to ensure sufficient compression and high-quality veneer.

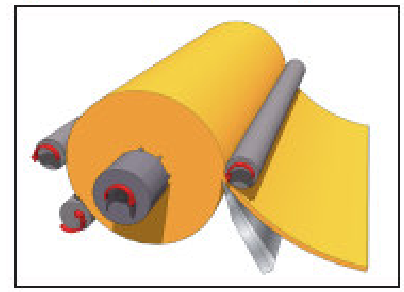


Figure 1.27. Peeling method

Figure 1.25. Peeler blocks being lifted from a conditioning chamber.

1.7 Further processing

1.7 FURTHER PROCESSING

LVL manufacturers offer further processing of their products according to customer specifications as value-added services. This is done either directly at the mill or by subcontractors equipped with special machinery for LVL processing. The value-added services save time and minimize waste for the customer and on the building site.

1.7.1 Sanded surfaces: optical or calibration sanding

Standard LVL is delivered unsanded. It can, however, be sanded with two alternative specifications. The visual appearance of LVL can be improved by optical sanding, which cleans and smoothens the surface by removing dark glue stains and equalizing local colour differences of the veneers. Optical sanding can be carried out on one or both sides and reduces the thickness of the product by approximately 2 mm (1 mm per surface). In visible applications it must be noted that on the front face of the LVL member the scarf-joints of the surface veneers are glued with colourless glue, but on the bottom side the scarf-joint glue line is dark brown, similar to the glue lines between veneers [11].

Another sanding treatment that can be performed is calibration sanding for thickness calibration, which is carried out on both sides of the LVL. Calibration sanding reduces the thickness of the product by approximately 3 mm (1.5 mm per surface) and the thickness tolerance after calibration is ± 0.5 mm. Unless a non-transparent coating is used on the surfaces, calibration sanding is not recommended for visible applications because it can sand through the surface veneers revealing the dark glue line, especially in thicker products.

The nominal sanded dimensions of the product must be used in structural design calculations.

Figure 1.46. Appearance of LVL veneer surface 1. Unsanded face side. 2. Optical sanded face side. 3. Calibration sanding revealing the dark glue line.

1.7.2 Special cutting

LVL panels or beams can be sawn to special shapes or sawn diagonally to produce tapered beams or columns. Manufacturers may also have special cutting tolerances for tailored products, e.g. of industrial customers.

Figure 1.47. Principle of diagonal sawing of LVL panel to produce single-tapered column and rafter members of portal frames.

1.7.3 CNC Machining

CNC machining enables drillings, holes, notches and end sloping of beams. The machining requires a geometry file of the members from the customer, e.g. a DWG drawing at 1:1 scale drawn with closed lines for each different type of member to be machined.

Figure 1.48. Holes in LVL panels.

Figure 1.49. LVL-P roof beam cut to special shape.

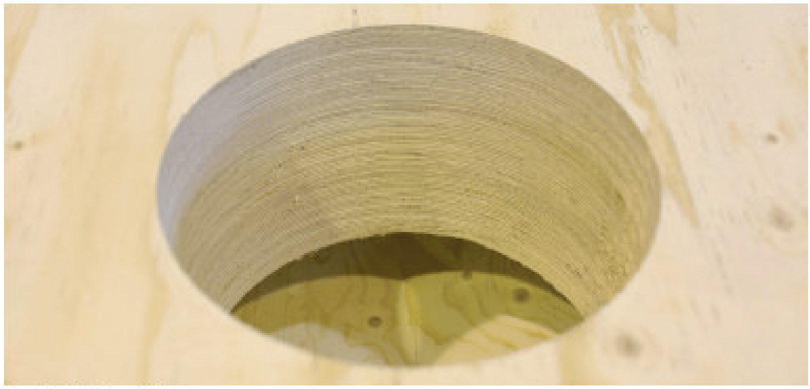


Figure 1.50. Hole in an LVL beam.

1.8 LVL layups and standard sizes

Table 1.6. Nominal product thicknesses and layups of LVL-P and LVL-C.

Thickness [mm]	Number of veneers	Layup of LVL-P	Layup of LVL-C	Number of cross veneers in LVL-C
24	8	IIIIIIII	II-II-II	2
27	9	IIIIIIIII	II-III-II	2
30	10	IIIIIIIIII	II-IIII-II	2
33	11	IIIIIIIIIII	II-IIIII-II	2
39	13	IIIIIIIIIIIII	II-III-III-II	3
42	14	IIIIIIIIIIIIII		-
45	15	IIIIIIIIIIIIIII	II-IIII-IIII-II	3
48	16	IIIIIIIIIIIIIIII		-
51	17	IIIIIIIIIIIIIIIII	II-IIIII-IIIII-II	3
57	19	IIIIIIIIIIIIIIIIIII	II-III-IIIII-III-II	4
63	21	IIIIIIIIIIIIIIIIIIIII	II-III-III-III-III-II	5
69	23	IIIIIIIIIIIIIIIIIIIIIII	II-IIII-III-III-IIII-II	5
75	25	IIIIIIIIIIIIIIIIIIIIIIIII	II-IIII-IIII-IIII-IIII-II	5

Table 1.7. Standard sizes of LVL-P beams.

Beam thickness [mm]	Beam height [mm]										
	200	220	225	240	260	300	360	400	450	500	600
27	■	■									
33	■	■	■	■	■						
39	■	■	■	■	■	■	■				
42	■	■	■	■	■	■	■				
45	■	■	■	■	■	■	■				
48	■	■	■	■	■	■	■				
51	■	■	■	■	■	■	■	■			
57	■	■	■	■	■	■	■	■	■		
63	■	■	■	■	■	■	■	■	■	■	
69	■	■	■	■	■	■	■	■	■	■	
75	■	■	■	■	■	■	■	■	■	■	■

1.9 LVL tolerances

Stora Enso

Figure 1.60. Straight and accurate LVL-P beams.

1.9 TOLERANCES

The tolerances of LVL members are defined in FprEN 14374:2018 and depend on the member sizes. The tolerance values are shown in Table 1.9 and the dimension definitions in Figure 1.61.

Table 1.9. Maximum deviations from nominal sizes and nominal angles for LVL, unsanded and not pressure treatment (FprEN 14374:2018).

Nominal sizes		Maximum deviations
Thickness *t*	*t* ≤ 27 mm	± 1 mm
	27 mm < *t* ≤ 57 mm	± 2 mm
	t > 57 mm	± 3 mm
Width *b*	*b* ≤ 300 mm	± 2 mm
	300 mm < *b* ≤ 600 mm	± 3 mm
	b > 600 mm	± 0.5%
Length *l*	*l* ≤ 5 m	± 5 mm
	5 m < *l* ≤ 20 m	± 0,1%
	l > 20 m	± 20 mm
Maximum deviation α of the right angles of the cross section, see Figure 1.61		1:50 (approx. 1,1°)

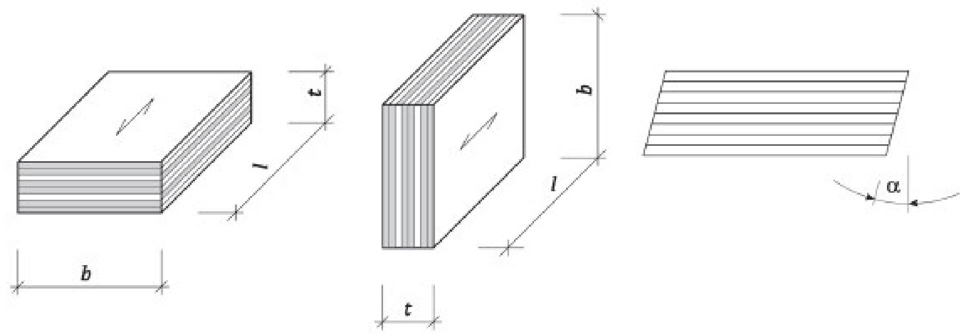


Figure 1.61. Dimensions of LVL. b = width (H=height), l = length, t = thickness. Arrow shows the grain direction of the surface veneer. Bottom: Example of the angle α deviation from the right angle of a cross section of LVL.

CE-marking, certification and design tools

1.10 CE MARKING AND CERTIFICATION OF LVL PRODUCTS

Structural LVL has its own harmonized European Standard, EN 14374, which provides the basis for mandatory CE marking and Declaration of Performance (DoP) of LVL products. Structural elements e.g. stressed skin panels made of LVL can be CE marked based on supplier specific European Technical Assessments (ETA).

As a glued engineered wood product for load-bearing applications, structural LVL has high requirements for assessment and verification of constancy of performance (AVCP). European Commission decision 97/176/EC defines AVCP System 1 for structural LVL and the requirements of the AVCP System 1 are defined in the construction product regulations (CPR) of the European Union (Regulation (EU) 305/2011, Annex V amended by Commission Delegated Regulation (EU) No 568/2014). In the AVCP System 1 a notified product certification body decides on the issuing, restriction, suspension or withdrawal of the certificate of constancy of performance of the construction product on the basis of the outcome of the following assessments and verifications carried out by that body 12:

- An assessment of the performance of the construction product carried out on the basis of testing (including sampling) to determine the bonding strength (glue bond quality) and reaction to fire of the product.
- Initial inspection of the manufacturing plant and of factory production control
- Continuing surveillance, assessment and evaluation of factory production control covering e.g. the essential strength characteristics.

To fulfil the requirements of AVCP System 1, LVL manufacturers must carry out:

- Testing or assessment of essential characteristics relevant for the intended uses which are declared (modulus of elasticity, bending strength, compression strength, tension strength, release of formaldehyde and durability)
- Factory production control
- Further testing of samples taken at the manufacturing plant by the manufacturer in accordance with the prescribed test plan
- Declaration of performance (DoP) of the LVL products
- CE marking of the LVL products

Requirements for building products are set at the national level. DoPs and CE marking provide harmonized means of showing compliance with these requirements with respect to the properties included within the scope of the harmonized product standards. Based on these properties the structural LVL products can be designed in accordance with the Eurocode design standards system for load-bearing structures.

Note: LVL products treated against fire and biological attack cannot be CE marked according to EN 14374:2004, since the treatments are currently not included in the scope of the standard.

LVL products may also have other voluntary certificates for properties that are not included in the CE marking and DoPs, such as building physics properties, emissions, or certain nationally required design parameters. Examples of such certificates are the Eurofins Product Certificate, the M1 emission certificate in Finland, and Allgemeine Bauartgenehmigung in Germany.

Figure 1.62. Left: Example of CE-mark label in LVL package, right: Example of CE-mark label in LVL product.

Figure 1.63. Design software for LVL structures: Calculatis by Stora Enso, Finnwood by Metsä Wood and portal of BIM objects by ProdLib.

1.11 DESIGN TOOLS

LVL structures are designed with similar computer-aided design tools to other load-bearing construction materials. Some structural calculation programs that support Eurocode compliant design also include LVL product libraries, but usually the user needs to enter the LVL product-specific properties into the software database. Examples of structural calculation software are Autodesk Robot Structural Analysis, Dlubal RF Timber, Frilo HO11+ and Mitek Roofcon/Truscon. Some of their design results, e.g. support reaction capacity, however need to be verified manually as they do not include all of the LVL-specific parameters for EN 1995 (Eurocode 5). The definition of LVL strength classes in product standard EN 14374 will guide software development in the future. LVL manufacturers are also specifying the properties of their product brands individually and also providing tailored calculation software, such as Finnwood® and Calculatis®.

For basic structural drawings 2D design tools such as Autodesk AutoCad are commonly used. More detailed LVL component information can be utilized with 3D building information modelling (BIM). In addition to the planning phase of the project, BIM supports the whole building process from cost and construction management to facility operation and the whole life cycle of the building. LVL suppliers have created BIM libraries of LVL components for the Autodesk Revit, Archicad, Vertex BD, HSB Cad, Cad Works and Trimble SketchUp design software environments, among others. The libraries are distributed, for example, via manufacturers' websites or portal program tools such as ProdLib 13, 14.

Design software can create steering files for CNC machines used for cutting LVL components (CAM) to improve the efficiency of the whole manufacturing process. HSBCad and Vertex BD softwares, for instance, have a strong position in integrated chain support, from design to off-site manufacture.

The IFC file transfer formats 2x3 and ifc4 support some basic properties of engineered wood products and the next generation formats will take these better into account. For example, due to the orthotropic properties of the products it is important to be able to accurately define their orientation (lengthwise, edgewise, flatwise parallel to surface veneer and flat across the surface veneer) in the IFC objects.

Basic properties of LVL

1.12.1 Strength and stiffness properties

LVL has homogeneous material properties, firstly, due to the breakdown and uniform distribution of natural defects, such as knots, in the product and, secondly, due to the effect of lamination, which further eliminates their impact. Strength grading of the veneers also reduces variation within each strength class of the product. This results in strength levels that are close to defect-free wood for the highest LVL grades and, due to low variation, the characteristic 5% fractal values used in structural design are also high.

LVL-P has the highest strength and stiffness properties parallel to grain. LVL-C has about 20% lower values parallel to grain due to its cross-bonded veneers, but is stronger and stiffer perpendicular to the grain direction of the surface veneer, properties which can be utilized in panel structures. Table 1.11 presents the basic mechanical properties of the typical strength classes of LVL.

The variation in bending strength and stiffness properties for LVL is typically less than 10% compared to 12-20% for glulam and plywood and 15-30% for structural timber. Therefore, the characteristic 5% fractile values of non-LVL materials for structural design are significantly lower [16]. Table 1.12 compares the basic mechanical properties of some common structural wood products.

For more information on the mechanical properties of LVL, see Section 4.2.

1.12.2 Building physics properties

Moisture

LVL products are delivered from the factory at a moisture content (MC) of 8-10%, which is close to the MC of service class 1 end uses. This significantly reduces initial dimensional changes due to moisture in structures if the members are protected against weather exposure. LVL swells when its moisture content increases and shrinks when its moisture content decreases [18].

The extent of these dimensional changes depends on the grain direction and the product type. Table 1.10. shows an example dimensional change for a 3% increase in moisture content. LVL-C undergoes a much smaller change in beam height because the cross veneers efficiently prevent movement in the height direction.

Untreated wood surfaces are hygroscopic, meaning that they absorb moisture from humid air and release moisture to the surrounding air when the RH is low. This moisture buffering phenomenon may be useful for improving the indoor air quality of buildings.

Thermal properties

LVL has a thermal conductivity λ of about 0,13 W/mK depending on its density and moisture content, and a specific heat capacity cp of 1600 J/(kg K) according to EN ISO 10456.

Thermal expansion of LVL is negligible and its dimensions remain stable during temperature changes. Therefore, temperature variation does not need to be considered in structural design, unlike swelling and shrinkage due to moisture changes.

For further information on building physics, see Chapter 8.

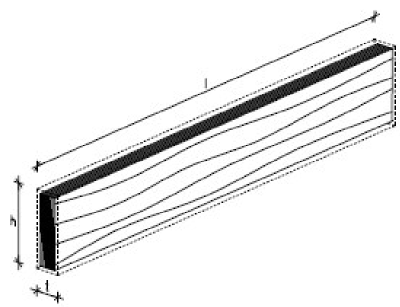


Figure 1.64. Dimensional changes due to increased moisture content.

Table 1.10. Example dimensional changes due to a 3% increase in moisture content (MC) %.

Product type	Direction	Original dimension	Dimension after +3% increase in MC	Difference
LVL-P	Length *l* [mm]	5000	5001,5	+1,5 mm
	Thickness *t* [mm]	57	57,5	+0,5 mm
	Height *h* [mm]	260	262,6	**+2,6 mm**
LVL-C	Length *l* [mm]	5000	5001,5	+1,5 mm
	Thickness *t* [mm]	57	57,5	+0,5 mm
	Height *h* [mm]	260	260,3	**+0,3 mm**

Table 1.11. Basic mechanical properties of common LVL strength classes.

