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Using of Cross Laminated Timber in Russia

Bachelor’s Thesis 2012

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ABSTRACT
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Using of Cross Laminated Timber in Russia, 52 pages, 3 appendices
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The purpose of this work was to study a way for the approval of new building materials from Finland in Russia. Also, it is a comparison of calculation conceptions according to SNiP and Eurocode. The subject of this work is Cross Laminated Timber panels, massive slabs for different types of structures.

The methods of this work were interviewing, self-investigation, consultation with specialists and using calculation programs. Many persons from universities and companies were interviewed about the main aspects of the problem. Special literature about the calculation of timber structure was learned.

A high level company should use qualitative materials. They can prove it in the test laboratories. Certification process is one of the most important questions of this work.

Also, to start every building process in Russia the contractor or company has to get the building permission. This process is described here, the main steps, time and documents.

In this work three causes for calculation were considered. It consists of floor, roof slabs and wall panel. Main checking according to SNiP and Eurocode was made. This work was done step by step in the table; it helps compare the results very easily.

The main conclusions observe the possibility of using CLT in Russia. The most popular materials are concrete, brick and lock timber in nowadays. The company should sell ready-made houses in township or, at least, CLT as a building material (slabs) for private house with detailed guidance. Sales would be successful with great advertisement or as a government program.

Analyzing the calculations shows small differences between two methods. Fundamentally, the methods are similar, but SNiP and Eurocode have different point of view on the cross layer. Fire and vibration calculations are done more detailed in Eurocode. Also, there are no strength classes for timber in Russia, the main parameters for CLT products have to be tested.

Keywords: Cross Laminated Timber, CLT, approvals, certification of the production, the building permission, comparative calculation, SNIP and Eurocode.

1 INTRODUCTION

1.1 Background

The main idea of Cross Laminated Timber can be very useful for Russia. It is important there to develop suburban, for example, in Saint-Petersburg and give allowable housing for people from the middle class. Nowadays, Northern America and Europe use CLT for solving this problem.

Why can CLT help? The features of the material will be described below, but the most important are fast and easy construction, using any materials for the production of CLT, any architectural decisions, strength and longevity.

Houses of CLT are built very fast. About 5 days are needed for a house with total floor area of $200m^2$. It gives big opportunities for individual housing construction and brings something new into the building process.

1.2 The targets

The targets of this work were formed by a company as a request. For easy understanding, the request can be presented in a few questions:

1. The validity of European Technical Approval (ETA) in Russia? In Finland CLT can be used according to this document. The approval allows using solid wood slabs as structural elements in buildings. It was given for “Stora Enso” by Deutsches Institut fur Dautechnik in 2011. It includes features of CLT, the main ideas for calculation, technical properties and drawings.
2. If ETA is not valid how to get approval for CLT in Russia? What kind of actions have to be done for it? The companies or the laboratories can help to solve this problem. How much time does it take?
3. Permission for the building. In the future Stora Enso wants to build a few objects. In Russia every building process must be allowed by local statement. How can the Finnish company get the permission? Time is one of the most important questions in this case.

4. Design criteria in Russia. What kind of factors must be taken into account in the design process?
5. Standard loads and impacts for different structures. Russian rules and norms for building give other values of live and proof loads. It means that the result of calculation for the same structure can be different. It is necessary to check.
6. Examples of calculation according to SNiP. The company asked to make the example of calculation on Russian style. CLT is a complicated material. It has an unusual structure and this problem SNiP and Eurocode solve differently. Will the result be the same or not? Strength, stability, deflections, vibration, fire-resistance must be taken into account in the calculations. Three main structures will be analyzed: wall panel (C3s 100 mm), floor slab (L5s 160 mm), roof slab (L5s 140 mm).

This work has been divided into two main directions (Figure 1.1). The first is organizational part. It includes the first three questions. The second part is the calculations (other questions are considered).

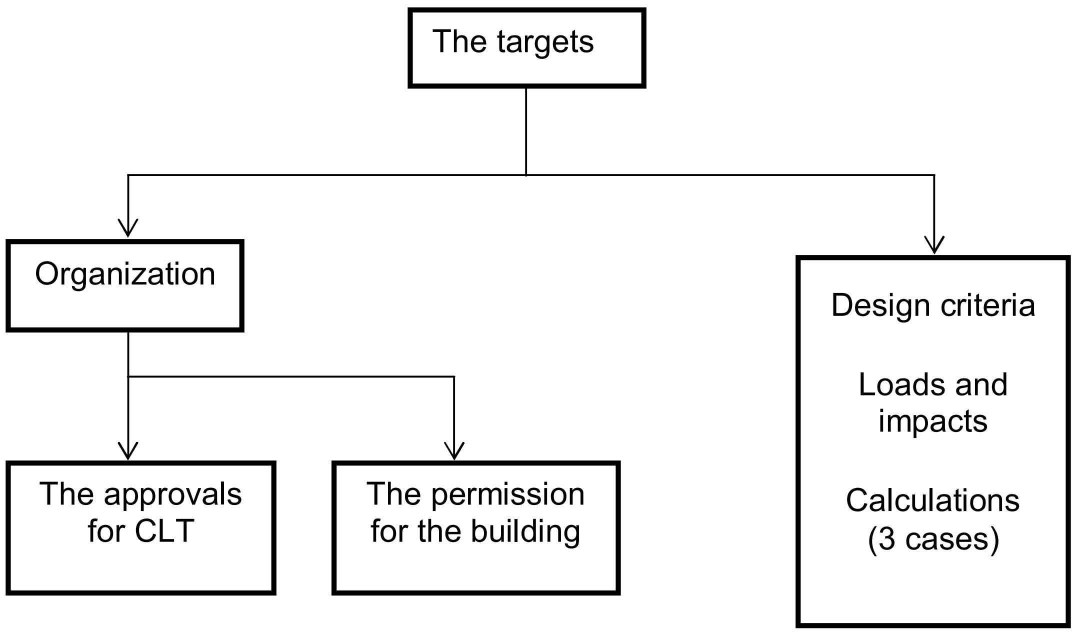


Figure 1.1 The way of investigation

1.3 Restrictions of the work

This work considers two-storey individual house for one family. The total floor area is about 70 m^2. The process for getting the building permission is described for individual house. The work does not take into account demands for public buildings: offices, schools, stores etc.

The calculation is done only for typical CLT products (slabs). There are no examples of calculations of beams, columns and rafters. Connections between elements are not calculated.

2 CROSS LAMINATED TIMBER AS A BUILDING MATERIAL

2.1 Overview

Cross laminated timber (CLT) is a new building system of interest in North American construction. It is a cost-competitive wood-based solution that complements the existing light and heavy-frame options, and is a suitable substitute for some applications which currently use concrete, masonry and steel.

It is a flexible building system, allowing for long spans and it can be used in all assemblies (e.g., floors, walls or roofs). Also, a high degree of finishing preinstalled off-site is possible. Its ability to be used as a panelized and or modular system makes it ideally suited for additions to existing buildings. It can be used jointly with any other material, such as light wood-frame, heavy timbers, steel or concrete, and accepts various finishes. (Cross Laminate Timber: a primer, 2001, slide I)

CLT is a multi-layer wooden panel made of lumber. Each layer of boards is placed cross-wise to the adjacent layers for increased rigidity and stability. The panel can have three to seven layers, or more, normally in odd numbers, symmetrical around the mid layer. Formaldehyde-free and environmentally friendly adhesives are employed for bonding. The cross structure of CLT components guarantees integral stability. The solid wood building system consists of ready-to-use building components which are assembled to form complete frameworks. Dimensional lumber is the main input material. It is possible to use low grade for the interior layers and higher grades for the outside and it can be pre-dressed (planed) or dressed at the factory once the panel is assembled. While softwoods dominate, it is feasible to manufacture CLT using hardwoods like poplar or even hybrid panels (e.g., OSB, LSL, OSL and LVL). (Cross Laminate Timber: a primer, 2001, slide 1)

Figure 2.1 shows a small part of CLT panel. It is a cube with dimensions 10x10x10cm. It has 5 layers. Every layer is perpendicular directed to each other.

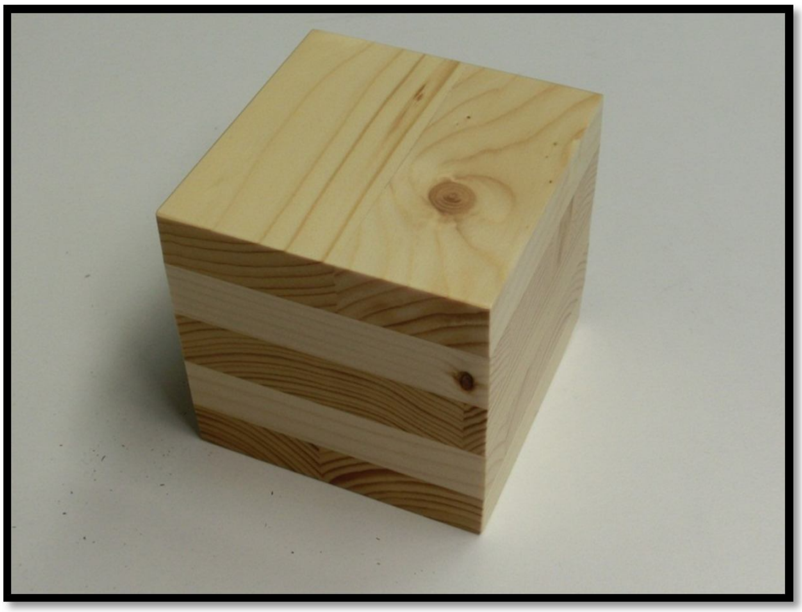


Figure 2.1 The part of CLT panel

Typical CLT products look like massive panels with certain dimensions. It is shown in figure 2.2:

Figure 2.2 Typical CLT products (eni.info internet site, http://www.esi.info/detail.cfm, Natural Recources Canada, http://www.nrcan.gc.ca/science/story/6000)

Because CLT is made of wood it possesses a number of positive environmental characteristics common to all wood products. These include carbon storage, less manufacturing greenhouse gas emissions than non-wood materials, and an overall lighter environmental footprint than non-wood materials, according to life cycle assessment studies.

CLT buildings can perform quite adequately in terms of sound performance as well as in their resistance to earthquakes and fire. Since it is prefabricated, the system is precise, and provides a construction process characterized by: faster completion, increased safety, less demand for skilled workers on site, less disruption to the community and less waste. (Cross Laminate Timber: a primer, 2001, slide I)

CLT is extremely versatile and is perfectly combinable with other construction materials. As a result of its extreme load distribution properties in both directions, CLT presents no limitations for architectural, residential or utility building projects. This is a significant reason for its increasing use in the construction of detached and multi-tenant residential properties or in the construction of commercial and industrial premises.

In addition, the enormous load-bearing and rugged properties of CLT ensure the increasing popularity of this high-quality construction product in the construction of bridges, carports, ancillary buildings, wood or concrete composite ceilings and in many other fields. (Stora Enso Wood Production, http://www.clt.info/index.php?id=3&L=2)

Element properties of CLT are shown in the next table (StoraENSO production):

Table 2.1 Technical details (Stora Enso Wood Production, http://www.clt.info/index.php?id=9&L=2)

Width:	up to 2,95 m
Length:	up to 16 m
Thickness:	19 mm, 27,5 mm, 35 mm and 42 mm
Pre-cutting:	Any cuts for windows, doors, and so on
Wood types:	Spruce (Pine and Larch) on requesst
Grading:	C 24 / C 16 (in line with DIN 4074) higher grades on request
Moisture content:	12% +/- 2%
Bonding adhesive:	Formaldehydfree adhesive for edge bonding, finger jointing and surface bonding
Optical qualities:	Standard and visible quality
Surface finish:	Sanded

Table 2.1 gives an understanding about the product. There are the main dimensions, materials, grade classes, moisture content and information about adhesive and quality.