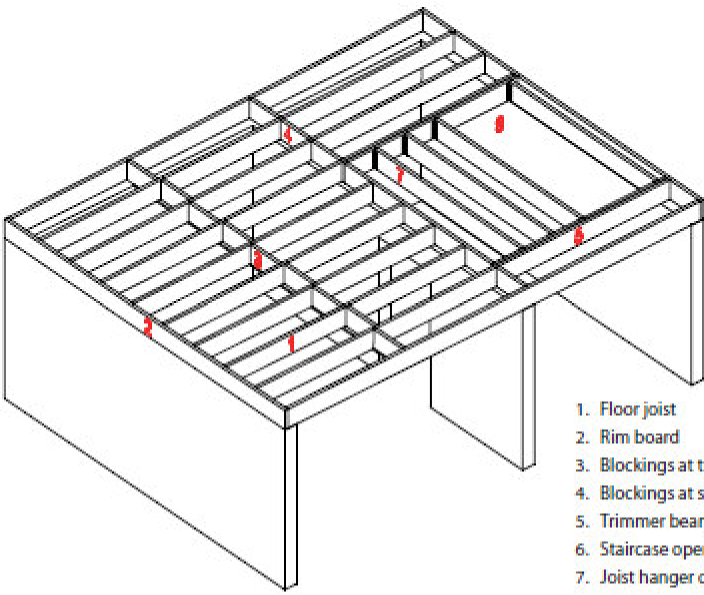
Typical use		LVL 48 P Beam	LVL 32 P Stud	LVL 36 C Panel	LVL 25 C Panel
Characteristic strength values, N/mm²					
Bending strength edgewise, h = 300 mm	$f_{m,0,edge,k}$	44	27	32	20
Bending strength flatwise	$f_{m,0,flat,k}$	48	32	36	25
Bending strength flatwise perpendicular to grain	$f_{m,90,flat,k}$	-	-	8	-
Compression parallel to grain	$f_{c,0,k}$	29	21	21	15
Compression perpendicular to grain edgewise	$f_{c,90,edge,k}$	6	4	9	8
Tension parallel to grain	$f_{t,0,k}$	35	22	22	15
Shear edgewise parallel to grain	$f_{v,edge,0,k}$	4,2	3,2	4,5	3,6
Shear flatwise parallel to grain	$f_{v,flat,0,k}$	2,3	2,0	1,3	1,1
Size effect parameter	s, [-]	0,15	0,15	0,15	0,15
Mean stiffness values, N/mm²					
Modulus of elasticity parallel to grain	$E_{0,mean}$	13800	9600	10500	7200
Modulus of elasticity perpendicular to grain in flatwise bending	$E_{m,90,mean}$	-	-	2000	-
Shear modulus edgewise	$G_{0,edge,mean}$	600	500	600	500
Density, kg/m³					
Mean value	ρ_{mean}	510	440	510	440
Characteristic value	ρ_k	480	410	480	410

Table 1.12. Basic mechanical properties of common structural wood products.

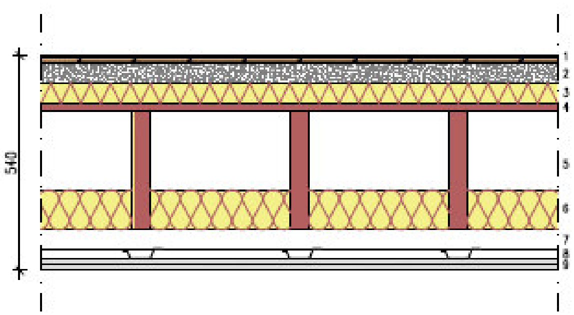
Typical use		Sawn timber C18 (EN 338:2016) Beam / stud	Glulam GL24h (EN 14080:2013) Beam	Spruce plywood 21 mm [17] Panel
Characteristic strength values, N/mm²				
Bending strength	$f_{m,0,k}$	18	24	20,6
Bending strength flatwise perpendicular to grain	$f_{m,90,flat,k}$	-	-	12,8
Compression perpendicular to grain	$f_{c,90,k}$	2,2	2,5	-
Shear parallel to grain	$f_{v,k}$	3,4	3,5	3,5
Mean stiffness values, N/mm²				
Modulus of elasticity parallel to grain	$E_{0,mean}$	9000	11500	8230
Modulus of elasticity perpendicular to grain in bending	$E_{m,90,mean}$	-	-	3770
Density, kg/m³				
Mean value	ρ_{mean}	380	420	460
Characteristic value	ρ_k	320	385	400

Section 2. LVL structures in floors, walls, roofs and in special applications

LVL Beam & Joist floors



1. Floor joist
2. Rim board
3. Blockings at the centre of a span
4. Blockings at support
5. Trimmer beam
6. Staircase opening, trimmer connection
7. Joist hanger connection



COMPARTMENT FLOOR
STRUCTURAL LAYERS

1. Flooring
2. Cast floor 50 mm
3. Impact sound insulation 50 mm
4. 18 mm plywood
5. 45x300 LVL joist c/c 400
6. 100 mm mineral wood insulation
7. Support battens c/c 400
8. Resilient bars c/c 400
9. Plasterboard 2x 15 mm

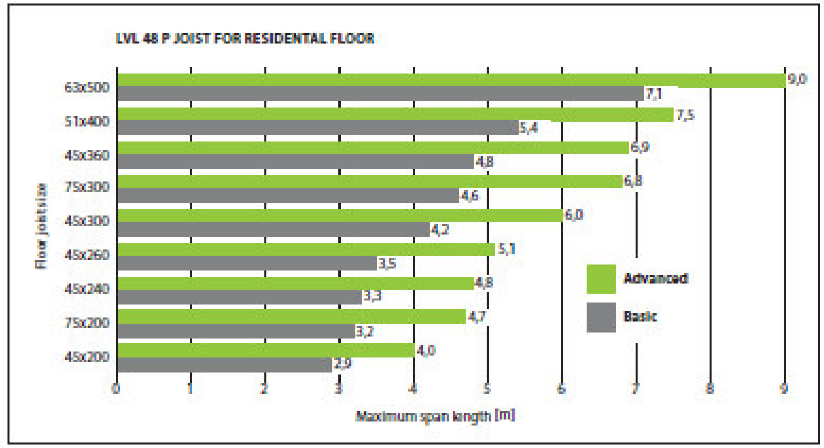


Figure 2.7. Maximum span lengths of LVL 48 P floor joists for predesign of residential floors. 2,0 kN/m² live load, 0,3 kN/m² partition load and 0,5 kN/m² self-weight. The **basic** option has c/c400 mm joist spacing, 22 mm chipboard decking without gluing and no transverse bracings. The **advanced** option has transverse bracing, glued deck panel and 45x45 c/c 400mm cross batten underneath the joists. Lowest natural frequency f_1 > 8 Hz and maximum deflection under 1kN point load is 0,5 - 0,8 mm depending on the span length (FI NA requirement for EN1995-1-1).

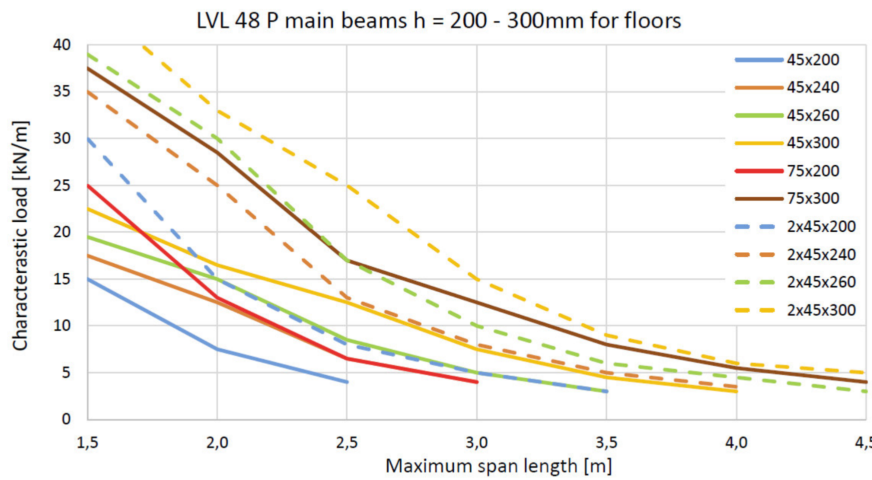
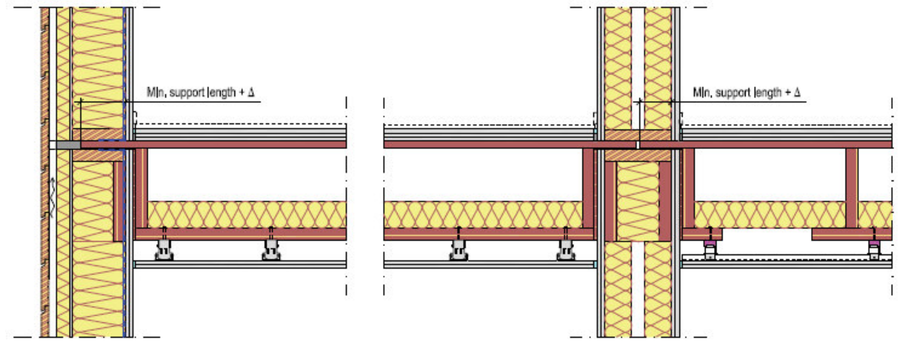
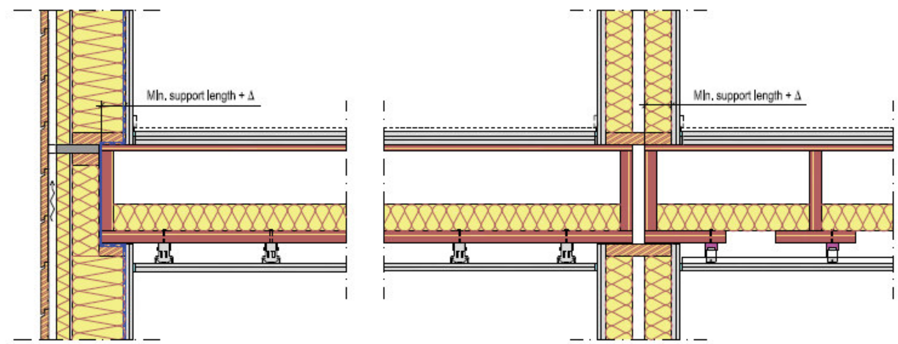


Figure 2.11. Span and capacity table of LVL 48 P main beams for predesign of floor structures. Calculations according to EN 1995-1-1:2004+A1:2008 and its Finnish National Annex. The permanent load is 20% of the characteristic load kN/m². The service class is 1 or 2 and the consequences class is CC2. The rafter has lateral torsional buckling supports on the top surface with spacing ≤ 600 mm and the loads are located at the lateral torsional buckling supports. The support length shall be calculated separately. The initial deflection w_{inst} ≤ L/400 and net final deflection $w_{net,fin}$ ≤ L/300. γ_M = 1.2. The table does not replace project-specific structural design. Double beams are calculated as separate beams in lateral torsional buckling.

Structurally glued LVL rib slabs floor structures

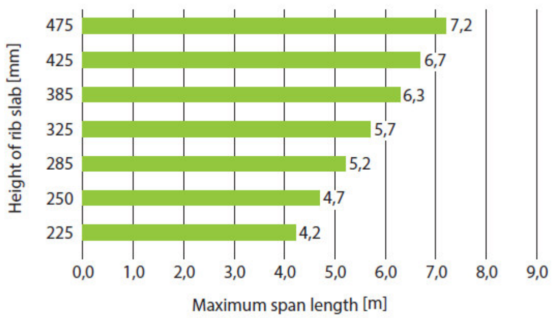


A

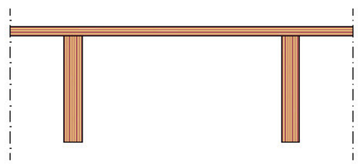


B

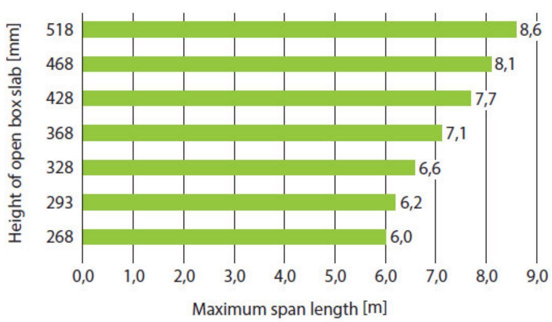
LVL RIB SLAB FLOORS



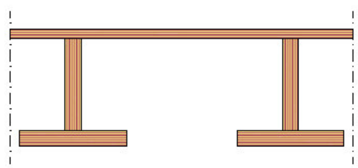
T-section with 25 mm LVL 36 C top slab and 51 x 200-450 mm LVL 48 P ribs in 612 mm spacing.



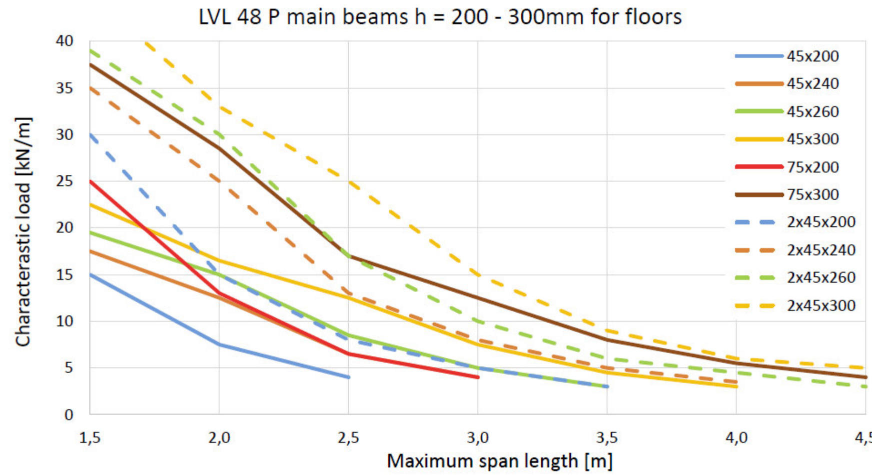
LVL OPEN BOX SLAB FLOORS

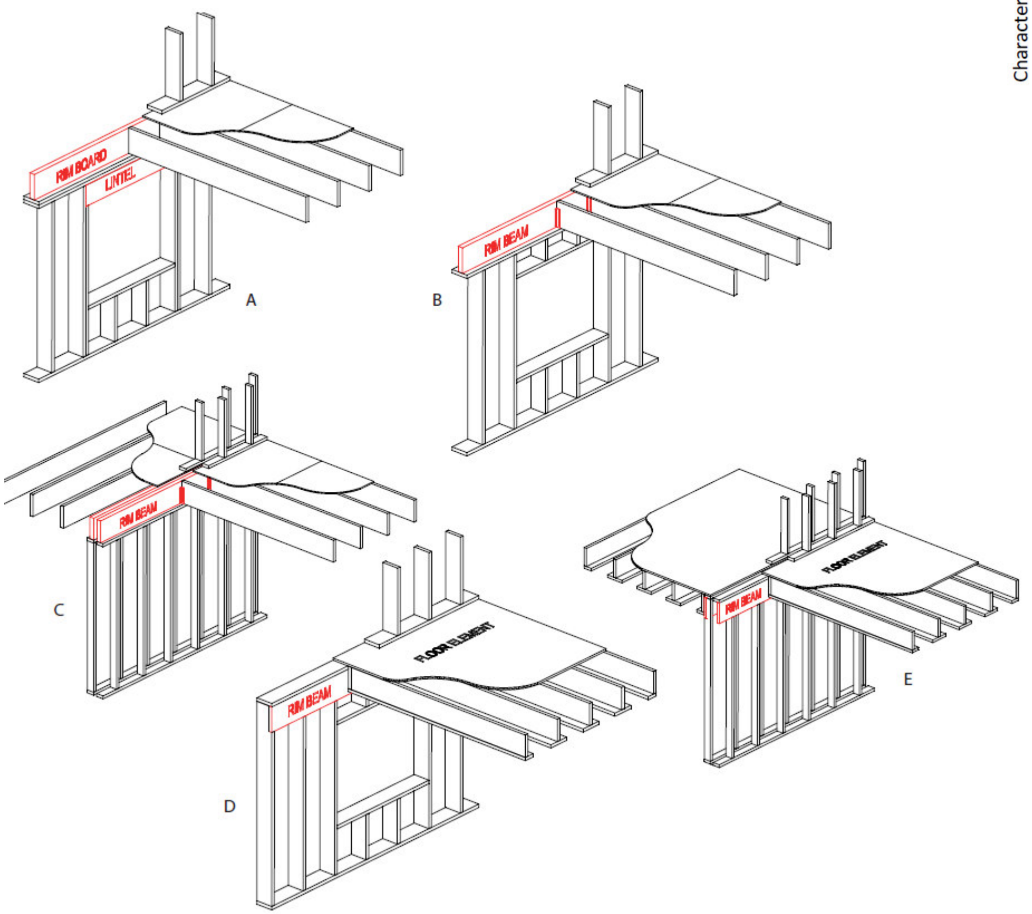


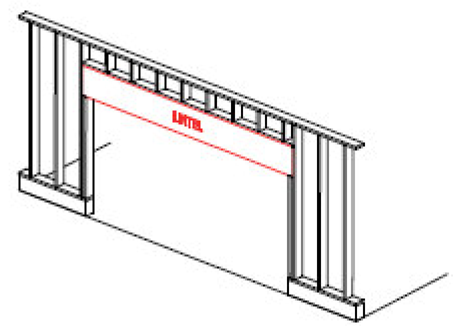
Open box section with 25 mm LVL 36 C top slab, 45 x 200-450 mm LVL 48 P ribs in 612 mm spacing and 43x300 mm sanded LVL 48 P bottom flange.

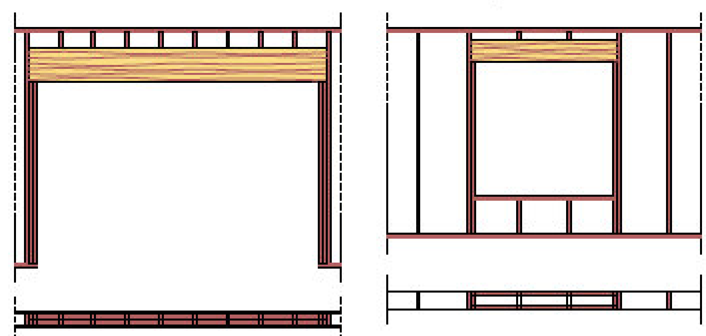


LVL Rim beams and Lintels









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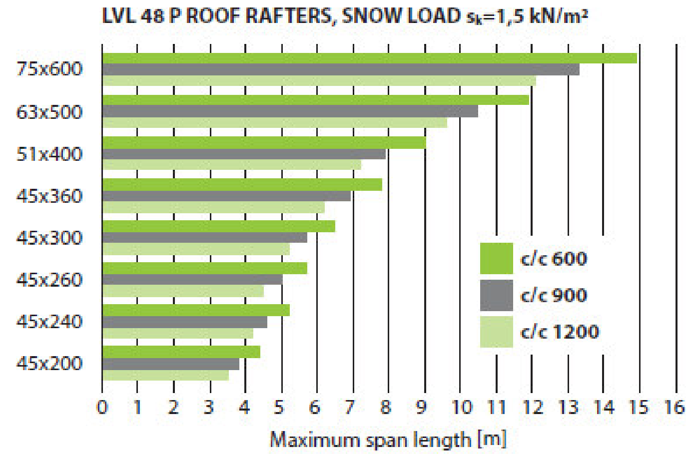
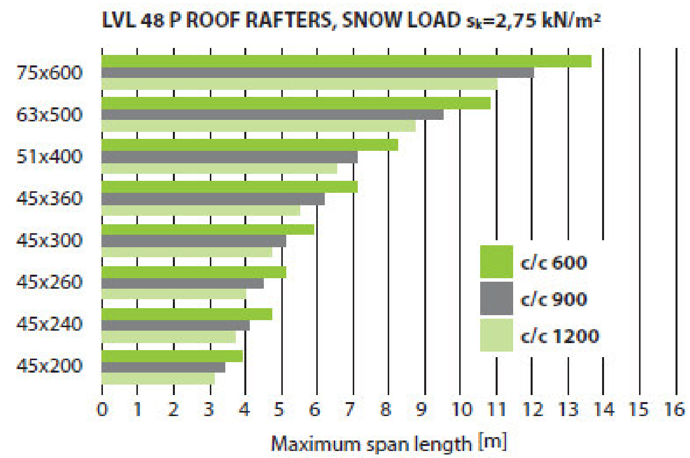
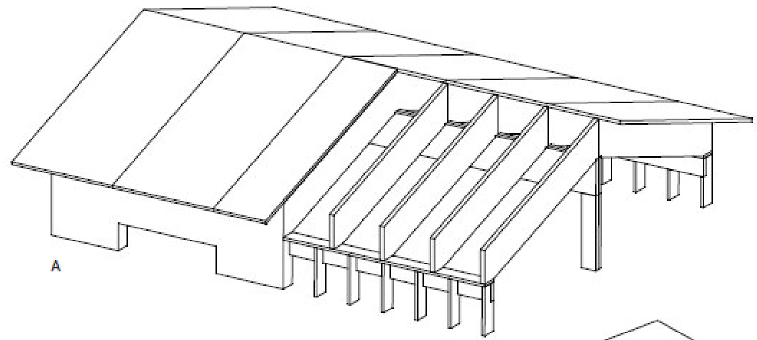
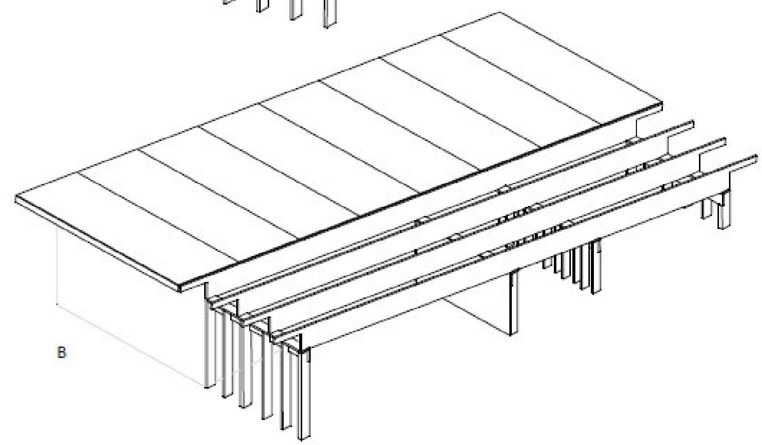
Finnish Woodworking Industries

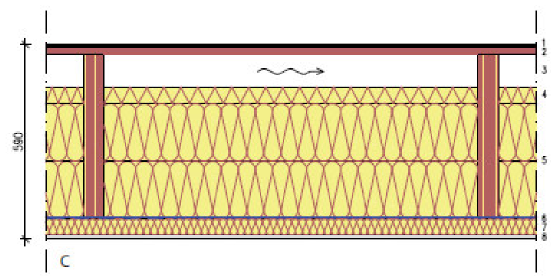
Roof rafters

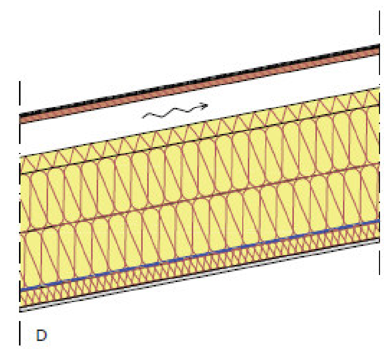








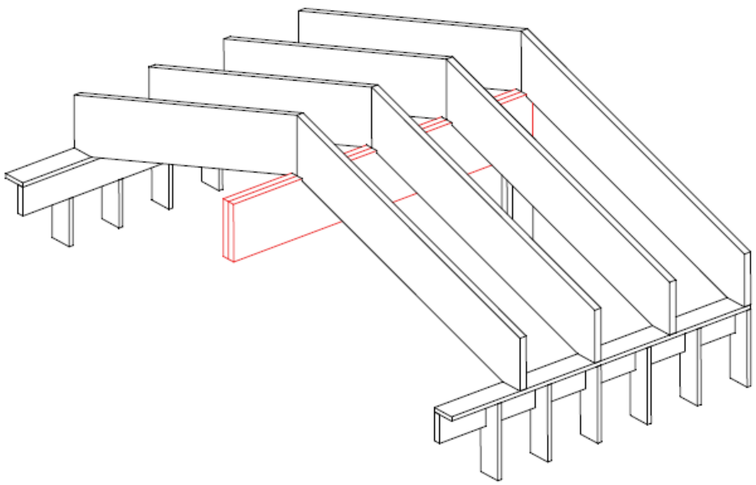


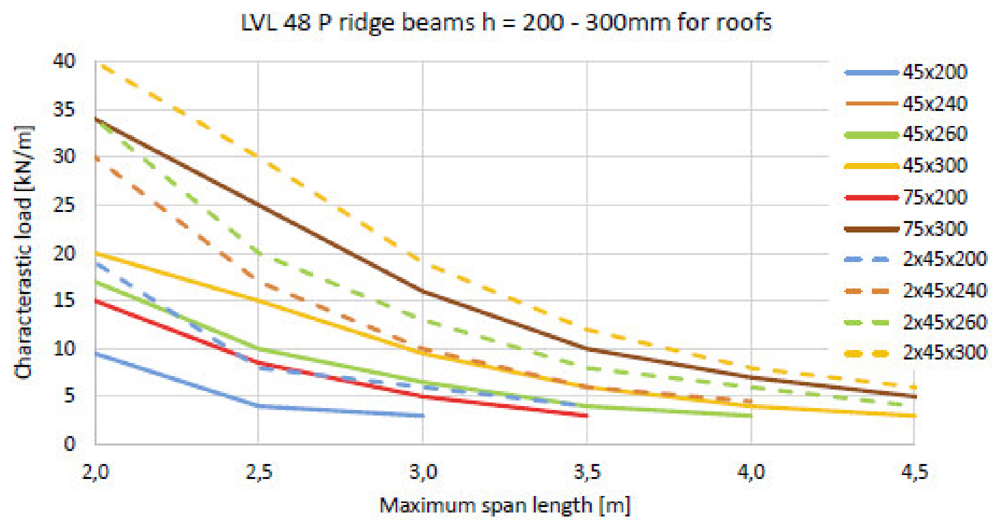


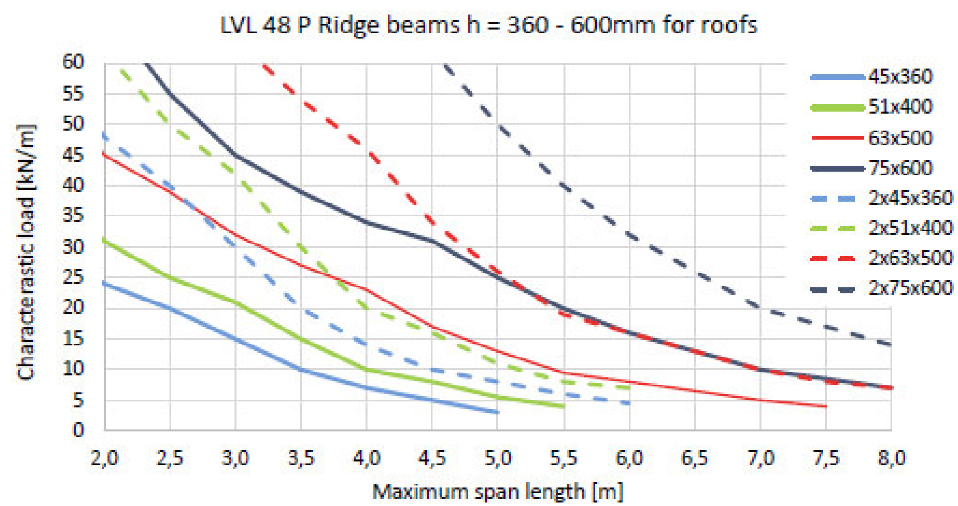
STRUCTURAL LAYERS

1. Roofing
2. 21 mm plywood
3. Air gap 100 mm
4. 50 mm windproof layer + insulation
5. 63x500 LVL 48 P beams c/c 1200 + 350 mm mineral wool insulation
6. Water vapor membrane
7. 48x48 solid wood cross-battens + 48 mm mineral wool insulation
8. Ceiling paneling

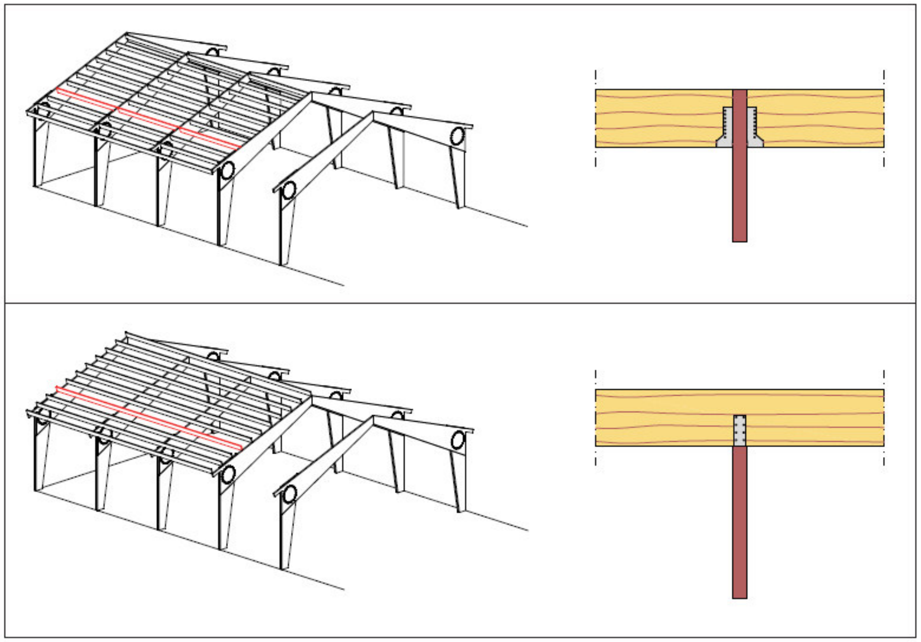
LVL Roof ridge beams







LVL Purlins



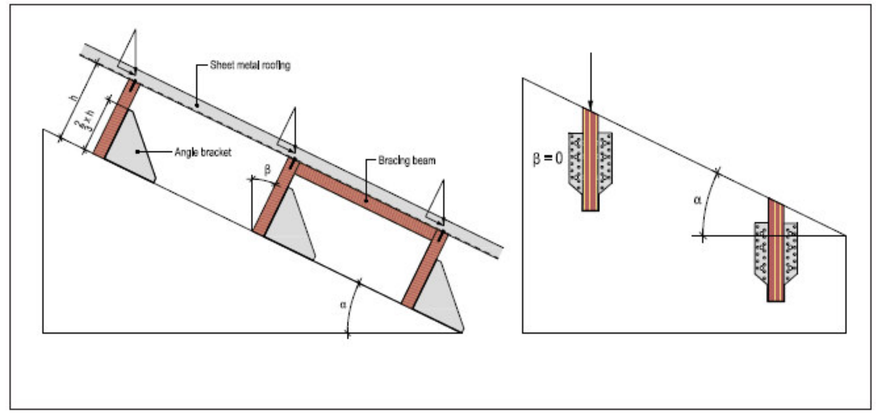


Figure 2.36. Support details of purlins installed vertically or perpendicular to the roof surface.

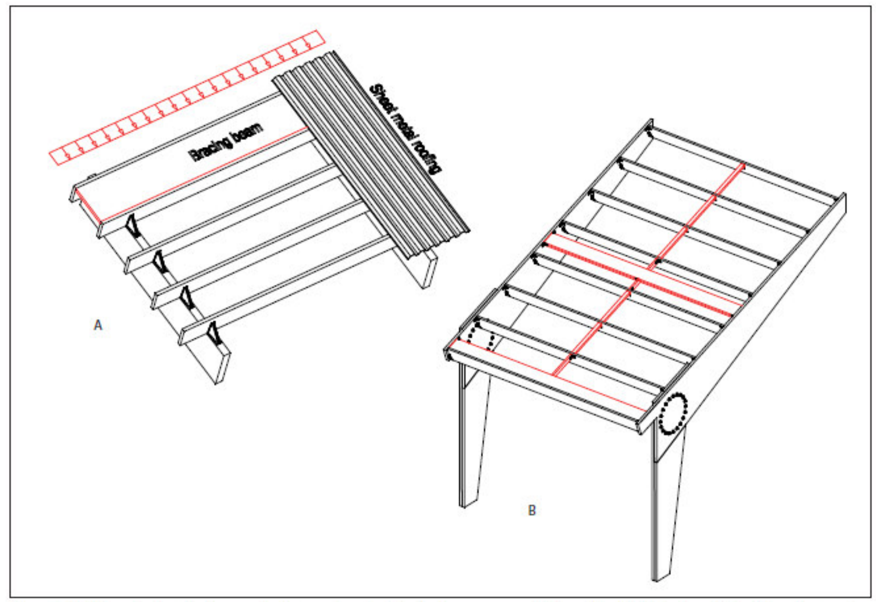


Figure 2.37. LVL purlins installed perpendicular to roof surface. Bracing beams are needed in purlin width directions. A) Steel sheeting transfers lateral torsional buckling support forces to the bracing beam B) Wooden batten side supports at the mid span transfer loads perpendicular to the span to bracing beams.