2.2 History

Initial development of CLT took place in Lausanne and Zurich, Switzerland in the early 1990s. Several companies started production using proprietary approaches. In 1996 Austria undertook an industry-academia joint research effort that resulted in the development of modern CLT. For several years progress was slow but in the early 2000s construction with CLT increased dramatically, partially driven by the green building movement; but also due to better efficiencies, code changes (e.g., Sweden, the Netherlands), and improved marketing and distribution channels. An important factor has been the perception that CLT is a “not light” construction system. European producers have followed a proprietary approach to manufacturing with European Technical

Approval (ETA) reports that allow them to operate, however there are efforts under way to develop a European (EN) standard. Typical building types include multi-family apartment buildings and educational buildings. The countries leading in the use of CLT are Austria, Germany, Switzerland, Sweden, Norway, and the UK with 0,3 million m^3 constructed in place and a 0,6 to 1,0 million m^3 forecast for 2015. New plants are soon to be built in Sweden, Australia, and North America. CLT is also known as X-lam ("cross lam") and "massive timber". (Cross Laminate Timber: a primer, 2001, slide 2)

The main European manufacturers are:

- KLH (Austria, UK, Sweden)
- Binderholz (Austria)
- Martinsons (Sweden)
- Moelven (Norway)
- Stora Enso (Austria)
- Thoma Holz GmbH (Austria)
- FinnForest Merk (Germany/UK)
- HMS (Germany) (Cross Laminate Timber: a primer, 2001, slide 1)

Every company has almost the same production process. The main differences are glue and dimensions of elements.

2.3 Production process

The manufacturing process consists of the following stages:

2.3.1 The lumber drying

The boards must be kiln dried to a moisture content of 12% ± 2% depending on target location. Proper moisture content prevents dimensional variations and surface cracking. Lumber can be procured dried or further drying may be needed at the factory. This stage is shown in figure 2.3.

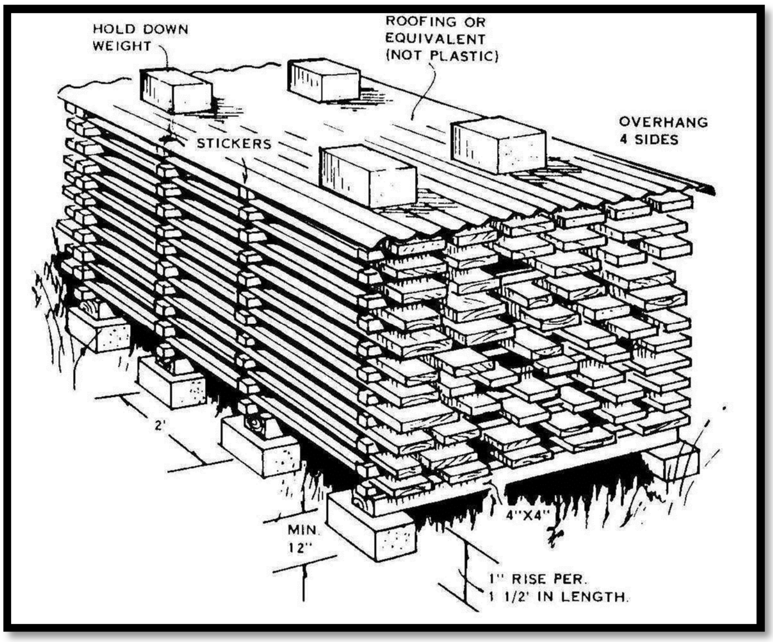


Figure 2.3 Lumber drying stage (A Positive Economic Attitude, http://www.lcida.org/airdry.html)

The parts of the future panel or slab are dried together. The parts cannot touch each other, the necessary distances are shown. It is very important to keep proper moisture content.

2.3.2 Finger jointing

Trimming and finger jointing are used to obtain the desired lengths and quality of lumber. Figure 2.4 shows a common view of the connection.

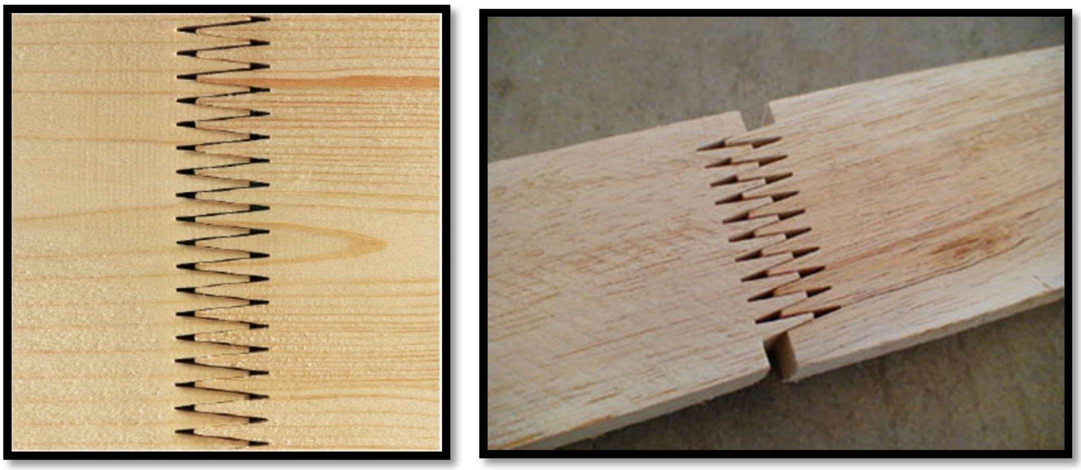


Figure 2.4 Connection with finger jointing (Made-in-China.com, http://www.made-in-china.com/showroom/woodwintimber/product-detailZoKJWfkbrLVv/China-Finger-Joint-Wood.html)

In the ends boards are connected through the “fingers”, on sides – with glue. Layers are connected with adhesive to each other.

2.3.3 Panel Assembly

Panel sizes vary by manufacturer. Typical widths are 0,6, 1,2, and 2,95 m (up to 4 m) while length can be up to 24 m, and thickness can be up to 0,5 m. The outer layers of panels used as walls normally orient boards with the grain direction parallel to vertical loads to maximize resistance. Likewise, for floor and roof systems the exterior layers run parallel to the span direction. The final width is obtained by joining panels together. Transportation regulations may impose size limitations. The assembly process can take from 15 minutes to 1 hour depending on equipment and adhesive. (Cross Laminate Timber: a primer, 2001, slide 2). It is presented in figure 2.5.

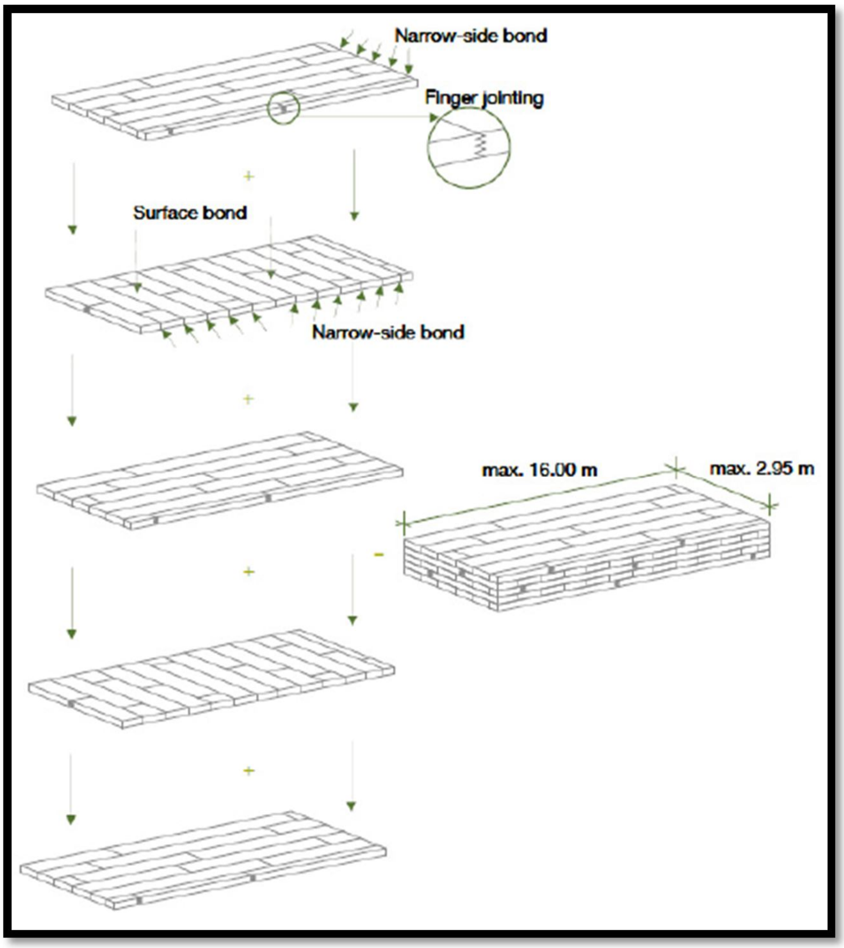


Figure 2.5 Assembly process schema (Stora Enso, Building Solution Urban construction, 2011, slide 4)

2.3.4 Glueing

Glue is the second input in CLT. Interior or exterior polyurethane (PUR) adhesives are normally used (formaldehyde and solvent free) although MUF and PRF may be used as well. Face and edge gluing can be used.

2.3.5 Press

The right pressure and homogeneity are critical. Hydraulic presses dominate, however the use of vacuum and compressed air presses is also possible, depending on panel thickness and adhesive used. Vertical and horizontal pressing are applied.

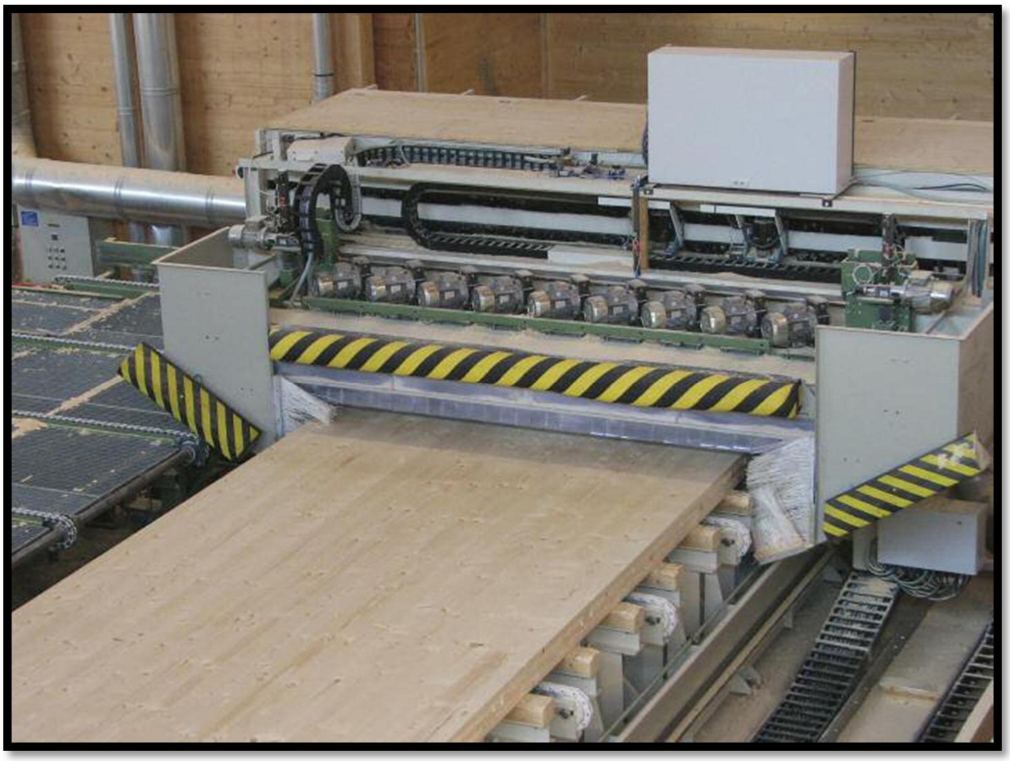


Figure 2.6 Pressing machine

Figure 2.6 shows the machine which presses CLT layers to each other sector by sector.