Roof elements for hall constructions

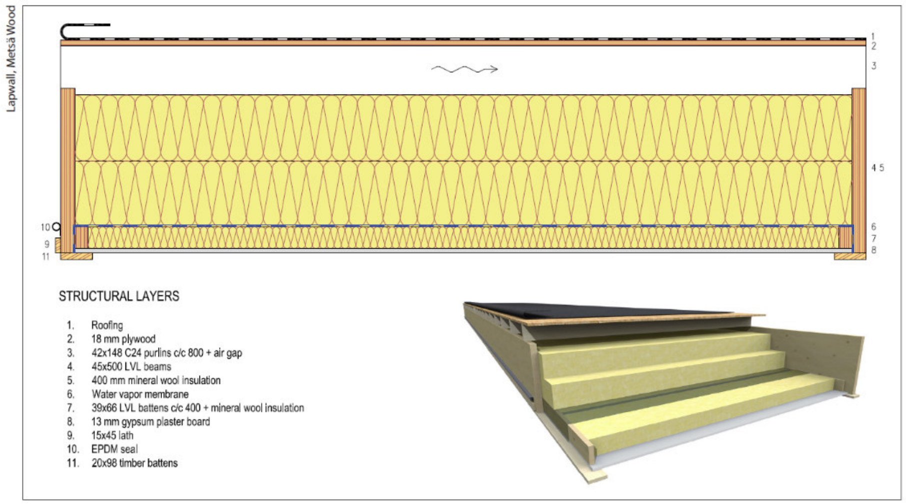


Figure 2.39. Cross section and detailing of roof elements with LVL purlins.

LVL-C Roof panels

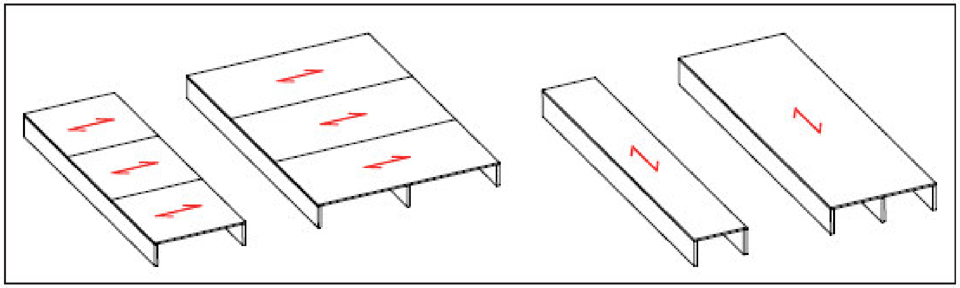
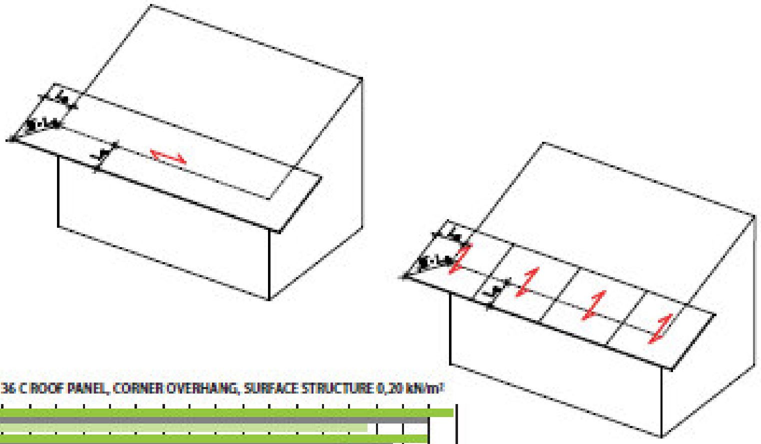
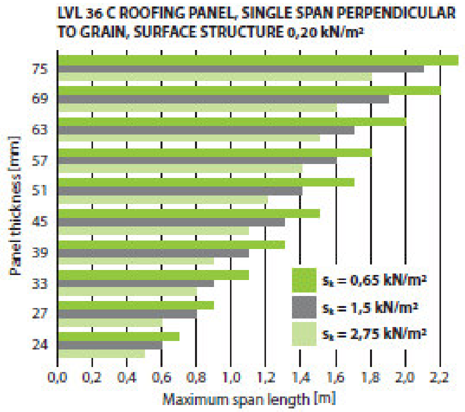
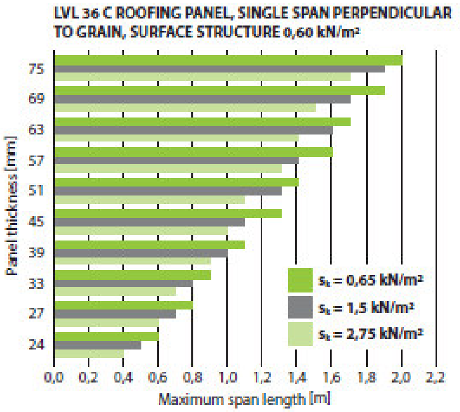
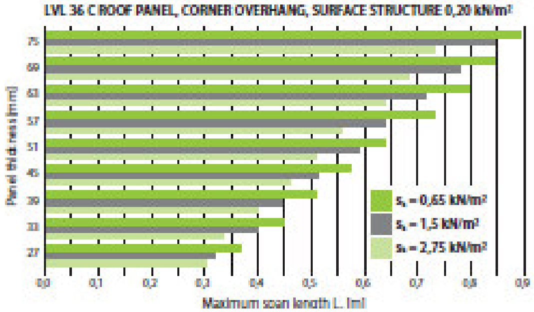


Figure 2.43. LVL-C roof panel orientations. Left: single span and multiple span parallel to grain of surface veneers. Right: single span and multiple span perpendicular to grain of surface veneers.









Calculations according to EN 1995-1-1:2004+A1:2008 and its Finnish National Annex. Service class 2, Loads: own weight of surface structure 0,20 or 0,60 kN/m², s_k = snow load on ground level 0,65, 1,5 or 2,75 kN/m² and snow load on roof level = 0,8 x s_k. Wind load w_k = 0,4kN/m²; maintenance load qH = 0,4 kN/m². Point loads are not taken into account. Deflection limit

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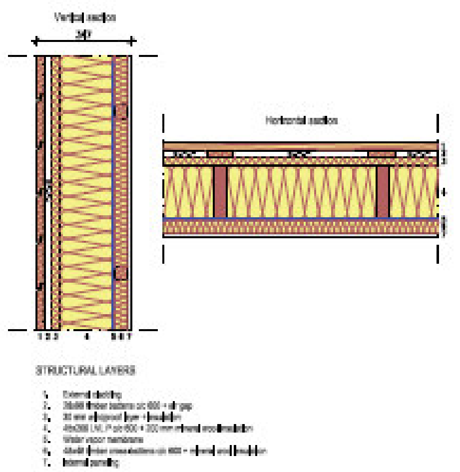
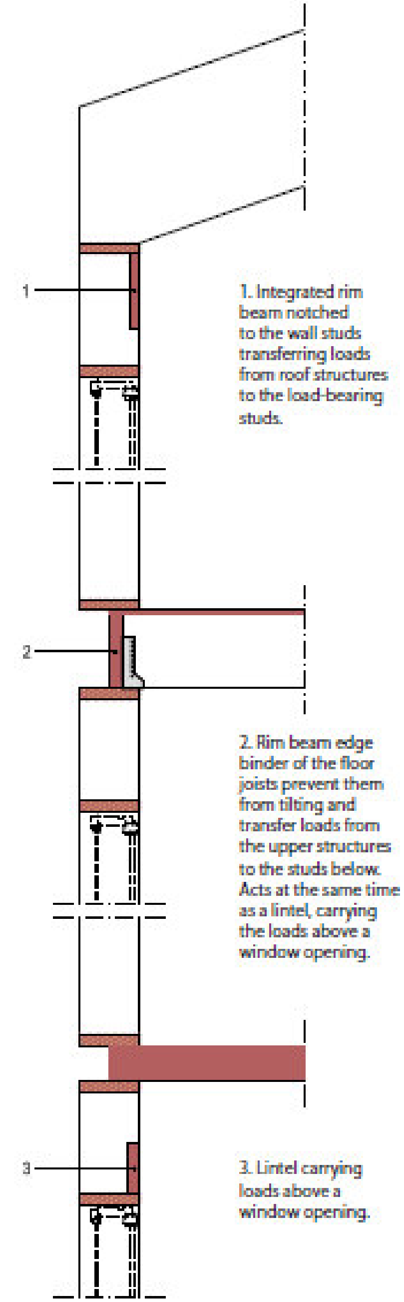
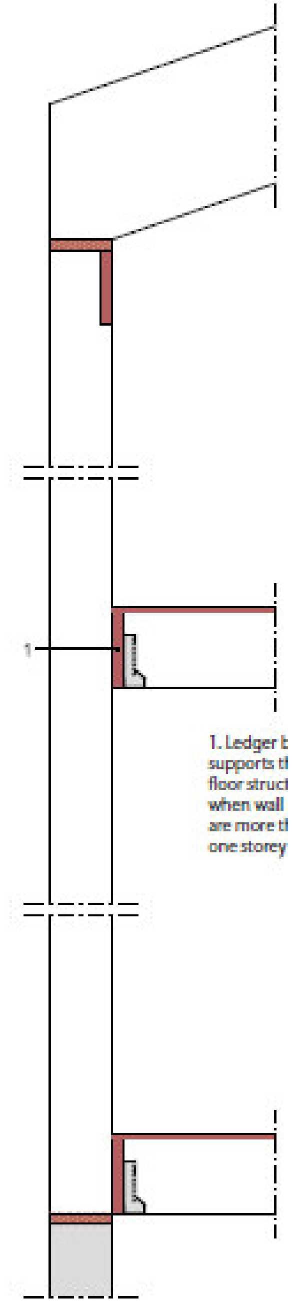
LVL-P for timber frame wall structures







LVL-C for panels bracing

Figure 2.71. Multiple-glued GLVL-C bracing column.

Figure 2.72. LVL-C bracing panels.

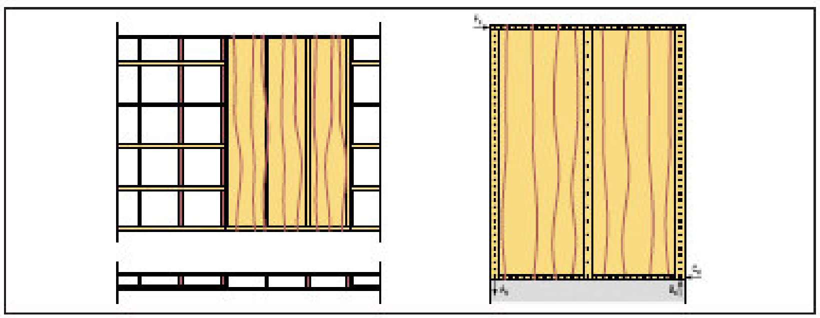


Figure 2.73. Robust LVL-C bracing panel integrated into the wall structure.

Table 2.1. Characteristic racking load capacity $F_{i,v,Rk}$ [kN] of LVL 36C panels nailed to LVL 48 P frame for predesign. The height of the LVL 36 C panel is 3,0 m. The distance between the frame studs should not be more than the panel width.

LVL 36 C PANELS NAILED TO LVL 48 P FRAME		Panel width					
		1200 mm			2400 mm		
Nail spacing at panel edges [mm]		150	100	75	150	100	75
Nail spacing at centre studs [mm]		300	200	150	300	200	150
Panel thickness [mm]	**Nail size $d \times L_{min}$ [mm]**	**Racking load capacity $F_{i,v,Rk}$ [kN] of wall panel**					
24	2,1x50	3,6	5,4	7,2	8,9	13	17
27	2,5x60	4,8	7,2	9,5	11,5	17	23
33	2,8x70	5,7	8,6	11,5	14	21	28
45	3,1x90	6,8	10	13	17	25	34

Table 2.2. Characteristic racking load capacity $F_{i,v,Rk}$ [kN] of LVL 36C panels nailed to C24 frame for predesign. The height of the LVL 36 C panel is 3,0 m. The distance between the frame studs should not be more than the panel width.

LVL 36 C PANELS NAILED TO C 24 FRAME		Panel width					
		1200 mm			2400 mm		
Nail spacing at panel edges [mm]		150	100	75	150	100	75
Nail spacing at centre studs [mm]		300	200	150	300	200	150
Panel thickness [mm]	**Nail size $d \times L_{min}$ [mm]**	**Racking load capacity $F_{i,v,Rk}$ [kN] of wall panel**					
24	2,1x50	3,3	4,9	6,6	8,2	12	16
27	2,5x60	4,4	6,6	8,8	10,5	16	21
33	2,8x70	5,3	7,9	10,5	13	19	26
45	3,1x90	6,2	9,4	12	15	23	31

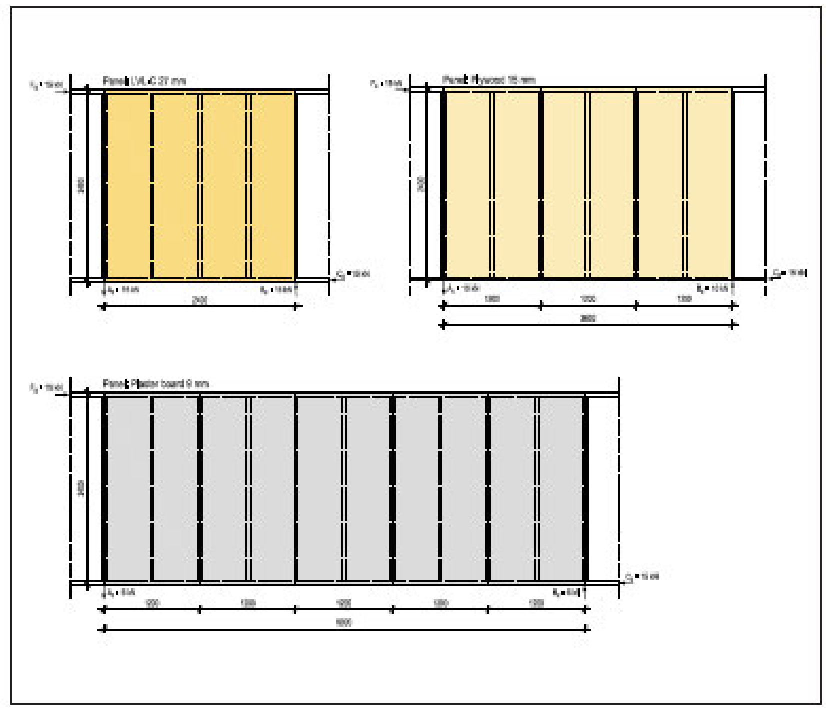


Figure 2.74. A wall diaphragm made with 27 mm LVL 36C panels, 15 mm plywood panels and 9 mm plasterboard panels have equal capacity. LVL-C panels are the best solution where space for bracing is limited; however, the increased anchoring force needs to be taken into account in connection detailing [24].

Special applications of LVL

Section 3. Purchasing, transport, handling and storage of LVL

Practical info about how to specify, order, process and take care of LVL

Figure 1.1 LVL roof structure, K-Rajamarket, Utsjoki, Finland.

Section 4. Structural design of LVL structures

- Design based on Eurocodes
- Material values and explanations of LVL specific features
- Equations
- Diagrams
- Tables
- Drawings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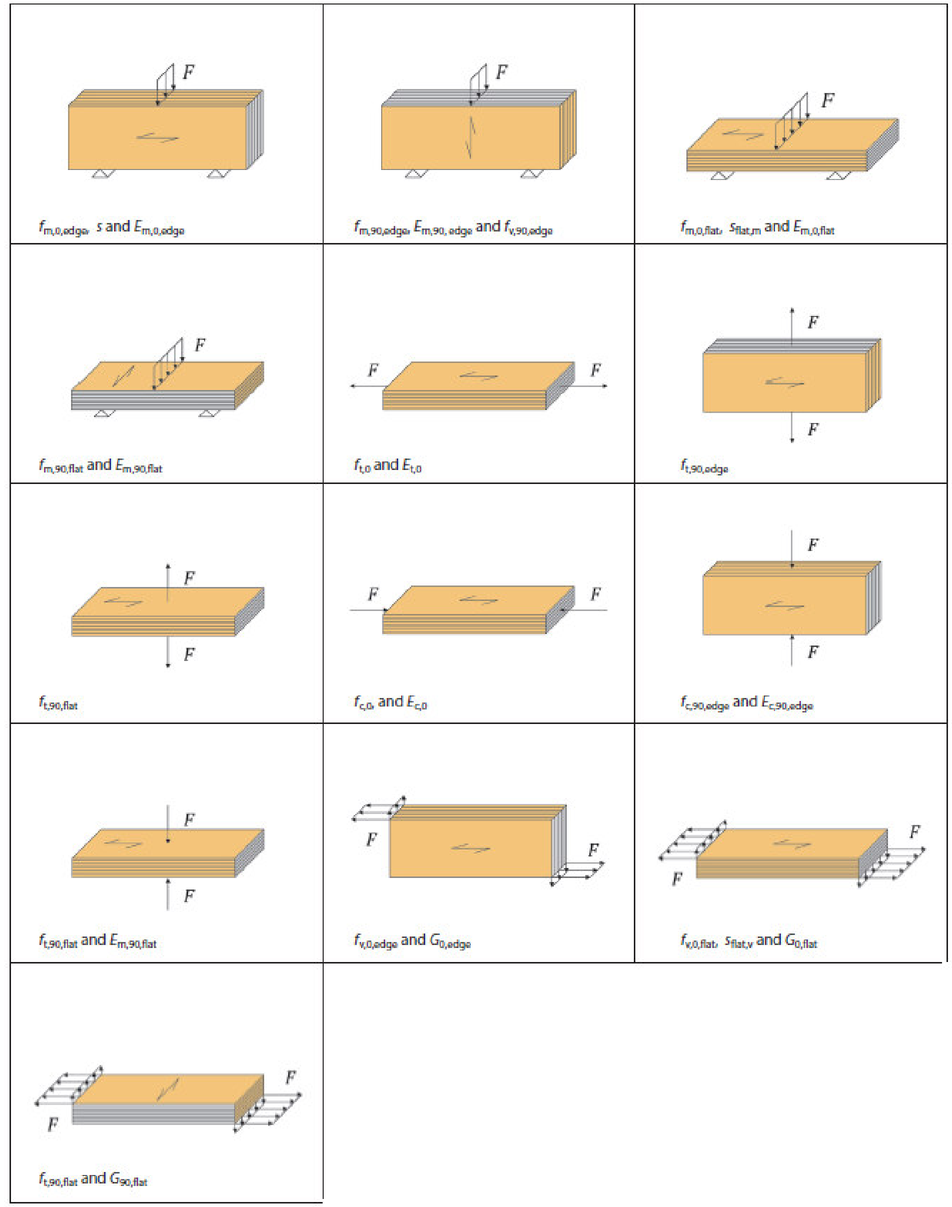
New European strength classes
September 2019


$f_{m,0,edge}$, s and $E_{m,0,edge}$
$f_{m,90,edge}$, $E_{m,90,edge}$ and $f_{v,90,edge}$
$f_{m,0,flat}$, $s_{flat,m}$ and $E_{m,0,flat}$
$f_{m,90,flat}$ and $E_{m,90,flat}$
$f_{t,0}$ and $E_{t,0}$
$f_{t,90,edge}$
$f_{t,90,flat}$
$f_{c,0}$, and $E_{c,0}$
$f_{c,90,edge}$ and $E_{c,90,edge}$
$f_{t,90,flat}$ and $E_{m,90,flat}$
$f_{v,0,edge}$ and $G_{0,edge}$
$f_{v,0,flat}$, $s_{flat,v}$ and $G_{0,flat}$
$f_{t,90,flat}$ and $G_{90,flat}$
F

New European strength classes

- **Launched in LVL Bulleting of the industry**
- **5 classes for LVL-P**
- **6 classes for LVL-C**

Table 4.5. Strength classes for structural LVL-P without crossband veneers [15].

Property [a]		Symbol	Unit	Strenght class LVL 32 P	LVL 35 P	LVL 48 P	LVL 50 P	LVL 80 P
Bending strength	Edgewise, parallel to grain (depth 300 mm)	$f_{m,0,edge,k}$	N/mm²	27	30	44	46	75
	Flatwise, parallel to grain	$f_{m,0,flat,k}$	N/mm²	32	35	48	50	80
	Size effect parameter	s	-	0,15	0,15	0,15	0,15	0,15
Tension strength	Parallel to grain (length 3 000 mm)	$f_{t,0,k}$	N/mm²	22	22	35	36	60
	Perpendicular to grain, edgewise	$f_{t,90,edge,k}$	N/mm²	0,5	0,5	0,8	0,9	1,5
Compression strength	Parallel to grain for service class 1	$f_{c,0,k}$	N/mm²	26	30	35	42	69
	For service class 2 according to EN 1995-1-1 [b]			21	25	29	35	57
	Perpendicular to grain, edgewise	$f_{c,90,edge,k}$	N/mm²	4	6	6	8,5	14
	Perpendicular to grain, flatwise (except pine)	$f_{c,90,flat,k}$	N/mm²	0,8	2,2	2,2	3,5	12
	Perpendicular to grain, flatwise, pine	$f_{c,90,flat,k,pine}$	N/mm²	MDV [c]	3,3	3,3	3,5	- [d]
Shear strength	Edgewise parallel to grain	$f_{v,0,edge,k}$	N/mm²	3,2	3,2	4,2	4,8	8
	Flatwise, parallel to grain	$f_{v,0,flat,k}$	N/mm²	2,0	2,3	2,3	3,2	8
Modulus of elasticity	Parallel to grain	$E_{0,mean}$ [e]	N/mm²	9 600	12 000	13 800	15 200	16 800
	Parallel to grain	$E_{0,k}$ [f]	N/mm²	8 000	10 000	11 600	12 600	14 900
	Perpendicular to grain, edgewise	$E_{c,90,edge,mean}$ [g]	N/mm²	MDV [c]	MDV [c]	430	430	470
	Perpendicular to grain, edgewise	$E_{c,90,edge,k}$ [h]	N/mm²	MDV [c]	MDV [c]	350	350	400
Shear modulus	Edgewise, parallel to grain	$G_{0,edge,mean}$	N/mm²	500 [i]	500 [i]	600	650	760
	Edgewise, parallel to grain	$G_{0,edge,k}$	N/mm²	300 [i]	350 [i]	400	450	630
	Flatwise, parallel to grain	$G_{0,flat,mean}$	N/mm²	320 [i]	380 [i]	380	600	850
	Flatwise, parallel to grain	$G_{0,flat,k}$	N/mm²	240 [i]	270 [i]	270	400	760
Density		ρ_{mean}	kg/m³	440	510	510	580	800
		ρ_k	kg/m³	410	480	480	550	730

[a] Additional strength, stiffness and density properties not covered by the classes given in this Table may be declared as individual values
[b] Value may also be applied in Service Class 1 as a conservative value
[c] Property is not expressed as strength class but rather as individual manufacturer´s declared value (MDV)
[d] Class not produced from pine
[e] Covering $E_{m,0,edge,mean}$, $E_{t,0,mean}$, $E_{m,0,flat,mean}$, and $E_{c,0,mean}$
[f] Covering $E_{m,0,edge,k}$, $E_{t,0,k}$, $E_{m,0,flat,k}$ and $E_{c,0,k}$
[g] Also covering $E_{t,90,edge,mean}$
[h] Also covering $E_{t,90,edge,k}$
[i] Property need not be tested if all other properties meet the minimum values for the strength class

Table 4.6. Strength classes for structural LVL-C with crossband veneers [15].

Property [a]		Symbol	Unit	Strenght class LVL 22 C	LVL 25 C	LVL 32 C	LVL 36 C	LVL 70 C	LVL 75 C
Bending strength	Edgewise, parallel to grain (depth 300 mm)	$f_{m,0,edge,k}$	N/mm²	19	20	28	32	54	60
	Flatwise, parallel to grain	$f_{m,0,flat,k}$	N/mm²	22	25	32	36	70	75
	Size effect parameter	s	-	0,15	0,15	0,15	0,15	0,15	0,15
	Flatwise, perpendicular to grain	$f_{m,90,flat,k}$	N/mm²	MDV [c]	MDV [c]	7	8	32	20
Tension strength	Parallel to grain (length 3 000 mm)	$f_{t,0,k}$	N/mm²	14	15	18	22	45	51
	Perpendicular to grain, edgewise	$f_{t,90,edge,k}$	N/mm²	4	4	5	5	16	8
Compression strength	Parallel to grain for service class 1	$f_{c,0,k}$	N/mm²	18	18	18	26	54	64
	For service class 2 according to EN 1995-1-1 [b]			15	15	15	21	45	53
	Perpendicular to grain, edgewise	$f_{c,90,edge,k}$	N/mm²	8	8	9	9	45	23
	Perpendicular to grain, flatwise (except pine)	$f_{c,90,flat,k}$	N/mm²	1,0	1,0	2,2	2,2	16	16
	Perpendicular to grain, flatwise, pine	$f_{c,90,flat,k,pine}$	N/mm²	MDV [c]	MDV [c]	3,5	3,5	- [d]	- [d]
Shear strength	Edgewise parallel to grain	$f_{v,0,edge,k}$	N/mm²	3,6	3,6	4,5	4,5	7,8	7,8
	Flatwise, parallel to grain	$f_{v,0,flat,k}$	N/mm²	1,1	1,1	1,3	1,3	3,8	3,8
	Flatwise, perpendicular to grain	$f_{v,90,flat,k}$	N/mm²	MDV [c]	MDV [c]	0,6	0,6	MDV [c]	MDV [c]
Modulus of elasticity	Parallel to grain, edgewise	$E_{0,edge,mean}$ [e]	N/mm²	6 700	7 200	10 000	10 500	11 800	13200
	Parallel to grain, edgewise	$E_{0,edge,k}$ [f]	N/mm²	5 500	6 000	8 300	8 800	10 900	12200
	Perpendicular to grain, edgewise	$E_{90,edge,mean}$ [g]	N/mm²	MDV [c]	MDV [c]	2 400	2 400	MDV [c]	MDV [c]
	Perpendicular to grain, edgewise	$E_{90,edge,k}$ [h]	N/mm²	MDV [c]	MDV [c]	2 000	2 000	MDV [c]	MDV [c]
	Perpendicular to grain, flatwise	$E_{m,90,flat,mean}$	N/mm²	MDV [c]	MDV [c]	1 200	2 000	MDV [c]	MDV [c]
	Perpendicular to grain, flatwise	$E_{m,90,flat,k}$	N/mm²	MDV [c]	MDV [c]	1 000	1 700	MDV [c]	MDV [c]
Shear modulus	Edgewise, parallel to grain	$G_{0,edge,mean}$	N/mm²	500 [i]	500 [i]	600	600	820	820
	Edgewise, parallel to grain	$G_{0,edge,k}$	N/mm²	300 [i]	300 [i]	400	400	660	660
	Flatwise, parallel to grain	$G_{0,flat,mean}$	N/mm²	70 [i]	70 [i]	80	120	430	430
	Flatwise, parallel to grain	$G_{0,flat,k}$	N/mm²	55 [i]	55 [i]	60	100	380	380
	Flatwise, perpendicular to grain	$G_{90,flat,mean}$	N/mm²	MDV [c]	MDV [c]	22	22	MDV [c]	MDV [c]
	Flatwise, perpendicular to grain	$G_{90,flat,k}$	N/mm²	MDV [c]	MDV [c]	16	16	MDV [c]	MDV [c]
Density		ρ_{mean}	kg/m³	440	440	510	510	800	800
		ρ_k	kg/m³	410	410	480	480	730	730

[a] Additional strength, stiffness and density properties not covered by the classes may be declared as individual values
[b] Value may also be applied in Service Class 1 as a conservative value
[c] Property is not expressed as strength class but rather as individual manufacturer´s declared value (MDV)
[d] Class not produced from pine
[e] Covering $E_{m,0,edge,mean}$, $E_{t,0,mean}$, $E_{m,0,flat,mean}$, and $E_{c,0,mean}$
[f] Covering $E_{m,0,edge,k}$, $E_{t,0,k}$, $E_{m,0,flat,k}$, and $E_{c,0,k}$
[g] Covering $E_{m,90,edge,mean}$, $E_{t,90,edge,mean}$ and $E_{c,90,edge,mean}$
[h] Covering $E_{m,90,edge,k}$, $E_{t,90,edge,k}$ and $E_{c,90,edge,k}$
[i] Property need not be tested if all other properties meet the minimum values for the strength class

Example: Compression in perpendicular to grain

The effective contact area perpendicular to the grain, A_{ef}, should be determined taking into account an effective contact length parallel to the grain, where the actual contact length, l, at each side is increased.

Eurocode 5 does not include the parameters $k_{c,90}$ and A_{ef} for LVL in different orientations. The value of $k_{c,90}$ should be taken as 1,0 for LVL in the edgewise loading direction. For LVL in the flatwise loading direction, $k_{c,90} = 1{,}4$ maybe used, when the distance $\ell_1 \geq 2h$ [15]. The contact length and width may be increased according to the Table 4.7, but not more than a, ℓ or $\ell_1/2$, see Figure 4.11. LVL suppliers also have their own tailored instructions that may give more favourable design results.

The increased contact length and factor $k_{c,90}$ are less favourable for LVL in edgewise direction, than in the flatwise direction or compared to other wood products have, due to the failure behaviour of the products. LVL in the flatwise direction, solid wood and glulam have ductile behaviour under compression perpendicular to the grain. LVL has high strength values in the edgewise direction $f_{c,90,edge,k} = 6–9$ N/mm². However, it breaks in a more brittle manner, see Figure 4.13. Figure 4.14 shows a calculation example for an LVL beam supported on an LVL sole plate.

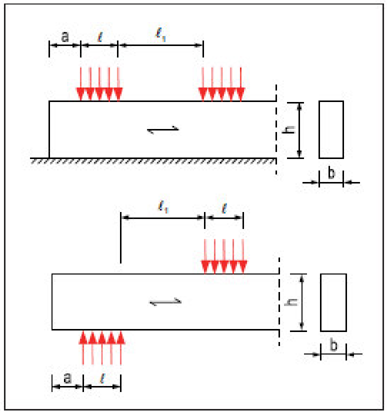


Figure 4.12. (a) Compression $F_{c,90}$ of a sole plate (b) Compression $F_{c,90}$ of beam on supports (EC5 Figure 6.2).

Table 4.7. $k_{c,90}$-values and increase of the actual contact length for the design of compression strength perpendicular to the grain of LVL [15].

Loading direction		$k_{c,90}$-values	Increase of the actual contact length* [mm]
Edgewise compression strength	$f_{c,90,edge,k}$	1,0	15
Flatwise compression strength	$f_{c,90,flat,k}$	1,4	
— parallel to the grain of the surface veneers			30
— perpendicular to the grain of the surface veneers			15

* One-sided or two-sided increase of the actual contact length, but not more than a, l or l_1/2 according to EN 1995-1-1.

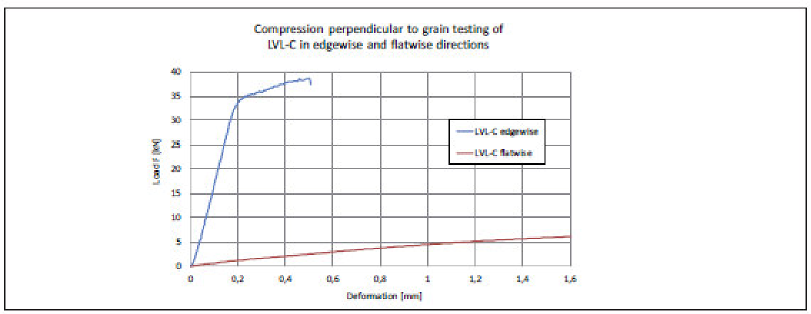
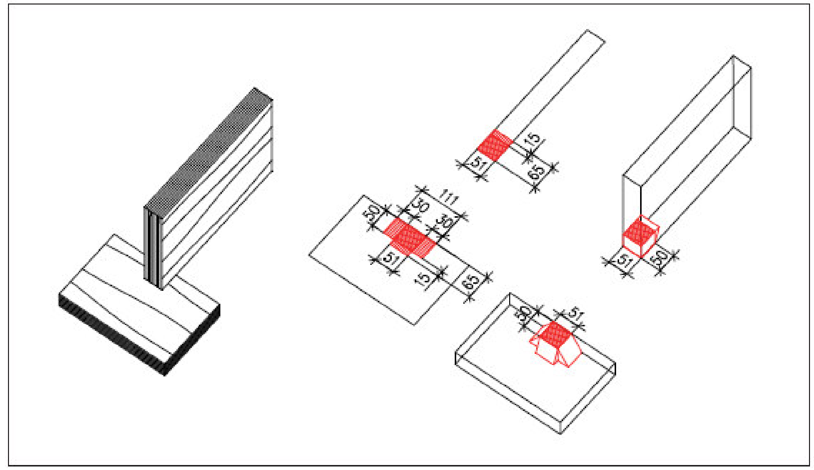


Figure 4.13. Example of LVL-C specimens in compression perpendicular to grain testing. In the flatwise direction LVL-C exhibits a ductile behaviour. In the edgewise direction orientation LVL-C is much stronger and stiffer, but undergoes more brittle failure due to buckling of the veneers.