2.3.6 Planer and sander

The assembled panels are planned or sanded for a smooth surface. A special machine makes this work. It is presented in figure 2.7.

Figure 2.7 Planning machine

2.3.7 Computer Numerical Control (CNC) router

CNC routers allow high precision. Panels are cut to size; openings are made for windows, doors and service channels, connections and ducts.

Figure 2.8 CNC Router

The figure above shows a machine which allows cutting openings with any configuration. By this way, any architectural decisions can be realized.

2.3.8 Quality control

Compliance with product requirements prescribed in the product standard must be checked at the factory (e.g., bending strength, shear strength, delamination).

2.3.9 Carpentry room and finishing

Installation of insulation and drilling for openings may take place at the factory. (Cross Laminate Timber: a primer, 2001, slide 3)

The production volume depends on the company, it is approximately 4000 m^3-71000 m^3 per year. Every company has its own list of products. Standard structures of StoraENSO Company are shown in the next figure:

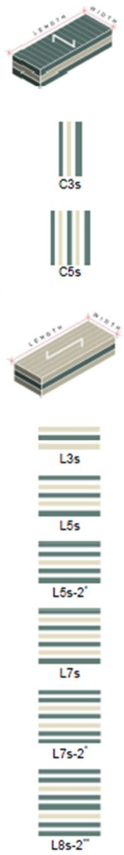
Table 2.2 The list of products (Stora Enso Wood Production, CLT Standard Structures, 2001, www.clt.info/index.php?id=80&L=2)

C-Boards

Nominal thickness [mm]	Designation [--]	Layers [--]	Lamella structure [mm]						
			C	L	C	L	C	L	C
60	C3s	3	20	20	20				
80	C3s	3	30	20	30				
90	C3s	3	30	30	30				
100	C3s	3	30	40	30				
120	C3s	3	40	40	40				
100	C5s	5	20	20	20	20	20		
120	C5s	5	30	20	20	20	30		
140	C5s	5	40	20	20	20	40		
160	C5s	5	40	20	40	20	40		

L-Boards

Nominal thickness [mm]	Designation [--]	Layers [--]	Lamella structure [mm]						
			L	C	L	C	L	C	L
60	L3s	3	20	20	20				
80	L3s	3	30	20	30				
90	L3s	3	30	30	30				
100	L3s	3	30	40	30				
120	L3s	3	40	40	40				
100	L5s	5	20	20	20	20	20		
120	L5s	5	30	20	20	20	30		
140	L5s	5	40	20	20	20	40		
160	L5s	5	40	20	40	20	40		
180	L5s	5	40	30	40	30	40		
200	L5s	5	40	40	40	40	40		
160	L5s-2*	5	60	40	60				
180	L7s	7	30	20	30	20	30	20	30
200	L7s	7	20	40	20	40	20	40	20
240	L7s	7	30	40	30	40	30	40	30
220	L7s-2*	7	60	30	40	30	60		
240	L7s-2*	7	80	20	40	20	80		
260	L7s-2*	7	80	30	40	30	80		
280	L7s-2*	7	80	40	40	40	80		
300	L8s-2**	8	80	30	80	30	80		
320	L8s-2**	8	80	40	80	40	80		



Two main CLT products are shown on the table above. The C-board is used for wall panel and partition walls. The main layers are directed from bottom to top for better load transferring and good stability.

The next one is L-Boards that are used for floor and roof structures. The main layers are directed along the span. This panel has great bending strength.

2.4 Connections between CLT panels

One of the most important questions is connections. CLT panel is big and massive but jointing is easy to do. Common types of connections in CLT assemblies are done as follow.

2.4.1 Wall to foundation

These connection examples are shown in figure 2.9.

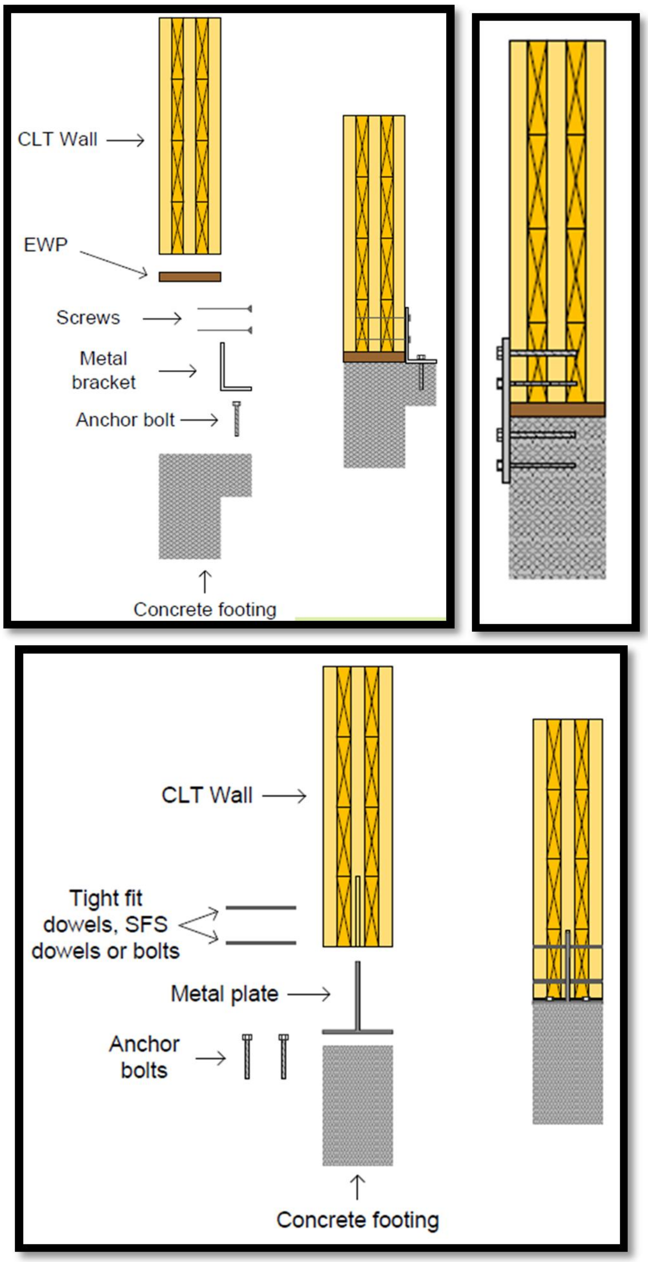


Figure 2.9 Different types of connections between wall and foundation (M. Mohammad, 2011. “Connections in CLT assemblies”, slide 18, 19)

The connections in figure 2.9 are performed through metal plates or EWP (Engineering Wood Product) with anchor bolt and screws easily and fast.

2.4.2 Wall to wall

It includes outside and inside walls. Examples are shown in figure 2.10.

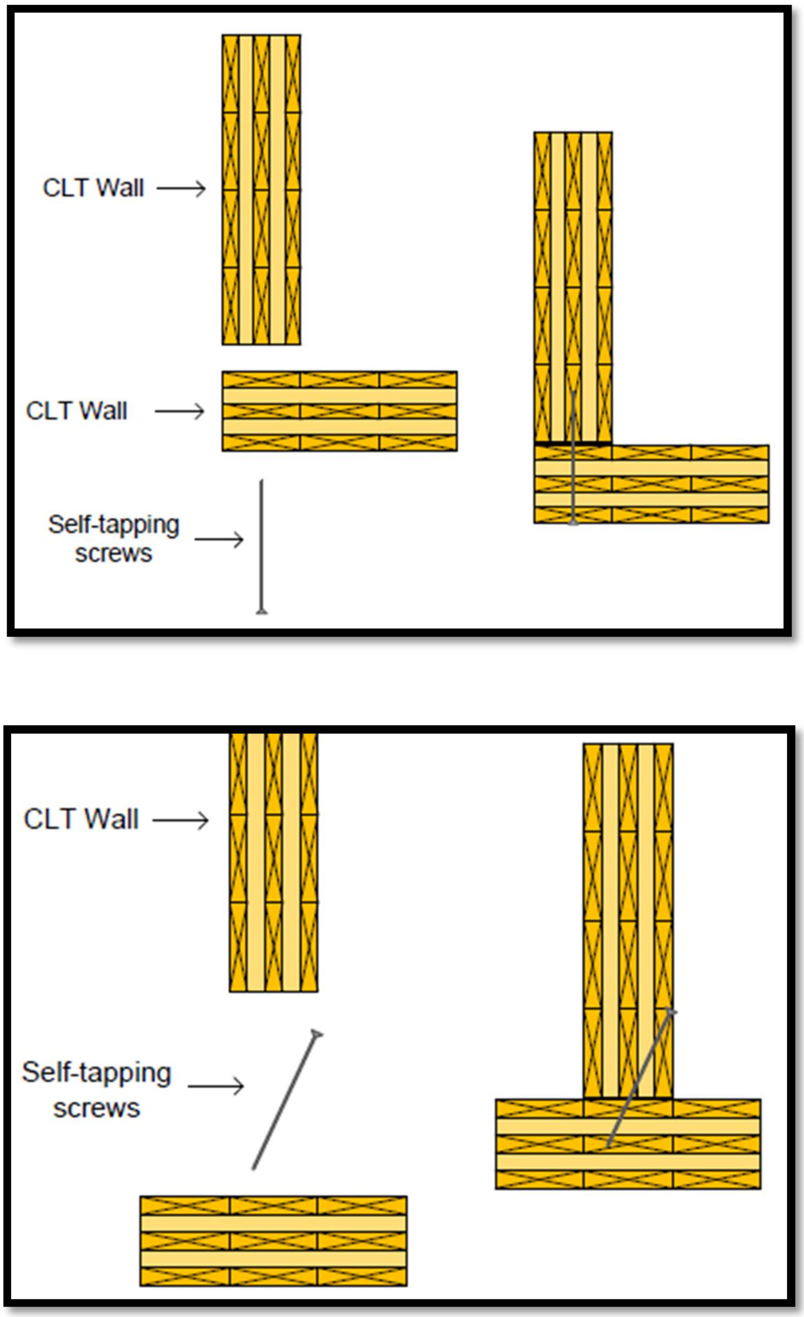


Figure 2.10 Connections between walls with screws (M. Mohammad, 2011. “Connections in CLT assemblies”, slide 21)

The figure above shows connections through diagonal and strait screws. It is used for exterior and interior walls.