LVL beam							
Product type	Beam thickness b [mm]	Support length l [mm]	Increase in actual contact length l_1 [mm]	Effective contact area $A_{ef} = b\cdot(l+l_1)$ [mm²]	Compression strength $f_{c,90,edge,k}$ [N/mm²]	$k_{c,90}$ [-]	Characteristic bearing capacity $F_{c,k} = A_{ef} \cdot k_{c,90} \cdot f_{c,90,edge,k}$ [kN]
LVL 48 P	51	50	15	3 315	6,0	1,0	20
LVL 36 C	51	50	15	3 315	9,0	1,0	30

LVL or solid wood sole plate							
Product type	Contact width b [mm]	Contact length l [mm]	Increase in actual contact length parallel l_1 and perpendicular l_2 [mm]	Effective contact area $A_{ef} = b\cdot(l+l_1) + (b\cdot l_2)$ [mm²]	Compression strength $f_{c,90,edge,k}$ [N/mm²]	$k_{c,90}$ [-]	Characteristic bearing capacity $F_{c,k} = A_{ef} \cdot k_{c,90} \cdot f_{c,90,edge,k}$ [kN]
LVL 48 P or 36 C	50	51	l_1 =30, l_2 =15	6 315	2,2	1,4	19,5
LVL 48 P or 36 C of pine	50	51	l_1 =30, l_2 =15	6 315	3,3	1,4	29
C24 solid wood	50	51	l_1 =30, l_2 =0	5 550	2,5	1,25	17,3

Figure 4.14. Example of an LVL beam supported on an LVL sole plate. Effective contact area is increased by 15 mm in the edgewise direction on the beam and separately by 60 mm (2x30 mm) in the length direction and 15mm in width direction on the sole plate.

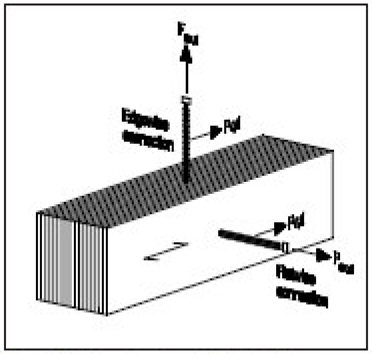
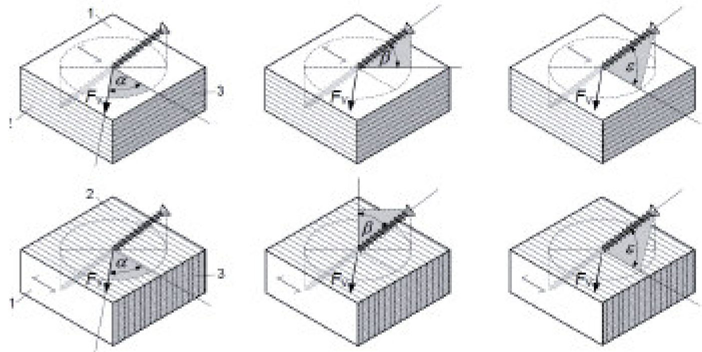
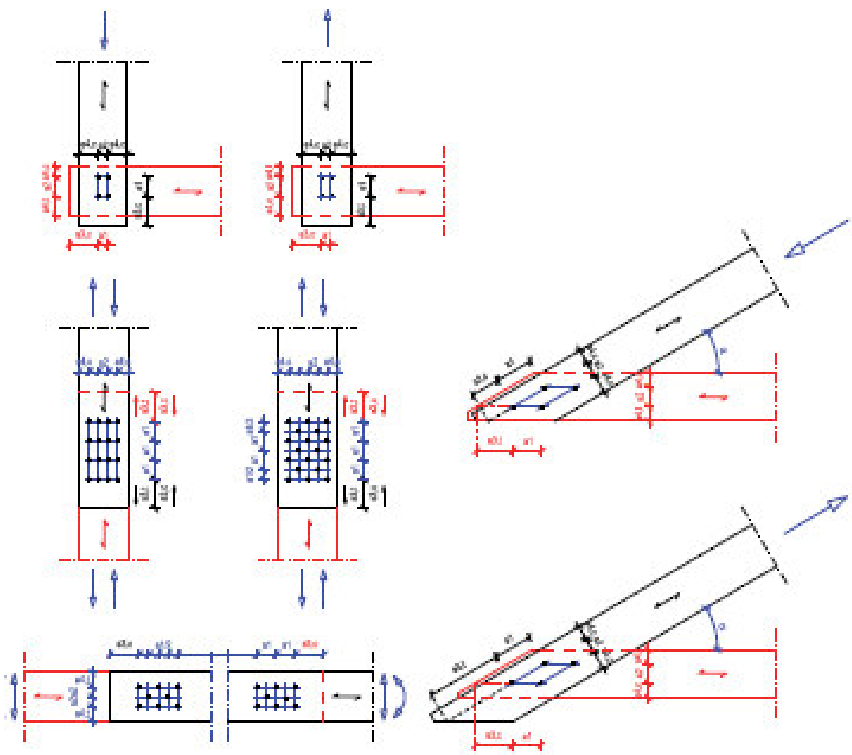


Figure 5.2. Edgewise (edge face) and flatwise (wide face) orientations and loading types of connections. $F_{ax,d}$ are forces of axially loaded and $F_{v,d}$ are forces of laterally loaded connections





Section 5. Connections

- Supplementary information for Design according to Eurocode 5
- Connector spacings, end and edge distances at edgewise and flatwise connections
- LVL-P and LVL-C properties
- Nailed, screwed, bolted and dowelled connections with some capacity tables
- Inclined screwing
- Design of wood failure modes.

Example pages of the LVL connection design section

5. STRUCTURAL DESIGN OF CONNECTIONS

Table 5.2. Maximum nail and screw size d [mm] for edge face (edgewise) connections

LVL thickness	Laterally loaded connections			Axially loaded connections
	Without pre-drilling $a_{4,c} \geq 7d$	With predrilling $a_{4,c} \geq 3d$		$a_{2,CG} \geq 4d$
	Nails and screws	Nails	Screws	Screws
27 mm	1,9	4,5	4,5	3,4
33 mm	2,4	5,5	5,5	4,1
39 mm	2,8	6,5	6,5	4,9
45 mm	3,2	7,5	7,5	5,6
51 mm	3,6	8,0	8,5	6,4
57 mm	4,1	8,0	9,5	7,1
63 mm	4,5	8,0	10,5	7,9
69 mm	4,9	8,0	11,5	8,6
75 mm	5,4	8,0	12,0	9,4

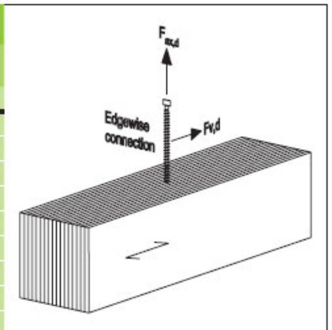


Table 5.3. Minimum spacings, end distances and edge distances for bolts and screws with max outer thread diameter >12 mm with predrilled holes [32]. Note: EN 1995-1-1:2004 (Eurocode has a limit of def < 6 mm which corresponds with 9 mm outer thread diameter.

Spacing or distance, see Figures 5.4-5.5 and 5.7	Angle α	Minimum spacing or end/edge distance	
		LVL-P / GLVL-P or LVL-C / GLVL-C edge face	LVL-C / GLVL-C wide face
Spacing a_1 (parallel to grain)	$0° \leq \alpha \leq 360°$	$(4 + 3 \mid\cos\alpha\mid)\, d$ [a]	$4d$
Spacing a_2 (perpendicular to grain)	$0° \leq \alpha \leq 360°$	$4d$	$4d$
Distance $a_{3,t}$ (loaded end)	$-90° \leq \alpha \leq 90°$	max (7d; 105 mm) [b]	max (4d; 60 mm) [c]
Distance $a_{3,c}$ (unloaded end)	$90° \leq \alpha < 150°$ $150° \leq \alpha < 210°$ $210° \leq \alpha \leq 270°$	$(1 + 6 \sin\alpha)\, d$ $4d$ $(1 + 6 \sin\alpha)\, d$	$4d$ $4d$ $4d$
Distance $a_{4,t}$ (loaded edge)	$0° \leq \alpha \leq 180°$	max [$(2 + 2 \sin\alpha)\, d$; 3d]	max [$(2 + 2 \sin\alpha)\, d$; 3d]
Distance $a_{4,c}$ (unloaded edge)	$180° \leq \alpha \leq 360°$	$3d$	$3d$

[a] minimum spacing a_1 may be reduced to 5d if $f_{h,0,k}$ is multiplied by $\sqrt{a_1 / (4 + 3 \mid\cos\alpha\mid)\, d}$
[b] minimum end distance $a_{3,t}$ may be reduced to 7d for d < 15 mm if $f_{h,0,k}$ is multiplied by $a_{3,t}$ /105 mm
[c] minimum end distance $a_{3,t}$ may be reduced to 4d for d < 15 mm if $f_{h,0,k}$ is multiplied by $a_{3,t}$ / 60 mm

Spacing and end/edge distances on circular patterns for double shear moment-resisting connections, see Figure 5.6	Minimum spacing or distance		
	LVL-P, GLVL-P wide face	LVL-C / GLVL-C wide face	Side member LVL-C / GLVL-C wide face Middle member LVL-P, GLVL-P or LVL-C wide face
a_1 (spacing on circle)	$6d$	$4d$	$5d$
a_2 (spacing between circles)	$5d$	$4d$	$5d$
$a_{3,t}$ (loaded end)	$6d$	$4d$	6d in middle member 4d in side member
$a_{4,t}$ (loaded edge)	$4d$	$3d$	4d in middle member 3d in side member

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5. STRUCTURAL DESIGN OF CONNECTIONS

where

$f_{ax,\varepsilon,1,k}$ is the characteristic withdrawal strength parameter for a screw at the head side member of the connection at an angle ε to the grain direction [N/mm²];
$f_{ax,\varepsilon,2,k}$ is the characteristic withdrawal strength parameter for a screw at the pointside member of the connection at an angle ε to the grain direction [N/mm²];
d is the outer threaded diameter [mm];
$l_{g,1}$ is the penetration length of the threaded part in the head side member [mm];
$l_{g,2}$ is the penetration length of the threaded part in the pointside member [mm];
$f_{tens,k}$ is the characteristic tensile capacity of the screw determined in accordance with EN 14592 [N];
f_{head} is the characteristic pull-through parameter of the screw for the associated density ρa [N/mm²];
d_h is the head diameter [mm];
ρ_k is the characteristic density of LVL [kg/m³]; and
ρ_a is the associated density for $f_{head,k}$ [kg/m³].

When the screwing direction in the beam is ε = 90° to the grain direction (even though the angle β is inclined between the edge face and the wide face), it is not allowed to add the tension capacity of the head to the withdrawal capacity of the treaded part in the beam. Therefore the characteristic withdrawal capacity $R_{T,k}$ of the screw is calculated by the equation:

$$R_{T,k} = \min \begin{cases} \max\left(f_{ax,90,1,k}\, d\, l_{g,1} \,;\, f_{head,k}\, d_h^2 \left(\frac{\rho_k}{\rho_a}\right)^{0,8}\right) \\ f_{ax,\varepsilon,2,k}\, d\, l_{g,2} \\ f_{tens,k} \end{cases} \quad (5.35)$$

The withdrawal strength $f_{ax,\varepsilon,k}$ is determined by testing according to EN 14592 and EN 1382 or it can be determined at angle ε to the grain as follows:

$$f_{ax,\varepsilon,k} = \frac{k_{ax} \cdot f_{ax,90,k}}{1{,}5 \cos^2\beta + \sin^2\beta} \left(\frac{\rho_k}{\rho_a}\right)^{0,8} \quad (5.36)$$ [32]

where

ε is the angle between the screw axis and the grain direction, ε ≥ 15°, see Figure 5.12;
β is the angle between the screw axis and the LVL's wide face, with $0° \leq \beta \leq 90°$, see Figure 5.7
k_{ax} in according to the equation (5.29)
ρ_k is the characteristic density of LVL [kg/m³];
ρ_a is the associated density for $f_{ax,k}$ [kg/m³]; and
$f_{ax,90,k}$ is the characteristic withdrawal strength parameter for a screw perpendicular to the grain direction [N/mm²]. It is determined by testing according to EN 14592 and EN 1382 or for screws in LVL, it may be assumed as $f_{ax,90,k}$ =15 N/mm² for ρ_a = 500 kg/m³ and screws 6 mm≤ d ≤ 12 mm in softwood LVL/GLVL [32].

Tension screwed connection

In a joint consisting of only screws in tension, contact between the wood members is required. Tension screw connection should not be used in conditions where wood drying could cause a gap of over 0.2d. The gap is determined from the wood shrinkage at a thickness of the LVL members in the screw length $(L \cdot \sin\alpha)$ [31].

The characteristic load-carrying capacity of the tension screw connection, see Figure 5.12 (b), is calculated by the equation:

$$R_k = n^{0.9}\, R_{T,k} (\cos\varepsilon + \mu \cdot \sin\varepsilon) \quad (5.37)$$

where

n is the number of screws in the connection;
$R_{T,k}$ is the characteristic withdrawal capacity, see (5.35);
α is the angle between screw axis and the shear plane ($30° \leq \alpha \leq 60°$), see Figure 5.12 (b); and
μ is the kinetic friction coefficient between the members, the following values may be used:
0.26 for untreated LVL edgewise or LVL to timber or timber-to-timber connections
0.30 for steel-to-timber connections
0.40 for untreated LVL flatwise connections

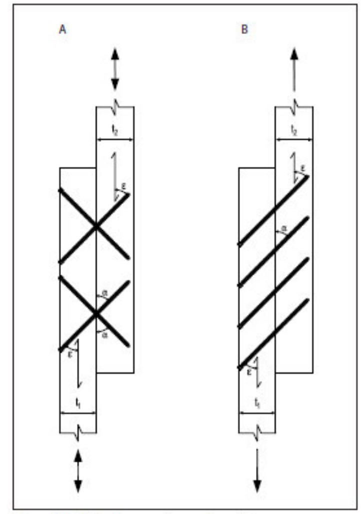

Figure 5.12. Inclined screwed connections (A) cross screw connection (B) tension screw connection

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Section 6. Performance of LVL in fire

re combustible ma- temperature of 270 nition does not oc- ng to structural fire he start of charring ture of timber sur-

d products is highly ng to the structural rning creates a char char layer acts as an nd protects the rest r, the high temper- and stiffness prop- e Figure 6.3, which e design.

Reaction to fire requirements are specified for wood surfaces to control the risk of flame spread in buildings. They set boundary conditions for the use of visible wood in claddings and structures. In some cases fire retardant treatments or sprinkler systems can allow more visible wood structures to be used in architectural design.

6.2 REACTION TO FIRE

In the European classification system defined in EN 13501-1, the reaction to fire performance class of LVL is D-s2, d0. This class can be applied to LVL without further testing when the density is at least 400 kg/m³ and the product thickness is ≥ 18 mm (European Commission Delegated Regulation (EU) 2017/2293) [37].

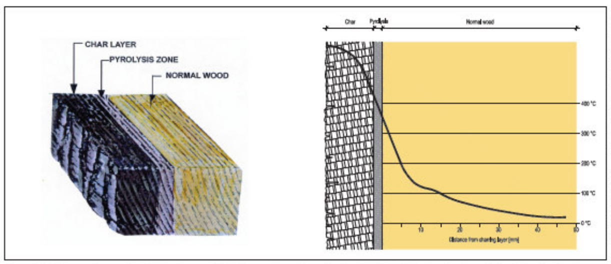


Figure 6.2. Temperature gradient in burning wood. The temperature drops significantly behind the charring layer. 15 mm from the charring zone the temperature is below 100 °C [36].

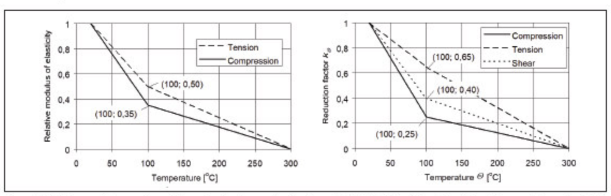


Figure 6.3. Influence of temperature on the mechanical properties of softwood. Left: Reduction of modulus of elasticity parallel to grain, Right: Reduction of strength parallel to grain (EN1995-1-2:2004, Figure B.4 and B.5).

Example: 133x400 mm GLVL-P beam in 30 minutes fire exposure on all sides:

$$d_{ef} = \beta_n \cdot t + k_0 \cdot d_0 = 0{,}70\frac{mm}{min} \cdot 30min + 1{,}0 \cdot 7mm = 28mm$$

Size of the effective cross section:
Width b: 133 mm - 2·28 mm = 77 mm
Height h: 400 mm - 2·28 mm = 344 mm

Design value of bending strength for LVL-48 P:

$$f_{m,d,fi} = k_{mod,fi} \cdot \frac{k_{fi} \cdot k_h \cdot f_{m,k}}{\gamma_{M,fi}} = 1{,}0 \cdot \frac{1{,}1 \cdot \left(\frac{300mm}{344mm}\right)^{0{,}15} \cdot 44\frac{N}{mm^2}}{1{,}0} = 47{,}4\frac{N}{mm^2}$$

When LVL-C panels are exposed to fire on one side, the one-dimensional charring rate β_0 is used for calculation of the effective panel thicknesses. Table 6.2 shows the thicknesses after 15, 30 and 60min fire exposure. It is recommended that the effective thickness has at least one cross veneer. The values are thus shown for cases where the effective thickness is at least 9 mm.

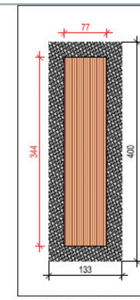


Figure 6.9. Effective cross section after 30 min fire exposure

Table 6.2. Effective thickness of LVL 36 C panels after 15 - 60 min fire exposure on one side.

LVL-C panel Original thickness [mm]	Effective thickness after 15 min [mm]	Effective thickness after 30 min [mm]	Effective thickness after 60 min [mm]
27	12	-	-
33	18	-	-
39	24	12	-
45	30	18	-
51	36	24	-
57	42	30	11
63	48	36	17
69	54	42	23
75	60	48	29

Table 6.3. Minimum thickness of LVL 36 C panel to give a fire exposure protection time 30 - 90 minutes for an underlying wooden structure.

Resistance to fire requirement R [min]	Minimum thickness h_{p1} of LVL 36 C panel protecting timber frame assemblies [mm]	Minimum thickness h_{p2} of LVL 36 C panel protection applied directly on beams or columns [mm]
30	29	27
45	39	36
60	49	46
75		
90		

6.4.4 LVL-C panel as a protection against fire exposure

When the LVL-C panel thickness is according to Table 6.3, the panel protects a wooden structure behind it for a certain fire resistance time t [min]. Other fire design calculations of the remaining wooden structure are not needed unless the panel is a part of the load-bearing system also in the structural fire design. In the case of timber frame assemblies, the LVL-C protection panel thickness hp1 [mm] is calculated for the required fire protection time t based on EN1995-1-2, equation (4.1) and (C.7) or (D.3):

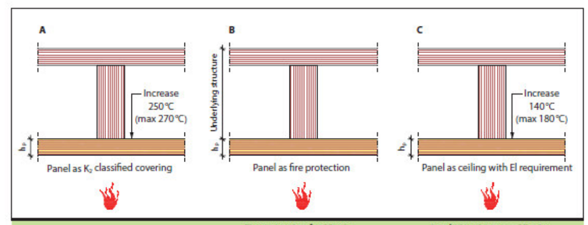
Minimum panel thickness $h_{p1} = \beta_0 \cdot (t+4min)+7mm$ (6.5)

When the protection panel is applied directly on beams or columns, the protection panel thickness h_{p2} [mm] is calculated for the required protection time t based on EN1995-1-2 equations (4.1) and (3.10):

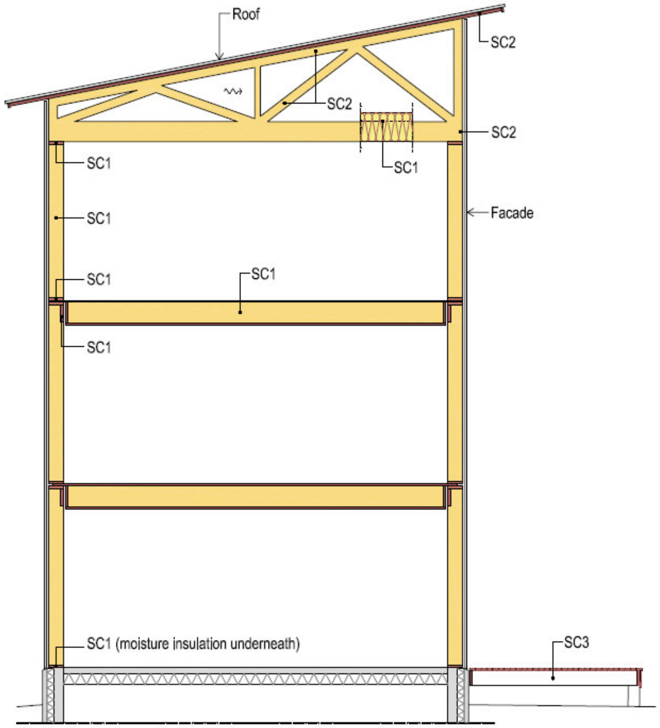
Minimum panel thickness $h_{p2} = \beta_0 \cdot t+7mm$ (6.6)

6.4.5 Summary of LVL-C panels for fire protection

Table 6.10 specifies the minimum thickness hp of LVL-C panel when used as a covering with fire protection ability for the underlying materials (column A), fire protection of the structures (column B) or when used as a ceiling structure which has a fire resistance requirement EI (column C). All of the different fire protection specifications also have requirements for the detailing of, e.g., joints between the panels.



K_2 10, when h_p ≥ 15 mm	Fire protection for 15 min, when h_p ≥ 18 mm	Insulation time t_{ins} = 15 min, when h_p ≥ 18 mm
K_2 30, when h_p ≥ 26 mm	Fire protection for 30 min, when h_p ≥ 29 mm	Insulation time t_{ins} = 30 min, when h_p ≥ 33 mm
K_2 60, when h_p ≥ 52 mm	Fire protection for 60 min, when h_p ≥ 49 mm	Insulation time t_{ins} = 60 min, when h_p ≥ 66 mm

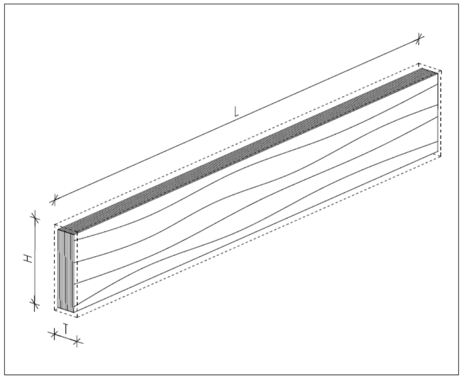


Section 7. Durability

- Use classes and service classes
- Service life of wooden structures
- Biological durability
- Durability of adhesive bonding
- Chemical durability
- Chemical wood treatment

Section 8. Building physics

- LVL and moisture
  - Moisture content in different relative humidity conditions
  - Dimensional changes due to moisture
  - Water vapour resistance
- Thermal properties
  - Thermal conductivity
  - Heat combustion
  - Influence on the mechanical properties
- Airtightness



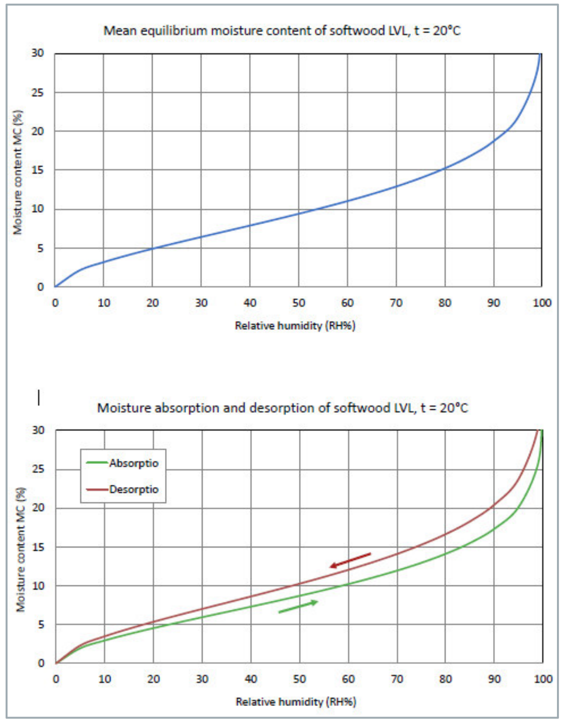


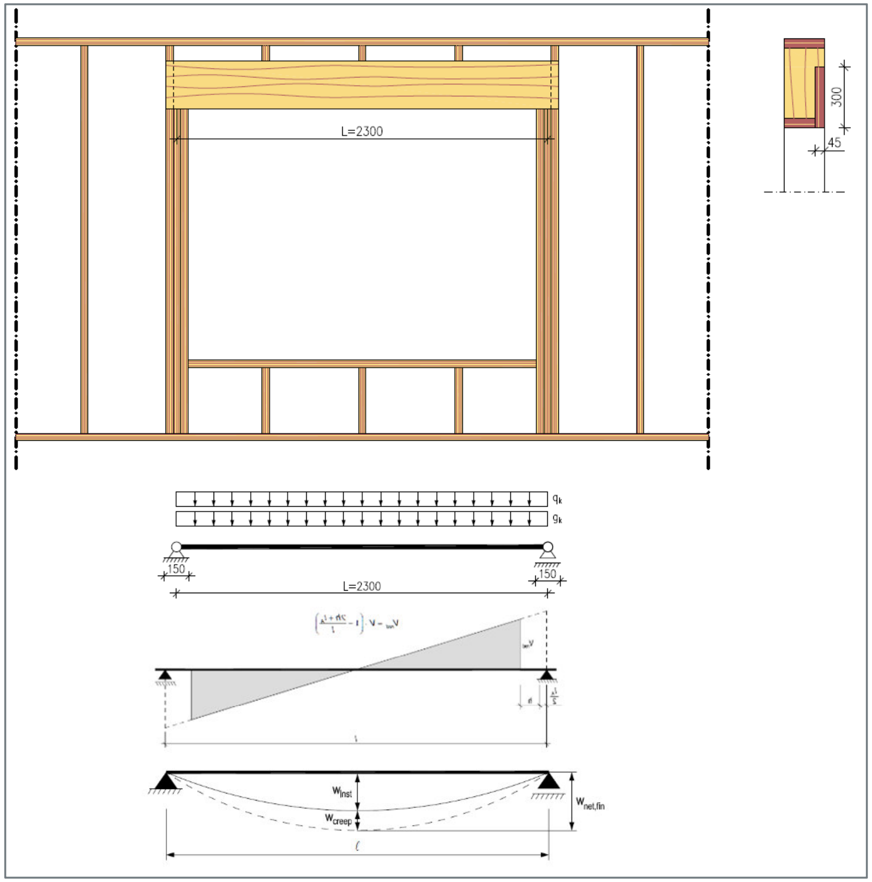
Table 8.1. Swelling and shrinkage factor αH for LVL products in % per 1% change in moisture content below fibre saturation point. Note: due to its cross band veneers, LVL-C undergoes much less dimensional change in the width direction than LVL-P (FprEN 14374:2018).

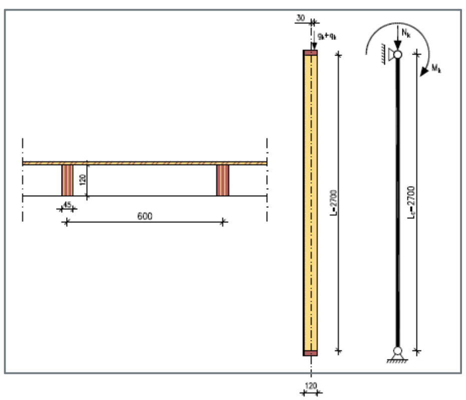
Dimension	LVL-P	LVL-C
Thickness *t*	0,32	0,32
Height *h* (or width of a panel)	0,32	0,03
Length *l*	0,01	0,01

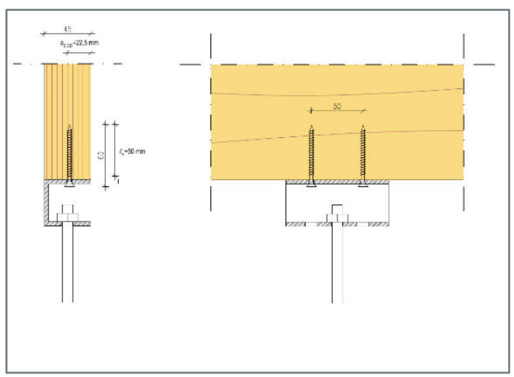
Table 8.3. Water vapour resistance factor μ and water vapour diffusion coefficient in air δ_p of softwood LVL.

	Water vapour resistance factor μ [-]		Water vapour diffusion coefficient in air δp [kg/(Pa·s·m)]	
Density ρ_{mean}	Dry cup	Wet cup	Dry cup	Wet cup
440 kg/m³	180	65	$0{,}73 \cdot 10^{-12}$	$2{,}3 \cdot 10^{-12}$
510 kg/m³	200	70	$0{,}96 \cdot 10^{-12}$	$2{,}7 \cdot 10^{-12}$

The dry cup values are tested in 23°C - 0/50 RH % and apply when the mean relative humidity across the material is less than 70 %. The wet cup values are tested in 23°C - 50/93 RH % and apply when the mean relative humidity across the material is greater than or equal to 70 %.







Section 9. Calculation examples of LVL structures

1 LVL 48P joist floor

2 Lintel over a window opening

3 Double LVL 48 P ridge beam for roof

4 Roof purlin

5 Wall stud

6 Axially loaded screw connection at the edge face

7 Inclined screw connection

8 Laterally loaded nail connection

9 Hole in LVL beam

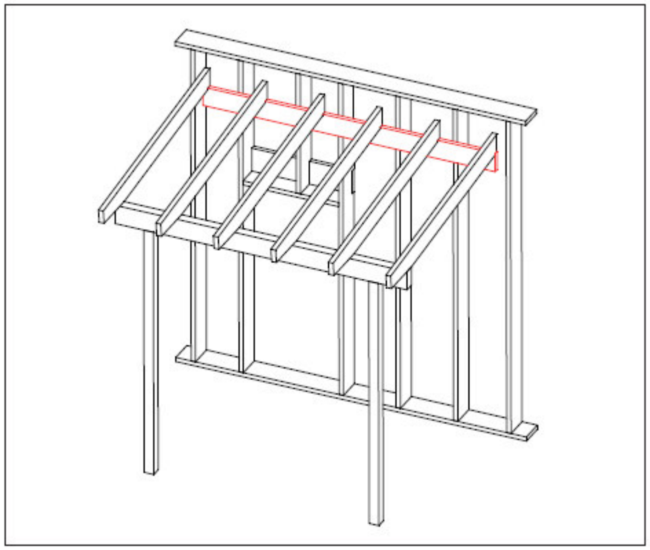
10 Bracing of a stud wall

11 Main beam of roof structure in 30min fire exposure

Calculation example:
Inclined screw connection between an LVL ledger beam and studs

9.7 INCLINED SCREW CONNECTION

A canopy over the entrance of a one family house is planned to be supported to the external wall by a 51x200 mm LVL 48 P ledger beam. The beam is connected with inclined screws in 45° angle to the edges of 51mm thick LVL 32 P wall studs which have spacing s = 600 mm. Line load from own weight g_k is 0,3 kN/m and imposed load from snow q_k is 3,5 kN/m. Service class SC2.



Loading combinations

The most critical ultimate limit state (ULS) load combination for each connection between the beam and stud:

$E_{d,ULS} = s \cdot (\gamma_G \cdot g_k + \gamma_Q \cdot q_k)$

$E_{d,ULS} = 0{,}6\text{m} \cdot (1{,}15 \cdot 0{,}3 \text{ kN/m} + 1{,}5 \cdot 3{,}5 \text{ kN/m}) = 3{,}4 \text{ kN}$

Note: Safety factors γ_G and γ_Q are according to Finnish National annex of Eurocode 0.