Also, this can be done with metal plates and nails or self-tapping screws (figure 2.11)

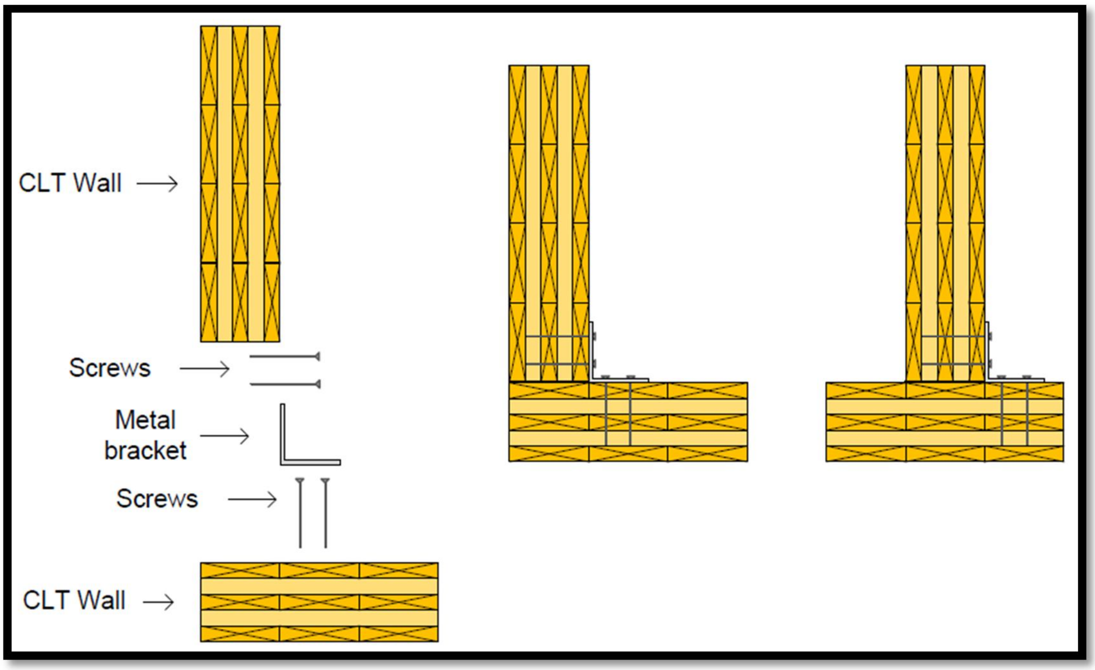


Figure 2.11 Using metal plates between walls (M. Mohammad, 2011. “Connections in CLT assemblies”, slide 22)

2.4.3 Floor to floor slab

Common floor to floor slab connection examples are shown in figure 2.12.

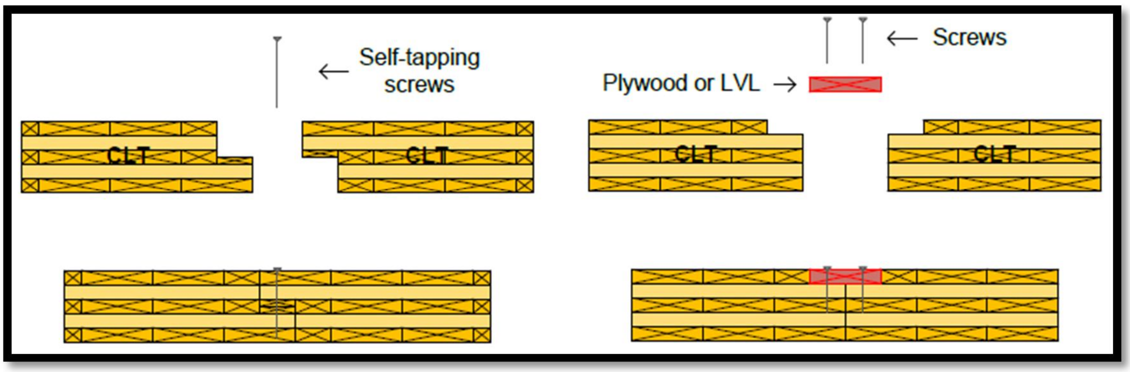


Figure 2.12 Two types of connections between floor slabs (M. Mohammad, 2011. “Connections in CLT assemblies”, slide 14)

There are many methods to connect floor slabs. Figure 2.12 presents the simples ones. The left type has better insulation, the right is easier to make. KNAPP Company offered an interesting connection with using “locks”. It is shown in figure 2.13.

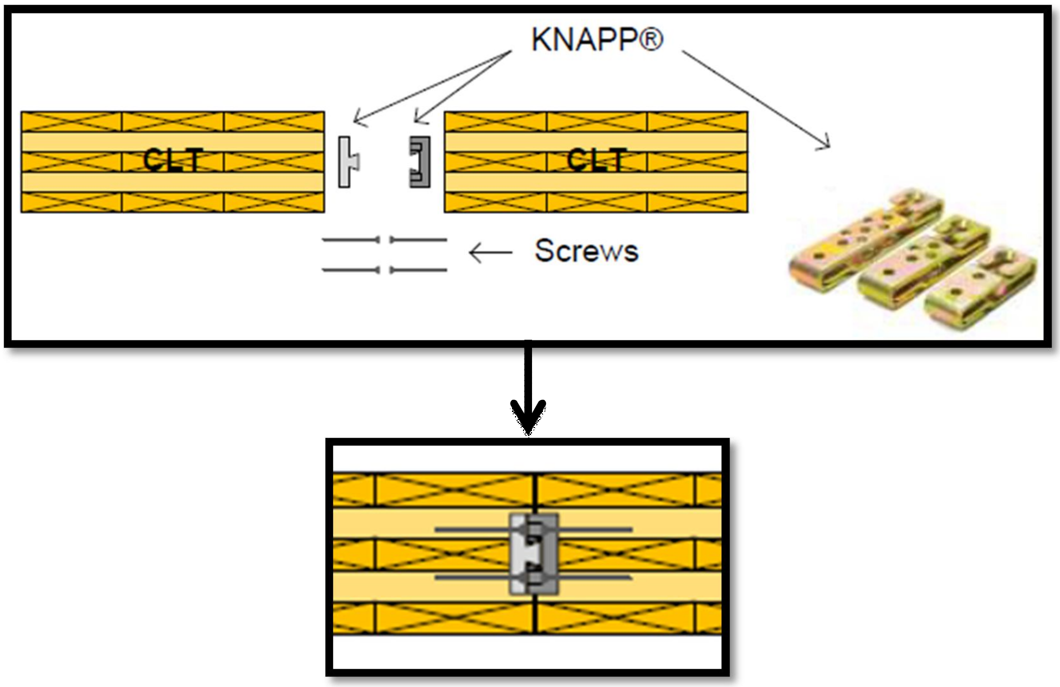


Figure 2.13 Details and the result of KNAPP connection (M. Mohammad, 2011. “Connections in CLT assemblies”, slide 16)

The main problem of KNAPP system is making a groove for details, but after that connection between slabs looks like a “lock” and it can be easily demolished.

2.4.4 Wall to floor (roof)

The most commonly used system between wall and floor is shown in figure 2.14. This method is suited for roof panels too. It includes screws or nails and metal brackets. Connection with diagonal screws (figure 2.15) can be made instead of the first type. Also, EWP or metal angle can be used like a support for floor panel (figure 2.16).

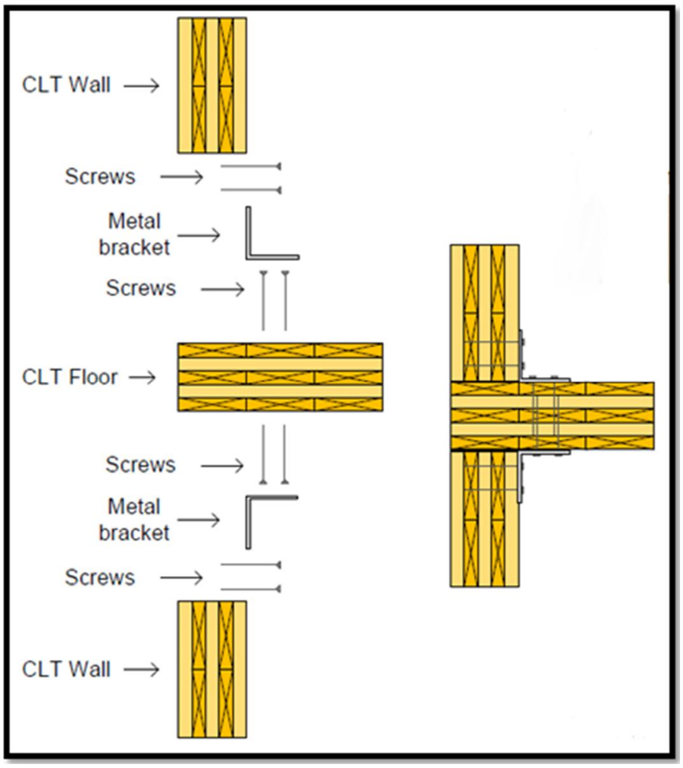


Figure 2.14 Connection wall to floor structure with metal brackets (M. Mohammad, 2011. “Connections in CLT assemblies”, slide 24)

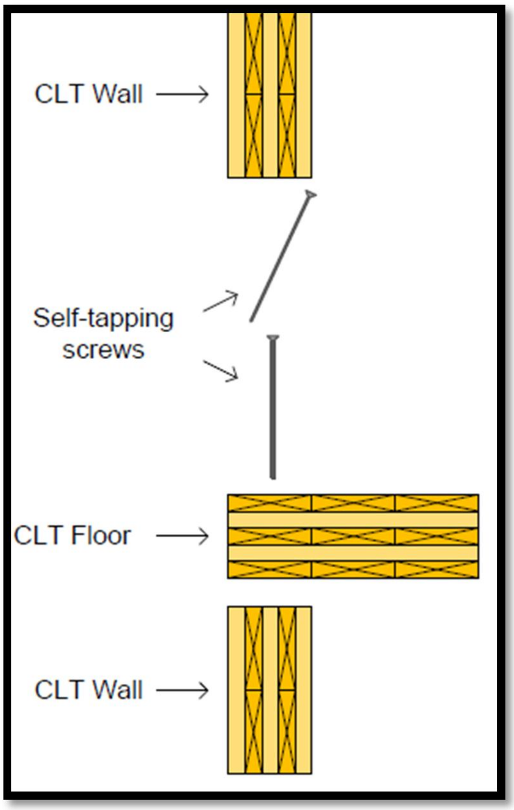


Figure 2.15 The same connection, but with diagonal screws (M. Mohammad, 2011. “Connections in CLT assemblies”, slide 25)

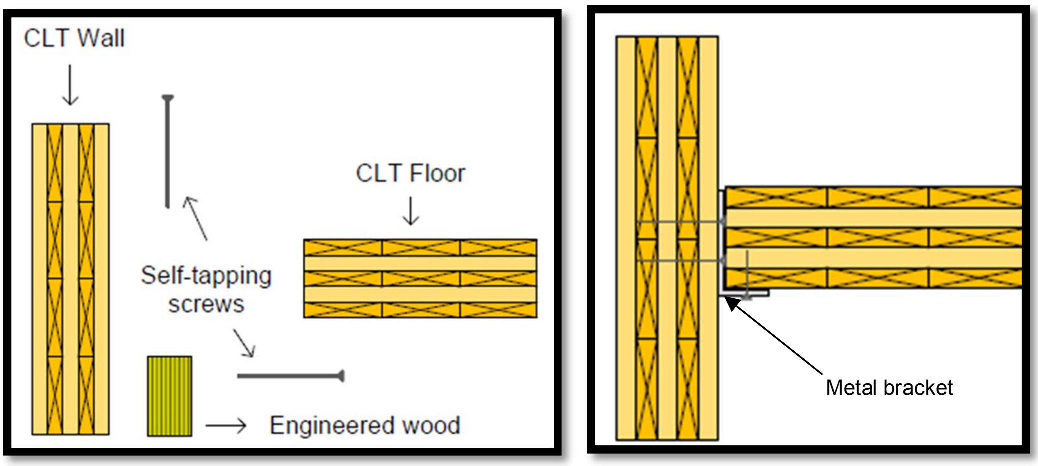


Figure 2.16 Connections with supports (M. Mohammad, 2011. “Connections in CLT assemblies”, slide 27)

All connections are articulate made and elements have a simple static model.

The basic panel to panel connection can be established through half-lapped, single or double splines made with engineered wood products. Metal brackets, hold-downs and plates are used to transfer forces. Innovative types of connection systems can also be used, including mechanical and carpentry connection systems. (Cross Laminate Timber: a primer, 2001, slide 11)

Dowel-type fasteners for connection of CLT panels:

- Nails
- Screws (traditional and proprietary self-tapping)
- Glulam rivets
- Dowels
- Bolts (Cross Laminate Timber: a primer, 2001, slide 12)

Nails in the lateral surfaces of "CLT - Cross Laminated Timber" might not be taken into consideration as load-bearing. These parts are known to everyone (European Technical Approval 08/0271, 2011, p.16)

2.5 Features

2.5.1 Environmental performance

CLT likely has better characteristics than functionally equivalent concrete and steel systems in several aspects of environmental performance.

European marketing literature on CLT often refers to the renewability of wood, recyclability, recoverability, carbon storage, etc.

CLT's cited positive environmental attributes have also been identified as key advantages for CLT in North America.

2.5.2 Fire performance

CLT assemblies can inherently have excellent fire-resistance due to the thick cross-sections which, when exposed to fire, char at a slow and predictable rate.

CLT construction typically has fewer concealed spaces within wall and floor assemblies which also can reduce the risk of fire spread.

Charring rate experiments conducted in Switzerland found that the adhesive used in the manufacturing of CLT panels can have a significant impact on the charring rate. This was because the protective char layer that forms and insulates the unburned wood from fire, fell off in layers when some polyurethane adhesives were used. When CLT panels with more traditional adhesives were used, the charring rate was found to be the same as that assumed for solid timber and Glulam members. (Cross Laminate Timber: a primer, 2001, slide 7)

2.5.3 Vibrations

The low damping ratio is one of the weaknesses of CLT floors. Damping to a large extent is affected by the degree of integration of the floor to the surrounding structural parts, especially by the addition of partitions.

Any measures for increasing the damping ratio of CLT product design and floor construction details will make CLT floor systems more cost-effective and better positioned to compete with concrete slabs.

Elevators can be detailed in such a way that their operation does not create perceptible vibrations.

2.5.4 Thermal performance

European sources often suggest that CLT provides thermal mass for a building, which can be associated with heating and cooling energy reductions.

CLT has the same fundamental thermal properties as the wood from which it is made. In terms of heat capacity and thermal resistance wood is average among building materials. Values for CLT are improved simply through the virtue of its thickness.

Good air tightness may be achieved. Foam tape is normally used at the joints for this purpose. Edge-gluing of the boards also helps. (Cross Laminate Timber: a primer, 2001, slide 9)

2.6 Examples of CLT-constructions

2.6.1 MURRAY GROVE

CLT at Murray Grove – the world's tallest modern timber residential building, designed by Waugh Thistleton Architects. It is a residential building with 1+8 stories. The main load bearing structures are wall panels and floor slabs. The building is situated in London. The year of construction was 2008. The main façade of the building is shown in the next figure.

Figure 2.17 Murray groove. The main view (e-architect, http://www.e-architect.co.uk/scotland/cross_laminated_timber.htm)

The total floor area is 2,352 m^2. For the building 950 m^3 of CLT (Walls: 128 mm, Floors: 146 mm) was used. The construction speed is 1 floor per 3 days.

CLT choice saved 22 weeks compared with concrete (30%). The basement was avoided since there was no need for heating system. No tower crane was used.

2.6.2 LIMNOLOGEN

Limnologen is Sweden's highest new residential buildings in wood (CLT). Walls and slabs are made of massive wood. Construction was done in a dry environment under a movable roof (figure 2.18).

Figure 2.18 LIMNOLOGEN complex. Movable roof under the last building (SESAC, http://www.concerto-sesac.eu/spip.php?rubrique141)

The residential building with 1+7 stories, the last as duplex. There are four similar building. The building is situated in Sweden. The year of construction was 2008.

The total floor area is 10,700 m^2. For the building 4,800 m^3 of CLT was used. The construction speed is a little bit slower, 1 floor per 4 days.

Tension rods were chosen to resist wind lift-up. Load-transferring connectors between walls were not needed. Floor heating system is cumbersome.

2.6.3 NORWICH OPEN ACADEMY

It is an educational building with 3 stories. The building is situated in the United Kingdom. The year of construction was 2010. The main view is shown in the next figure.

Figure 2.19 NORWICH OPEN ACADEMY. The main view (BBC News, http://www.bbc.co.uk/news/uk-england-norfolk-11222767)

Total floor area is 9,500 m^2. For the building 3,600 m^3 of CLT was used. The construction speed is 18 weeks.

The main structures is CLT panels for walls, floors and roof, also there were used studs, beams and arches made of glued laminated timber. The arches were necessary because of big hall in the middle of the building. Inside walls have big pre-cut openings and low load-bearing capacity because of it. Inside panels are connected to bearing studs.

2.6.4 I.S.C. NORSK SALSENTER

It is an equestrian center. The building is situated in Norway. The year of construction was 2010/February. Envelop structure are made of CLT panels. Load-bearing structures are studs and one-pin arches made of glued laminated timber (figure 2.20)

Figure 2.20 Views of the inside structures (Norsk salsenter, http://www.norsksalsenter.no/salsenteret)

The total floor area is 1,500 m^2. For the building 225 m^3 of CLT was used. The construction speed is impressive - 5 days.

Box-type warehouses are an ideal application for CLT: fast and simple to erect, economically well.

3 APPROVALS AND PERMISSIONS FOR CLT

3.1 Approvals

The first part is the approvals for CLT in Russia. The main question is "How to get it for CLT?"

There are many companies and laboratories in Russia which have the statement permission to get conclusions about CLT. There are certification body and test centers. They work together but the first contact should be with certification body. The company has to send an application to the certification body with a request. The request will be carefully looked by specialists.

The next step is the choice of certification scheme. The certification scheme is a set of actions, formally accepted as a proof of conformity to specified requirements. There are ten different schemes.

Scheme 3 and 3a match for CLT:

Certification scheme 3 requires the sample of the product for tests, but without studying the production and after the issuance of a certificate of compliance - inspection control by testing a sample of the goods before shipment to the consumer. The selected sample is tested in an accredited laboratory.

Certification scheme 3a includes obligatory testing of a sample of the goods and studying the state of production, as well as supervisory control similar to the control conducted by scheme 3. Certification Scheme 3 and 3a are held for the production of a quality that is stable over a long period of time.

The certificate of conformity is given for 3 years. It includes annual inspections of the production process and factories. The company takes all costs of this process.

There is no obligatory certification in Russia but the certificate of conformity has a statement approval. It guarantees the good qualities of the product. It is a document for every case.

The certification body has to contact some laboratory or test center for getting the certificate of conformity. After that tests of the product have to be done.

Is European Technical Approval (ETA) valid in Russia? The main problem is absence of a document to compare the results of the tests. European Technical Approval was made by Deutsches Institut fur Dautechnik. This institute has no Russian agreement and ETA is not valid. It means that a new document for CLT has to be made in Russian style. The document contains all CLT features and necessary information. It names the standard of organization (STO) and looks like a small SNiP. The purpose is the same. STO can be made by an accredited test center at the same time as the tests. Also, for this work is very important to have a department in Russia to make contracts.

The scheme described before is presented in figure 3.1.

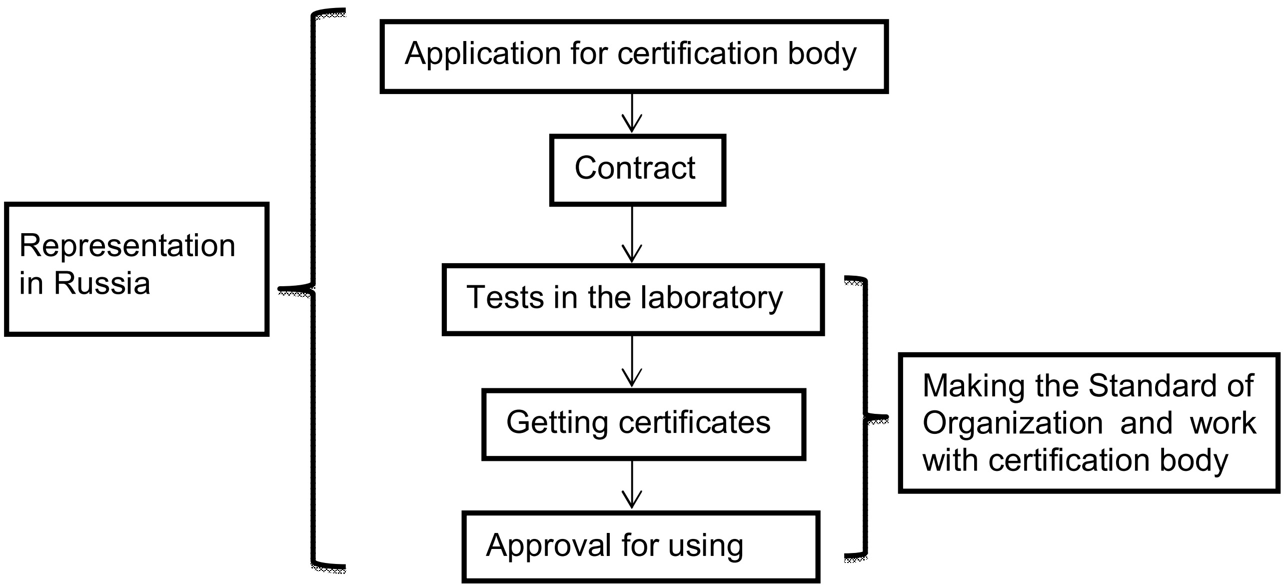


Figure 3.1. Certification process

3.2 The building permission

In Russia all building processes are regulated by **Urban Development Code**. It rules for building, documents and expertise. The document is made by government.

To start the building process the company should get **the building permission**.

The building permission is a document confirming that project documentation responds to requirements of **the urban plan of the land** and gives a right for a builder to carry out the building, reconstruction of capital construction objects, as well as their renovation, instead for causes provided the Code. (Urban Development Code of Russian Federation, 2009, p.49)

According to the request from Stora Enso the target is two-storey private house. The house is classified as an **object of individual housing construction** in Russia. For these types the process is simpler.

These types are included in **objects of individual housing construction:**

- Detached dwelling houses not higher than 3 floors for one family
- Dwelling houses not higher than 3 floors consist of a few blocks not more than 10 blocks, each block for one family. These blocks have a total wall without apertures.
- Multi-flat buildings not higher than 3 floors consist of one or a few blocks, the amount of the blocks is not more than 4. Every block has a few flats with own exit at the street.
- Detached capital construction objects not more than 3 floors, the total volume is not more than 1500 m^2 and not for residence of citizens or industrial processes, instead dangerous, technical hard and unique objects.
- Detached capital construction objects not more than 3 floors, the total volume is not more than 1500 m^2, for industrial processes without sanitary-protective zones. (Urban Development Code of Russian Federation, 2009, p.46)

For getting **the building permission** for objects of **individual housing construction** it is necessary to have the following documents:

- The land document confirming that the company is an owner of the land
- The urban plan for the land (takes about 30 days)
  - ✓ The land document (with permission for **individual housing construction**)
  - ✓ The statement for local self-government
  - ✓ All information about the project (a package of the following drawings: general plan, facades, floor plans and sections, details and calculations in the explanatory note)
- Development plan with all objects on the land (can be done by the company)

This process takes about 1 year. All departments work as fast as possible. In the future it will be made simpler and faster according to Russian president's order.

4 CROSS LAMINATED TIMBER IN RUSSIA

4.1 The technology

At Holzhaus in 2007 International Exhibition, Paleks-Stroy Construction Company presented solid timber panel, a completely new technology for cross-laminated timber panel housing.

CLT is a principal new system in Russia. The company took CLT technology and dimensions from Austrian company KLH. It was the first company which tried to put in place CLT production process in Russia. Also, Ledinek Company from Slovenia presented new solutions of CLT on the conference in Moscow in 2011. The conference's topics were:

- CLT panels in construction of houses, community and industrial facilities in Europe.

- CLT projects in Russia – “Ladozhsky Integrated House-Building Factory”
- Equipment for CLT manufacturing and processing

The main idea of all these actions is simplification of construction process and reducing construction time. It is very important to develop low-rise building and countryside in Russia and, also, make individual housing allowable.