Screw properties

Size 6,0x140mm full threaded screw

Threaded length l_g	= 123 mm
Unthreaded length l_u	= 17 mm
Head diameter d_h	= 12 mm
Tensile strength $t_{tens,k}$	= 10 kN, determined in accordance with EN 14592.
Head pull-through strength $f_{head,k}$	= 13 N/mm², when ρ_a = 350 kg/m³
Modification factor kmod for medium-term load, SC2	= 0,8
Material safety factor γm for connections (default value in EC5)	=1,3

Geometry conditions:

Minimum distance to edge $a_{2,CG}$ in stud ≥ $4d$ = 4·6,0 mm = 24 mm. Stud thickness 51 mm/2 = 25,5 mm
→ Screw size 6,0x140 mm is OK for the stud
Min. screw spacing a_1 in stud ≥ $10d$ = 60 mm
Min. screw spacing a_2 in beam ≥ $5d$ = 30 mm
→ a_1 in the stud is more critical
Distance to edge of the beam $a_{2,CG}$ ≥ $4d$ = 24 mm. When the screwing angle is 45°, the beam thickness $t_1/2$ = 25,5 mm gives the minimum distance.

Maximum number of screws in the connection:

$$1 + \frac{(h_{beam} - 2 \cdot \min a_{2,CG})}{(\min a_{1,stud} / \sin 45°)} = 1 + \frac{(200 \text{ mm} - 2 \cdot 25{,}5 \text{ mm})}{(60 \text{ mm} / \sin 45°)} = 1 + \frac{149 \text{ mm}}{85 \text{ mm}} = 2{,}79$$

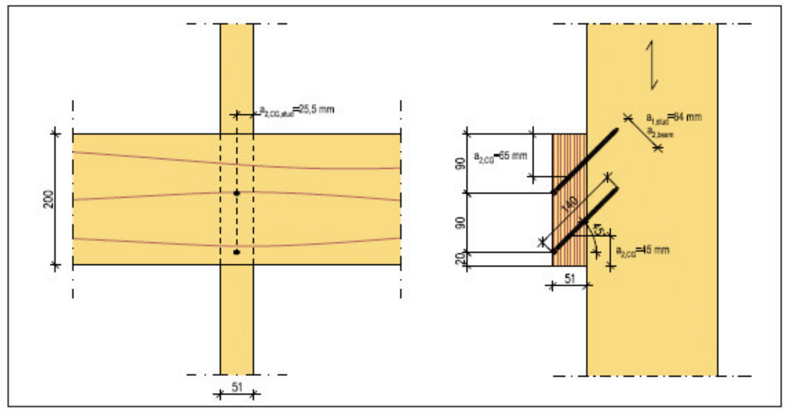
→ 2 screws are chosen for the connection, so that the heads of the screws are 20 mm and 110 mm from the bottom edge of the beam.

Minimum distance to the beam end $a_{1,CG}$ ≥ 10d = 60 mm. Therefore the end of the bean shall exceed the stud edge.
Effective penetration length $l_{ef,1}$ in ledger beam is

$$l_{ef,1} = l_{g,1} = \frac{t_1}{\sin 45°} - l_u = \frac{51 \text{ mm}}{\sin 45°} - 17 \text{ mm} = 55 \text{ mm}$$

Penetration length in wall stud $l_{g,2} = l - \frac{t_1}{\sin 45°} = 140 \text{ mm} - \frac{51 \text{ mm}}{\sin 45°} = 68 \text{ mm}$

For the beam the angles in the connections are: $\alpha = 45°$, $\beta = 45°$ and $\varepsilon = 90°$ and for the stud they are: $\alpha = 45°$, $\beta = 0°$ and $\varepsilon = 45°$.



Connection capacity

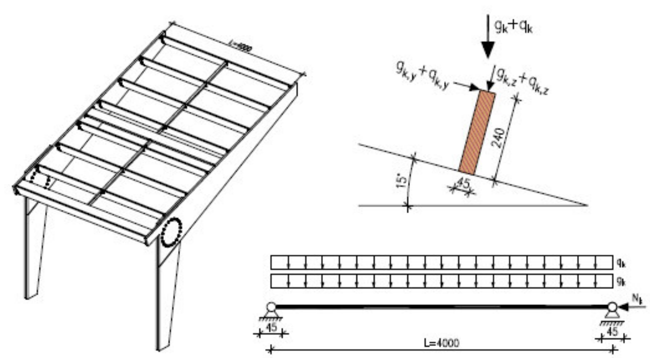
The characteristic load-carrying capacity of the tension screw connection, see Figure 5.11(b), is calculated by the equation:

$$R_k = n^{0,9} R_{T,k} \ (\cos \alpha + \mu \sin \alpha) \qquad (5.33)$$

Calculation example: Roof purlin

9.4 ROOF PURLIN

Single-span purlins of the roof of an unheated (service class 2) portal frame hall are 45x240 LVL 48 P beams. Roof angle is 15°, span length is $L = 4000$ mm, spacing $s = 900$ mm and the purlins are perpendicular to the roof plane having a side support line at the middle of the span. Support length is 45mm. Snow load s_k is 2,5 kN/m² and own weight of the roof structure is 0,30 kN/m². For simplification there is no wind load in the example. The purlins are connected to the sides of the portal frame beams and they act also as lateral torsional buckling supports. Therefore the purlins have an axial load of $N_k = 3$ kN mainly from snow load. Service class SC2.



Beam properties:

Bending strength edgewise $f_{m,0,edge,k}$	= 44 N/mm²
Bending strength flatwise $f_{m,0,flat,k}$	= 48 N/mm²
Shear strength edgewise $f_{v,0,edge,k}$	= 4,2 N/mm²
Compression parallel to grain $f_{c,0,SC2,k}$	= 29 N/mm²
Compression perpendicular to grain edgewise $f_{c,90,edge,k}$	= 6 N/mm²
Modulus of elasticity $E_{0,k}$	= 11 600 N/mm²
Modulus of elasticity $E_{0,mean}$	= 13 800 N/mm²
Modulus of rigidity $G_{0,edge,k}$	= 600 N/mm²
Modulus of rigidity $G_{0,edge,mean}$	= 400 N/mm²
Area of cross section $A = b{\cdot}h$	= 10800 mm²
Section modulus $W_y = b{\cdot}h^2/6$	= 4,32·10⁵ mm³
Section modulus $W_z = h{\cdot}b^2/6$	= 8,10·10⁴ mm³
Moment of inertia $I_y = b{\cdot}h^3/12$	= 5,18·10⁷ mm⁴
Moment of inertia $I_z = h{\cdot}b^3/12$	= 1,82·10⁶ mm⁴
Torsion moment of inertia $I_{tor} = 0{,}3{\cdot}h{\cdot}b^3$	= 6,56·10⁶ mm⁴
Moment stiffness of the joist EI_y = 13800 N/mm² · 6,56·10⁶ mm⁴	= 7,15·10¹¹ Nmm²
Shear rigidity of the joist GA = 600 N/mm² · 40800 mm²	= 6,48·10⁶ N
Modification factor k_{mod} for medium-term, SC2	= 0,8
Modification factor k_{def} for SC2	= 0,8
Material safety factor γ_M (default value in EC5)	=1,2
Size effect factor $k_h = (300/240)^{0,15}$	= 1,034

Loading combinations

Own weight in z-direction $g_{k,z}$: cos15° · 0,9m · 0,3 kN/m² = 0,26 kN/m
Own weight in y-direction $g_{k,y}$: sin15° · 0,9m · 0,4 kN/m² = 0,07 kN/m.

Snow load at roof level $q_k = \mu_1 \cdot C_e \cdot s_k$ Form factor $\mu_1 = 0{,}8$, when roof angle is less than 30° and in normal conditions $C_e = 1{,}0$.
$q_k = 0{,}8 \cdot 1{,}0 \cdot 2{,}5$ N/m² = 2 kN/m² (horizontal projection).
$q_{k,z} = \cos 15° \cdot \cos 15° \cdot 2$kN/m = 1,68 kN/m
$q_{k,y} = \cos 15 \cdot \sin 15° \cdot 2$kN/m = 0,45 kN/m
The most critical ultimate limit state (ULS) load combination:
$E_{d,z,ULS} = \gamma_G \cdot g_{k,z} + \gamma_Q \cdot q_{k,z}$
$E_{d,z,ULS} = 1{,}15 \cdot 0{,}26$ kN/m² + $1{,}5 \cdot 1{,}68$ kN/m² = 2,82 kN/m
$E_{d,y,ULS} = \gamma_G \cdot g_{k,y} + \gamma_Q \cdot q_{k,y}$
$E_{d,y,ULS} = 1{,}15 \cdot 0{,}07$ kN/m² + $1{,}5 \cdot 0{,}45$ kN/m² = 0,76 kN/m
Axial compression $N_{c,d} = \gamma_Q \cdot N_{c,k} = 1{,}5 \cdot 3$ kN/m² = 4,5 kN

Note: Safety factors γ_G and γ_Q are according to Finnish national annex of Eurocode 0.

Most critical serviceability limit state (SLS) load combination:
$E_{d,z,SLS} = \gamma_G \cdot g_{k,z} + \gamma_Q \cdot q_{k,z}$
$E_{d,z,ULS} = 1{,}0 \cdot 0{,}26$ kN/m² + $1{,}0 \cdot 1{,}68$ kN/m² = 1,94 kN/m

ULS design

Bending moment resistance in y-direction

$$M_{d,z} = E_{d,z,ULS} \cdot L2/8 = 2{,}82\text{kN/m} \cdot (4\text{m})^2/8 = 5{,}64\ \text{kNm}$$

$$\sigma_{m,y,d} = \frac{M_{d,z}}{W_y} = \frac{5{,}64\ \text{kNm}}{4{,}32 \cdot 10^5 \text{mm}^3} = 13{,}1\ \text{N/mm}^2$$

$$f_{m,0,edge,d} = \frac{k_{mod}}{\gamma_M} \cdot k_h \cdot f_{m,0,edge,k} = \frac{0{,}8}{1{,}2} \cdot 1{,}034 \cdot 44 \frac{\text{N}}{\text{mm}^2} = 30{,}3\ \text{N/mm}^2$$

Bending moment resistance in z-direction at centre support of a 2-span beam

$$M_{d,y} = E_{d,y,ULS} \cdot (L/2)^2/8 = 0{,}76\ \text{kN/m} \cdot (4\ \text{m}/2)^2/8 = 0{,}38\ \text{kNm}$$

$$\sigma_{m,z,d} = \frac{M_{y,d}}{W_z} = \frac{0{,}38\ \text{kNm}}{8{,}10 \cdot 10^4 \text{mm}^3} = 4{,}7\ \text{N/mm}^2$$

$$f_{m,0,flat,z,d} = \frac{k_{mod}}{\gamma_M} \cdot f_{m,0,flat,z,k} = \frac{0{,}8}{1{,}2} \cdot 48 \frac{\text{N}}{\text{mm}^2} = 32{,}0\ \text{N/mm}^2$$

Lateral torsional buckling (LTB) is prevented at the middle of the span.

The purlin is loaded from the compression side and supported against torsion at the main supports and in the middle of the span. According to Table 6.1 of EN1995-1-1, for uniformly distributed load, the effective length is L_{ef} = 2000 mm+2·240 mm = 2480 mm.

$$\sigma_{m,y,crit} = \frac{M_{z,crit}}{W_y} = \frac{\pi\sqrt{E_{0,05} I_z G_{0,05} I_{tor}}}{l_{ef} W_y} \quad (4.42)$$

$$\sigma_{m,y,crit} = \frac{\pi\sqrt{10600\ \text{N/mm}^2 \cdot 1{,}82 \cdot 10^6\ \text{mm}^4 \cdot 400\ \text{N/mm}^2 \cdot 6{,}56 \cdot 10^6 \cdot \text{mm}^4}}{2480\ \text{mm} \cdot 4{,}32 \cdot 10^5 \text{mm}^3}$$

$$\sigma_{m,y,crit} = 21{,}6\text{N/mm}^2$$

$$\lambda_{rel} = \sqrt{\frac{k_h \cdot f_{m,k}}{\sigma_{m,y,crit}}} = \sqrt{\frac{1{,}03 \cdot 44\ \text{N/mm}^2}{21{,}6\ \text{N/mm}^2}} = 1{,}45 \quad (4.41)$$

when $1{,}4 < \lambda_{rel,m}$, $k_{crit} = \frac{1}{\lambda_{rel,m}{}^2} = \frac{1}{1{,}45^2} = 0{,}48$

$$k_{crit} \cdot f_{m,y,d} = 0{,}48 \cdot 30{,}3\ \text{N/mm}^2 = 14{,}4\ \text{N/mm}^2 \quad (4.40)$$

$$\sigma_{m,y,d} \le k_{crit} \cdot f_{m,y,d} \rightarrow \text{OK} \quad (4.38)$$

Axial compression

$$\frac{N_{c,d}}{A} = \frac{4{,}5\text{kN}}{10800\ \text{mm}^2} = 0{,}42\ \text{N/mm}^2$$

$$f_{c,0,d} = \frac{k_{mod}}{\gamma_M} \cdot f_{c,0,SC2,k} = \frac{0{,}8}{1{,}2} \cdot 29 \frac{\text{N}}{\text{mm}^2} = 19{,}3\ \text{N/mm}^2$$

Buckling, buckling length l_c = 2000 mm in z-direction and 4000 mm in y-direction

$$\lambda_z = \sqrt{12}\left(\frac{l_c}{b}\right) = 3{,}46 \cdot \frac{2000\ \text{mm}}{45\ \text{mm}} = 154 \quad (4.37)$$

$$\lambda_y = \sqrt{12}\left(\frac{l_c}{h}\right) = 3{,}46 \cdot \frac{4000\ \text{mm}}{240\ \text{mm}} = 58$$

$$\lambda_{rel,z} = \frac{\lambda_z}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{154}{3{,}14} \cdot \sqrt{\frac{29\ \text{N/mm}^2}{11600\ \text{N/mm}^2}} = 2{,}45 \quad (4.36)$$

$$\lambda_{rel,y} = \frac{\lambda_y}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{58}{3{,}14} \cdot \sqrt{\frac{29\ \text{N/mm}^2}{11600\ \text{N/mm}^2}} = 0{,}92$$

$$k_z = 0{,}5 \cdot (1 + 0{,}1 \cdot (2{,}45 - 0{,}3) + (2{,}45)^2 = 3{,}61 \quad (4.34)$$

$$k_y = 0{,}5(1 + \beta_c(\lambda_{rel,y} - 0{,}3) + \lambda_{rel,y}^2)$$

$$k_y = 0{,}5 \cdot (1 + 0{,}1 \cdot (0{,}92 - 0{,}3) + (0{,}92)^2 = 0{,}95$$

$$k_{c,z} = \frac{1}{k_z + \sqrt{k_z^2 - \lambda_{rel,z}^2}} = \frac{1}{3{,}61 + \sqrt{3{,}61^2 - 2{,}45^2}} = 0{,}16 \quad (4.32)$$

$$k_{c,y} = \frac{1}{k_y + \sqrt{k_y^2 - \lambda_{rel,y}^2}} = \frac{1}{0{,}95 + \sqrt{0{,}95^2 - 0{,}92^2}} = 0{,}83$$

The following expressions shall be satisfied with km = 0,7 for rectangular cross sections:

$$\frac{\sigma_{c,0,d}}{k_{c,z} \cdot f_{c,0,d}} + k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \le 1 \quad (4.29)$$

$$\frac{0{,}42 \frac{\text{N}}{\text{mm}^2}}{0{,}16 \cdot 19{,}3 \frac{\text{N}}{\text{mm}^2}} + 0{,}7 \cdot \frac{13{,}1 \frac{\text{N}}{\text{mm}^2}}{30{,}3 \frac{\text{N}}{\text{mm}^2}} + \frac{4{,}7 \frac{\text{N}}{\text{mm}^2}}{32{,}0 \frac{\text{N}}{\text{mm}^2}} = 0{,}14 + 0{,}30 + 0{,}15 = 0{,}59 \rightarrow \text{OK}$$

$$\frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \le 1 \quad (4.30)$$

$$\frac{0{,}42 \frac{\text{N}}{\text{mm}^2}}{0{,}83 \cdot 19{,}3 \frac{\text{N}}{\text{mm}^2}} + \frac{13{,}1 \frac{\text{N}}{\text{mm}^2}}{30{,}3 \frac{\text{N}}{\text{mm}^2}} + 0{,}7 \cdot \frac{4{,}7 \frac{\text{N}}{\text{mm}^2}}{32{,}0 \frac{\text{N}}{\text{mm}^2}} = 0{,}03 + 0{,}43 + 0{,}10 = 0{,}56 \rightarrow \text{OK}$$

Some statistics of the book

224	Pages
122	Photos
270	Technical drawings and other illustrations
54	Diagrams & Charts
43	Tables
136	Equations
11 + 9	Calculation examples
~ 1000	Calculation cases