In Russia the panels are divided into two classes – economy and deluxe. Economy panels are made of the 5th grade timber or lower. In fact, it is sawmill waste. When panels are sawn into ready components they are milled for service lines. Just after the house is erected and service lines installed, the ceiling, floor and walls may be finished because panels do not shrink, deform or crack. At the customer’s request, the interior can be finished with wood or plasterboards; the latter mounted directly on the panel without expensive fixtures. In its turn, plasterboards can be finished with decorative plaster, wallpaper or paint. Flooring types are abundant too. However, it is important that interior materials have the same vapor permeability as timber used in panels.

Surface layers of deluxe panels are made of higher-grade timber, so that panels are more aesthetic. The panel surface can be milled to imitate a beamed wall or be smooth as a furniture panel. In deluxe panels, service channels are drilled inside the wall. The interior of such a house does not require any finishing. (Paleks-Story.Com, http://www.paleks-stroy.com/index.php?i1=1&i2=3&p=7)

At that time CLT was not so popular because people usually used bricks and locks for individual construction. These materials are cheap and known in Russia. The main problem in using CLT can be the price for $1m^3$ of the material. It should be lower or the same as typical Russian materials. Also, construction time can involve people to buy CLT. A good invested calculation should be presented to explain everyone why it is profitable.

Houses made of cross-laminated timber panels are aimed primarily at the purchasing capacity of the middle class. According to the manufacturers’ estimates, the projected price of 1 m^2 in such a house will be USD 1000, so a

200 m^2 house will be priced at USD 200000. The state of affairs in Russia’s mortgage lending system makes such houses affordable for the middle class.

4.2 The first project

In September 2008 near Moscow the first house of CLT panels was built. The building process took three days and many experts found the result very impressive.

The project name is “Roman”. The main view and plans are shown in the following figures.

Figure 4.1 Main view and plans (Paleks-Story.Ru, http://www.paleks-stroy.ru/index.php?i1=3&i2=3)

“Roman” is intended for round-year living for one family. There is a kitchen and a dining room, a living room with fireplace, a cabinet and a bathroom on the first floor. Sleeping rooms and another bathroom are situated on the second floor. The plans and view of the house are shown in figure 4.1. The total area is 215 m^2. The building process form foundation to roof is shown in figure 4.2.

Figure 4.2 Building process (Paleks-Story.Ru, http://www.paleks-stroy.ru/index.php?i1=3&i2=3)

Outside walls are decorated with natural stone and special boards. The roof is natural sand-cement tiling.

4.3 Economy

The domestic market to overstock changed after Russian ban on duty-free export of round timber. Under these conditions producers are looking for distribution channels inside Russia. Introduction of the cross-laminated timber technology, especially in Northern regions, may raise timber consumption manifold

The new technology will contribute to saving natural reserves of merchantable wood. Both sawmill wastes and wood stock that is not traditionally used in timber construction (fir, aspen, alder, and birch) can be used to produce cross-laminated timber panels.

A heat-insulated house helps to reduce energy consumption throughout the heating season. That parameter is very important in Russian case. (Paleks-Story.Com, http://www.paleks-stroy.com/index.php?i1=1&i2=3&p=7)

4.4 Certificates

The central research and development institute of building structures named after V.A. Kucherenko gave a conclusion about CLT's technology. Properties of CLT panels are described in the conclusion and CLT is recommended for using as a building material in Russia. Also the technology has technical approvals from many German companies.

Now a European Standard for CLT is under construction. It is called "Cross-laminated timber (Eurocode 5) design guide for project feasibility". It will be ready in September of 2012. European tests showed good strength properties and, also, good fire endurance. (Paleks-Story.Com, http://www.paleks-stroy.com/index.php?i1=1&i2=3&p=7)

4.5 Future plans

Paleks-Stroy has made a decision to set up a plant in the Kaluga Region. It will manufacture, at full operating rates, up to 250,000 m^2 of cross-laminated timber panels and pre-fabricated components annually.

The factory will make deep timber recycling according to Russian statement's instructions about the development of this field. The important part is environmental friendliness of the manufacturing, wastes will be recycled and sawdust will be used for heating. Soot and charcoal will be used as fertilizer.

The technology and the main idea of the factory were approved by Russian Architectural Union. They sent a request for the president to develop prefabricated wooden housing and give an opportunity of distribute factories in Russia. This program was named "Allowable and comfortable accommodation for Russian citizens". Nowadays several projects are developed for building with CLT panels in different cities.

5 CALCULATIONS

5.1 Cases for calculation

In this chapter the calculation process of three main elements will be described. Floor and roof slabs, wall panel are taken. These elements are common structures of any building made of CLT.

The main idea of this work is to find differences in Eurocode and SNiP methods of calculation and understand what kind of tests must be done in the laboratory, because some strength values cannot be used.

Static models, loads, materials of each case will be described in APPENDICES. Commentaries about this work are in CONCLUSIONS.

6 CONCLUSIONS

6.1 About CLT and approvals for it

A few main words about this work:

- Russia is opened for new ideas, solutions and offers. Many industries must be developed; also, it is building industry. Many European companies work in Russia, they produce something or sell their production. Russians like it, because production has European quality.
- As for Cross Laminated Timber, it is not a new building system. As was said above, a few companies tried to produce it, but CLT has not found wide application. Production was not successful and nowadays it is difficult to find even one house made of CLT in a Russian suburban. Of course, there were many plans about CLT, but they were not realized.
- The main problem is the price of Cross Laminated Timber. There are many building materials that Russians know and use every day. They have low price and known properties. Bricks and locks are the most popular material.

- A good solution is to sell ready houses made of CLT not panels or slabs, but the price is still important here. This program must have a slogan, for example, “A village made with Finnish quality”. Nowadays, Finland is very popular in the North West district of Russia, also, in Saint-Petersburg. Everyone knows about Finnish quality and new interesting technologies there. This advertisement would be a motivation to purchase CLT houses.
- It is better to build a small suburban area (like a village) with houses made of CLT and sell these houses with a landscape. After that CLT technology will become a popular product. CLT has many undisputable advantages, but usually the most important is the price.
- Approval for CLT is very easy to get, because one company worked with this material a few years ago. Also, laboratory tests will be cheaper in Russia, these tests are obligatory. The tests will be described below.

6.2 Analyzing the calculation

There are no problems with CLT in every case. Commentaries about the calculation part:

- Cross Laminated Timber is an unusual structure for Russia, but it can be calculated according to SNiP with using common rules and formulas.
- The calculation process is similar; there are a few coefficients different from each other. Small differences are in collecting loads, determination of geometrical characteristics and strength checking.
- In Eurocode example the cross layer is not taken into account. In SNiP it is calculated like a reduction cross section via multiplying on reduction coefficient. The results are almost the same.
- Vibration calculation according to Eurocode is more detailed. Many parameters are taken into account. SNiP has one formula for this case, it includes geometrical parameters of the slab, dead and live load and human’s steps frequency. This formula gives a limit for deflection from steps and loads. Design deflection is determined with common formula for two-pin beams. This part is shown in APPENDIX 1.

- Also, Eurocode describes more exactly the deflection from any loads. It shows the behavior of the slab in the future from dead load. Three cases are calculated in SNiP: deflection from dead, live load and unit force 1kN, frequency from walking.
- SNiP allows fire calculation, but does not give formulas for it. There are many other demands for the main structures of any types of houses. They are presented in appendices. Fire endurance of the structure can be proved in the laboratory with typical burning tests. The laboratory will give a certificate about the results of the fire investigation.
- Finally, Standard of Organization is necessary for CLT. The results of the tests and calculations must be compared with some Russian document. There is no suitable document about CLT and strength classification is a new thing. Usually, STO contains the properties, dimensions, strength values for comparison, allowable deflections and fire rate of the material, and, also, materials for CLT, the production process, acceptance of the work and quality control. The company should order this work from one of the certification centers.

6.3 Future of CLT in Russia

According information from Forestry University CLT will find a place in individual housing in the future, but not in nowadays. Cast-in-place concrete construction is more popular in Russia for public and apartment buildings. Brick and timber locks are typical material for individual housing. Of course, building companies use new material or new methods, but very rarely. Usually, it is an experiment.

Several companies tried to introduce CLT, but they were not successful. It is still new system for Russia and few people have heard about it. Great advertisement can change the situation and involve people, new government programs can help here too.

Individual housing is very popular in Russia, but usually only adult people think about it and they like to use traditional materials and methods. Young people like new technologies, but usually they think about own flat in a city and, far into the future, about private house in a suburban.

There are two ways for good sells of CLT in Russia. Firstly, sell CLT like building material with adequate price and good maintenance on each building stage. Secondly, build a township with houses made of CLT and sell these houses, but very important to create there good infrastructure and find a place away from highway. Adequate price is important too.

7 FIGURES

8 TABLES

9 REFERENCES

SNIP II-25-80, 2002. “Timber Structures”

SP 64.13330.2011 SNIP II-25-80, 2011 “Timber Structures. Actualized version”

SP 20.13330.2011 SNIP 2.01.07-85 “Loads and Impacts. Actualized version”

Vdovin V.M., Karpov V.N., 1999. “Structures made from plastic and timber”. Moscow: ASV

Pilagin A.V., 2006. “Design of bases and foundations of buildings and structures”, Moscow: ASV

Otreshko A.I., 1957. “Timber Structures. Designer’s handbook”, Moscow: State Publishing House of Building and Architecture

“Puurakenteiden suunnitteluohje” eurocodi: EN 1995-1-1. RIL 205-1-2009

DIBt, 2011. European Technical Approval 08/0271, CLT-Cross Laminated Timber

Urban Development Code of Russian Federation from 29th of December 2009, № 190-F3, article 51.

M. Mohammad, 2011. “Connections in CLT assemblies”, Cross Laminated Timber Symposium, Vancouver

Pablo Crespell, Sylvian Gagnon, 2001. FPInnovations. “Cross Laminate Timber: a primer”, Canada

“Cross Laminated Timber Standard structures” from www.clt.info (Accessed in 7th of April, 2012)

“The UrbanTwoStorey™ concept” the project of a urban house. Made by StoraEnso

Calculation of the floor slab

Dimensions:

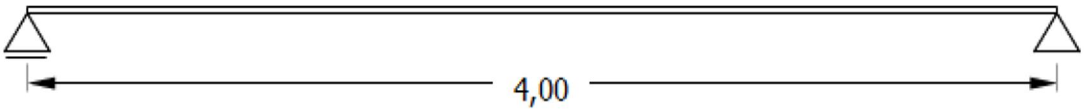


Figure A1.9.1 Static model

- l = 4,0 m - span
- w = 1,5 m - width
- h = 160 mm (CLT 160L5s)
- strength class – C24

Loads for Eurocode calculation:

- q_k= 2 kN/m^2 – live load
- g_k= 1,09 kN/m^2 – self-weight of the structure

Loads and impacts were taken from SNiP for calculation according to Russian rules. Take 160 L5s CLT slab with 4 m length and 1,5 m width. The slab can be calculated like a beam if ratio of width to length is more than 2:

$$\frac{w}{l} = \frac{1{,}5}{4} = 2{,}66 > 2$$

Floor structure is shown in figure below:

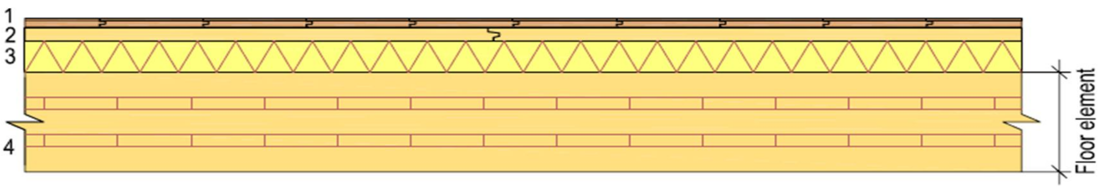


Figure A1.9.2 Floor structure with numbers

The numbers are:

1. Parquet – 1.5 cm
2. Participle board – 2.2 cm
3. Mineral wool – 5 cm

4. CLT L5s - 16 cm

Loads were collected according to Finnish and Russian rules. The calculation and the results are shown in APPENDIX 1.

Load for SNiP calculation are shown on the next table:

Proof load	γ_f	Design loads
Parquet $0{,}015m * 7\,kN/m^3 = 0{,}105\,kN/m^2$	1,3	0,136
Particle board $0{,}022m * 6\,kN/m^3 = 0{,}132\,kN/m^2$	1,2	0,172
Mineral wool $0{,}05m * 1\,kN/m^3 = 0{,}05\,kN/m^2$	1,2	0,06
CLT 160L5s $0{,}16m * 5\,kN/m^3 = 0{,}8\,kN/m^2$	1,1	0,88
Live load 1,5 kN/m^2	1,3	1,95
Sum: 2,587 kN/m^2		**Sum:** 3,198 kN/m^2

The calculation steps:

Floor slab	
Eurocode example	**SNiP example**
Impacts: Loads from structure G were taken from table. Loads for 1m of the slab: $q_g = 1{,}25 * K_{FI} * G_{kj,CLT} + 1{,}15 * K_{FI} * G_{kj} + 1{,}5 * K_{FI} * Q_{k,1} + 1{,}5 * K_{FI} * \sum_{i>1} \Psi_{0,i} * Q_{k,i} = 1{,}25 * 0{,}9 * 0{,}8\ kN/m + 1{,}15 * 0{,}9 * 0{,}29\ kN/m + 1{,}5 * 0{,}9 * 2\ kN/m = 5{,}01\ kN/m$ For this calculation a special programm was used. The programm provided by Stora Enso on www.clt.info. The main formulas for calculation will be shown, but the result value will be taken from the programm.	Live load and γ-coefficient are taken from SNiP 2.01.07-85* "Loads and Impacts" par.7, 8.2, table 8.3. **Design loads for 1m of the slab (width is 1,5m):** $q^d = P^d * w = 3{,}198\, kN/m^2 * 1{,}5m = 4{,}8kN/m$ **Proof loads for 1m of the slab (width is 1,5m):** $q^k = P^k * w = 2{,}587\, kN/m^2 * 1{,}5m = 3{,}88kN/m$
Bending moment and cross-axis force: $\mathrm{M_{y,d}} = \frac{\mathrm{q_d} \times \mathrm{l}^2}{8} = \frac{5{,}01\mathrm{kN/m} \times 4{,}0^2\mathrm{m}^2}{8} = 10{,}0\ \mathrm{kNm}$ $V_{z,d} = A = B = \frac{q_d * l}{2} = \frac{5{,}01\mathrm{kN/m} * 4{,}0m}{2} = 10{,}0kN$	**Bending moment in the middle:** $M_{max} = \frac{q^d * l^2}{8} = \frac{4{,}8\frac{kN}{m} * 4^2 m^2}{8} = 9{,}6kNm$ **Cross-axis force on the supports:** $Q_{max} = \frac{q^d * l}{2} = 9{,}6kN$
Comparative E-modulus: $\mathrm{n_2} = \frac{\mathrm{E_{2(crosslayer)}}}{\mathrm{E_v}} = \frac{370\ \mathrm{m/mm^2}}{11000\mathrm{m/mm^2}} = 0{,}03$	**Reduction coefficient:** $\mathrm{n_{red}} = \frac{\mathrm{E_{(crosslayer)}}}{\mathrm{E}} = \frac{370\ \mathrm{Pa}}{11000\mathrm{Pa}} = 0{,}034$
Effective cross-area: $\mathrm{A_{eff}} = 1200\ cm^2$ Cross layers are not taken into account.	**Reduction cross-area:** $\mathrm{A_{red}} = A_1 + A_{12} * \mathrm{n_{red}} + A_2 + A_{23} * \mathrm{n_{red}} + A_3 = 4 * 100 + 2 * 100 * 0{,}034 + 4 * 100 * 2 * 100 * 0{,}034 + 4 * 100 = 1213{,}6cm^2$
Gravity center of the cross area: $z_s = \frac{A_1 * \left(\frac{d_1}{2}\right) + 2 * A_{12} * \left(d_1 + \frac{d_{12}}{2}\right) * \mathrm{n_2}}{A_{eff}} + \frac{2 * A_{12} * \left(d_1 + d_{12} + \frac{d_2}{2}\right)}{A_{eff}}$ $z_s = 8\mathrm{cm}$	**Gravity center of the cross area relative to the lower edge:** $y_{c.g.} = \frac{\sum(A_1 * y_1 + A_2 * y_2 + A_3 * y_3)}{A_{red}} + \frac{\sum(A_{12} * y_{12} * n_{red} + A_{12} * y_{12} * n_{red})}{A_{red}}$

	$y_{c.g.} = 8cm$
Compliance of γ-factor: $\gamma_1 = \frac{1}{1+(\frac{\pi^2 * E_1 * A_1}{l^2} * \frac{d_{crosslayer}}{G * b})} = \frac{1}{1+(\frac{\pi^2 * 11000 * 40000}{4000^2} * \frac{20}{50 * 1000})} = 0{,}902$	Nothing similar has been found
Effective moment of inertia: $I_{eff} = I_1 + 2 * I_2$ $I_1 = \frac{b * h^3}{12} = \frac{100 * 4^3}{12} = 533{,}3\ cm^4$ $I_2 = \frac{b * h^3}{12} + \gamma_1 * A_2 * a^2 = \frac{100 * 4^3}{12} + 0{,}902 * 400 * 6^2 = 14443{,}7\ cm^4$ $I_{eff} = 533{,}3 + 2 * 14443{,}7 = 27580\ cm^4$	**Reductive moment of inertia relative to the c.g.:** $I_{red} = I_2 + 2 * \left(I_{12} + A_{12} * \left(\frac{d_2}{2} + \frac{d_{12}}{2}\right)^2\right) * n_{red} + 2 * \left(I_3 + A_3 * \left(\frac{d_2}{2} + d_{23} + \frac{d_3}{2}\right)^2\right) = \frac{100 * 4^3}{12} + 2 * \left(\frac{100 * 2^3}{12} + 2 * 100 * (2+1)^2\right) * 0{,}034 + 2 * \left(\frac{100 * 4^3}{12} + 100 * 4 * (2+2+2)^2\right) = 533{,}33cm^4 + 126{,}93cm^4 + 29866{,}67 = 30526{,}93cm^4$
Resisting moment: $\mathrm{W_{eff}} = \frac{\mathrm{I_{eff}}}{\gamma_1 * \mathrm{a_1} + \frac{\mathrm{d_1}}{2}}$ $\mathrm{W_{eff}} = 3{,}721cm^3$	**Reduction resisting moment:** $\mathrm{W_{red}} = \frac{\mathrm{I_{red}}}{y_{c.g.}} = \frac{30526{,}93cm^4}{8cm} = 3815{,}87cm^3$
Static moment: $S_{eff} = d_1 * b * z_{1s} + d_2 * b * z_{1s} = 2600cm^3$	**Reduction static moment of the half cross area:** $S_{\frac{1}{2},red} = A_1 * y_1 + A_{12} * y_{12} * n_{red} + \frac{A_2}{2} * y_2 = 100 * 4 * (2+2+2) + 100 * 2 * 0{,}034 + 100 * \frac{4}{2} * \frac{2}{2} = 2400cm^3 + 20{,}4cm^3 + 200 = 2620{,}4cm^3$
Bending resistance along the fibers: $\mathrm{f_{c,0,k}} = 21\mathrm{N/mm^2}$ $\mathrm{k_{mod}} = 0{,}8$	**Bending strength:** $\frac{M_{max}}{W_{red}} \leq m_m * f_{m,k}$

$\gamma_{\mathrm{m}} = 1{,}25$ $\mathrm{f_{c,0,d}} = \frac{21\mathrm{N/mm^2}*0{,}8}{1{,}25}$=13,44 $\mathrm{N/mm^2}$ **Bending stress:** $\sigma_{m,d} = \frac{M_d}{W} = \frac{1000\ kN/cm}{3721cm^3}$ $= 0{,}269\ kN/cm^2 = 2{,}69\,N/mm^2$ **Allowable stress:** $\mathrm{f_{m,k}} = 24\mathrm{N/mm^2}$ $\mathrm{k_{mod}} = 0{,}9$ $\gamma_{\mathrm{m}} = 1{,}25$ $\mathrm{k_l} = 1{,}1$ $\mathrm{f_{m,d}} = \frac{24\mathrm{N/mm^2} * 0{,}9}{1{,}25} * 1{,}1$ $= 19{,}00\ \mathrm{N/mm^2}$ **Checking:** $\frac{\sigma_{m,d}}{\mathrm{f_{m,d}}} = \frac{2{,}69\,N/mm^2}{19{,}00\mathrm{N/mm^2}} = 0{,}14\ (14\%)$	m_m – depends on material, $m_m = 0{,}8$ $f_{m,k} = 24MPa$ $\frac{9{,}6kNm}{3815{,}87cm^3 * 10^{-6}} = 2515{,}8\frac{kN}{m^2}$ $= 2{,}52MPa < m_m * f_{m,k}$ $= 0{,}8 * 24MPa = 19{,}2MPa$ $\frac{2{,}52MPa}{19{,}2MPa} * 100\% \approx 13\%$
Shearing stress: $\tau_{v,d} = \frac{V_d * S_{eff}}{I_{eff} * b} = \frac{10{,}00kN * 2600cm^3}{27580cm^4 * 100cm}$ $= \frac{0{,}009kN}{cm^2} = 0{,}09N/mm^2$ **Allowable shear:** $\mathrm{f_{v,k}} = 1{,}25\mathrm{N/mm^2}$ $\mathrm{k_{mod}} = 0{,}9$ $\gamma_{\mathrm{m}} = 1{,}25$ $\mathrm{f_{v,d}} = \frac{1{,}25\mathrm{N/mm^2} * 0{,}9}{1{,}25} = 0{,}9\mathrm{N/mm^2}$ **Checking:** $\frac{\tau_{v,d}}{\mathrm{f_{v,d}}} = \frac{0{,}09N/mm^2}{0{,}9\mathrm{N/mm^2}} = 0{,}10\ (10\%)$	**Shearing stress:** $\tau_{v,d} = \frac{Q_{max} * S_{1/2,red}}{I_{red} * b}$ $= \frac{9{,}6kN * 2620{,}4cm^3}{30526{,}93cm^4 * 100cm}$ $= 0{,}0082\frac{kN}{cm^2} = 0{,}082MPa$ $< m_m * \mathrm{f_{v,k}}$ $= 0{,}8 * 1{,}25\mathrm{MPa} = 1\mathrm{MPa}$ $\frac{\tau_{v,d}}{0{,}8 * \mathrm{f_{v,d}}} = \frac{0{,}082MPa}{0{,}8 * 1{,}25MPa} * 100\% \approx 8\%$
Shearing between the layers: $\tau_{R,d} = \frac{V_d * S_{R,eff}}{I_{eff} * b} = \frac{10{,}00kN * 2600cm^3}{27580cm^4 * 100cm}$ $= \frac{0{,}009kN}{cm^2} = 0{,}09N/mm^2$ **Allowable shear:** $\mathrm{f_{R,k}} = 1{,}25\mathrm{N/mm^2}$ $\mathrm{k_{mod}} = 0{,}9$ $\gamma_{\mathrm{m}} = 1{,}3$ $\mathrm{f_{v,d}} = \frac{1{,}25\mathrm{N/mm^2} * 0{,}9}{1{,}25} = 0{,}9\mathrm{N/mm^2}$ **Checking:** $\frac{\tau_{R,d}}{\mathrm{f_{R,d}}} = \frac{0{,}09N/mm^2}{0{,}9\mathrm{N/mm^2}} = 0{,}10\ (10\%)$	It is necessary to know the strength of glued connection.
Deflection from g_k and q_k:	**Deflection from the dead load:**

$$w_{g,inst} = \frac{5}{384} * \frac{g_k * l^4}{E_{0,mean} * I_{eff}} = \frac{5}{384} * \frac{0{,}02\frac{kN}{cm} * 400^4 cm^4}{1100\frac{kN}{cm^2} * 27580 cm^4} = 0{,}22cm = 2{,}2mm$$

$$w_{q,inst} = \frac{5}{384} * \frac{q_k * l^4}{E_{0,mean} * I_{eff}} = \frac{5}{384} * \frac{0{,}0109\frac{kN}{cm} * 400^4 cm^4}{1100\frac{kN}{cm^2} * 27580 cm^4} = 0{,}12cm = 1{,}2mm$$

The final deflection from q_k and q_k:

$$w_{g,fin} = W_{g,inst} * (1 + k_{def}) = 2{,}2mm * (1 + 0{,}6) = 3{,}58mm$$

$$w_{q,fin} = W_{q,inst} * (1 + k_{def}) * \Psi_{2,1} = 1{,}2mm * (1 + 0{,}6) * 0{,}2 = 0{,}38mm$$

$$w_{q,fin} = W_{q,inst} * (1 + k_{def} * \Psi_{2,1}) = 1{,}2mm * (1 + 0{,}68 * 0{,}2) = 1{,}36mm$$

Summary deflection:

$$w_{fin} = w_{g,fin} + w_{q,fin} = 3{,}58mm + 0{,}38mm = 3{,}96mm$$

$$w_{zul} = \frac{l}{250} = \frac{4000mm}{250} = 16mm$$

$$\frac{w_{fin}}{w_{zul}} = \frac{3{,}96mm}{16mm} = 0{,}247\ (25\%)$$

Increasing of the deflection:

$$w_{fin} = w_{g,fin} + w_{q,fin} = 3{,}58mm + 1{,}36mm = 4{,}94mm$$

$$w_{zul} = \frac{l}{300} = \frac{4000mm}{300} = 13{,}3mm$$

$$\frac{w_{fin}}{w_{zul}} = \frac{4{,}94mm}{13{,}3mm} = 0{,}37\ (37\%)$$

$$w_{fin} - w_{g,inst} = 4{,}94mm + 2{,}2mm = 7{,}14mm$$

$$w_{zul} = \frac{l}{200} = \frac{4000mm}{200} = 20mm$$

$$\frac{w_{fin} - w_{g,inst}}{w_{zul}} = \frac{7{,}14mm}{20mm} = 0{,}36\ (36\%)$$

$$f = \frac{5}{384} * \frac{q^k * l^4}{E_{slab} * I_{red}} = \frac{5}{384} * \frac{3{,}88\frac{kN}{m} * 4^4 m^4}{11000 * 10^3\frac{kN}{m^2} * 30526{,}93 * 10^{-8} m^4} = 0{,}0038cm = 3{,}8mm$$

$$f = 3{,}8mm < f_u = \frac{l}{250} = \frac{4000mm}{250} = 16mm$$

Allowable deflection from the steps:

$f_u = \frac{g*(p+p_1+q)}{30*n^2*(b*p+p_1+q)}$ - limit

$g = 9{,}81\frac{m}{c^2}$ – free fall accelerations

$p = 0{,}25\ \frac{kN}{m^2}$ – proof load from people making vibrations

$p_1 = 1{,}5\ \frac{kN}{m^2}$ – live load

$q = 1{,}1\ \frac{kN}{m^2}$ – self-weight of the calculated structure

$n = 1{,}5\ 1/s$ – frequency of the human steps

$$b = 125 * \sqrt{\frac{Q}{\alpha * p * a * l}}$$

$\alpha = 1$ – coefficient depends on static model

$a = 1{,}5m$ – width of the slab

$l = 4m$ – length of the slab

$Q = 0{,}8kN$ – self weight of one man

$$b = 125 * \sqrt{\frac{0{,}8kN}{1 * 0{,}25\ \frac{kN}{m^2} * 1{,}5m * 4m}} = 91{,}29$$

$$f_u = \frac{9{,}81 * (0{,}25 + 1{,}5 + 1{,}1)}{30 * 1{,}5^2 * (91{,}29 * 0{,}25 + 1{,}5 + 1{,}1)} = 0{,}0117m = 11{,}7mm$$

Calculate deflection from this load

$P^{step} = (\varphi_1 * p + p_1 + q)$

$\varphi_1 = 1$ if $A_1 > A$

$A = 6m^2$ – floor slab area

$A_1 = 9m^2$

$$q^{step} = (\varphi_1 * p + p_1 + q) * w = \left(1 * 0{,}25\frac{kN}{m^2} + 1{,}5\frac{kN}{m^2} + 1{,}1\frac{kN}{m^2}\right) * 1{,}5m = 4{,}28\frac{kN}{m}$$

	$f = \frac{5}{384} * \frac{q^{step} * l^4}{E_{slab} * I_{red}} = \frac{5}{384} * \frac{4{,}28 \frac{kN}{m} * 4^4 m^4}{11000 * 10^3 \frac{kN}{m^2} * 30526{,}93 * 10^{-8} m^4} = 0{,}004 cm = 4mm$ $f = 4mm < f_u = 11{,}7mm$ **No problem from with deflection from the steps.**
Stiffness calculation: Stiffness in the width direction: $(EI)_b = \frac{0{,}05^3 m^3 * 26000\ MN/m^2}{12} = 0{,}271\, MN/m^2\ /m$ Stiffness in the longitudinal direction: $(EI)_l = E_0 * I_{eff} = 11000\ MN/m^2 * 27580\ * 10^{-8} m^4 = 3{,}03\, MN/m^2/m$	SNiP makes this calculation with using next formula: $f_u = \frac{g*(p+p_1+q)}{30*n^2*(b*p+p_1+q)}$. This formula includes loads, frequency and geometrical parameters of the slab. The formula limits frequency from human steps. All parts are described above. Eurocode checks vibration more detailed.
Determination of m_{perm}: $m_{perm} = g = 1{,}09 \frac{kN}{m^2} * \frac{1000}{9{,}81} = 111{,}11\ \frac{kg}{m^2}$	
Natural frequency: $k_Q = \sqrt{1 + \frac{(EI)_b * l^4}{(EI)_l * b^4}} = \sqrt{1 + \frac{0{,}271\ MN/m^2\ /m * 4^4 * m^4}{3{,}03\, MN/m^2/m * 4{,}8^4 * m^4}} = 1{,}02$ $f_{1,EN} = \frac{\pi}{2 * 4^2 * m^2} * \sqrt{\frac{3{,}03\, MN/\frac{m^2}{m} * 10^6}{111{,}11\ \frac{kg}{m^2}}} * 1{,}02 = 16{,}61\ Hz > f_{Grez} = 8\ Hz$	
Estimation of vibration acceleration: $b_{m,stat} = \frac{1}{1{,}1} * \left(\frac{(EI)_b}{(EI)_l}\right)^{0{,}25} * l = \frac{1}{1{,}1} * \left(\frac{0{,}271 \frac{MN/m^2}{m}}{3{,}03\, MN/\frac{m^2}{m}}\right)^{0{,}25} * 4m = 1{,}99m$	

$M_{gen} = m * \frac{l}{2} * b_{m,stat} = 111{,}11 \frac{kg}{m^2} * \frac{4m}{2} * 1{,}99m = 442\ kg$	
Determination of acceleration: $a = 0{,}4 * \frac{P_0 * \alpha(f_1)}{M_{gen}} * \frac{1}{\sqrt{\left(\left(\frac{f_1}{f_F}\right)^2 - 1\right)^2 + \left(2 * D * \frac{f_1}{f_F}\right)^2}} = 0{,}4 * \frac{700\ H * 0{,}06}{442\ kg} * \frac{1}{\sqrt{\left(\left(\frac{16{,}61}{6{,}9}\right)^2 - 1\right)^2 + \left(2 * 0{,}02 * \frac{16{,}61}{6{,}9}\right)^2}} = 0{,}008 \frac{m}{s^2} < 0{,}4 \frac{m}{s^2} = a_{grenz}$	
Determination of effective deflection: $W_{EF} = \frac{1}{43{,}37} * \frac{1\ kN * l^2}{(EI)_b^{\ 0{,}25} * (EI)_l^{\ 0{,}75}} = \frac{1}{43{,}37} * \frac{1\ kN * 4^2}{0{,}271^{0{,}25} * 3{,}03^{0{,}75}} = 0{,}22mm$	**Deflection from the concentrated force** $P = 1kN$ should be less than 0,7 mm (CP 20.13330.2011 “Loads and Impacts” app.E.2.1, table E.1, par.4) $f = \frac{P * l^3}{48 * E_{slab} * I_{red}} = \frac{1kN * 4^3 m^3}{48 * 11000 * 10^3 \frac{kN}{m^2} * 30526{,}93 * 10^{-8} m^4} = 0{,}0004m = 0{,}4mm < 0{,}7mm$ **No problem.** Eurocode and SNiP check deflection from 1kN in the middle, but slab’s parameters are taken more detailed in Eurocode.
Limited deflection: $W_{Grenz} = 1{,}0\ mm * 1{,}15 = 1{,}15mm$ $W_{EF} < W_{Grenz}$ $0{,}22mm < 1{,}15mm$ (19%)	
Checking: $v = 0{,}4 * \frac{1}{(EI)_b^{\ 0{,}25} * l * m_{perm}^{\ 0{,}75}} = 0{,}4 * \frac{1}{0{,}271^{0{,}25} * 4 * 111{,}11^{0{,}75}} = 0{,}004 \frac{m}{s} = 4 \frac{mm}{s}$ $v_{grenz} = \frac{100^{(f_{1,EN} * D - 1)}}{3} = \frac{100^{(16{,}61 * 0{,}02 - 1)}}{3} = 0{,}0154 \frac{m}{s} = 15{,}4 \frac{mm}{s} > v = 4 \frac{mm}{s}$ (26%)	
Fire safety calculation: Load in cause of fire:	**Fire safety:** Fire calculations can be done for proving

$q_g = G_{kj} + \Psi_{1,i} * Q_{k,1} = (0{,}8\ kN/m + 0{,}29\ kN/m) + 0{,}5 * 2\ kN/m = 2{,}09\ kN/m$	fire safety of the house, but it is not necessary. SNIP does not require that calculation. Fire endurance of the main structures can be proved in the laboratory. According SP 2.13130.2009 **par.6.5.8.3.** There are no demands for fire resistance and structural class of fire risk for **two-store buildings**. **Par.6.5.8.4.** There are several demands for main structures of three-store houses: • Load-bearing structures – R45 • Floor structures – REI45 • Non load-bearing structures – RE15 • Built-up roof – RE15 • Trusses, beams, summers – R15 • Participle walls – no rules If the total floor area is more than 150m² it is possible to take fire resistance rating for load bearing structures at least R30, floor structures – REI30.
Geometrical characteristics including fire damage: Fire speed for floors $\beta_0 = 0{,}65\ mm/min$ After 30th minutes: $d_{char} = 0{,}65 \frac{mm}{min} * 30min + 7mm = 26{,}3mm$ $d_{eff} = 40mm - 26{,}5mm = 13{,}5mm$	
Bending moment and cross-axis force: $\mathrm{M_{y,d}} = \frac{\mathrm{q_d} \times \mathrm{l}^2}{8} = \frac{2{,}09\mathrm{kN/m} \times 4{,}0^2\mathrm{m}^2}{8} = 4{,}18\ \mathrm{kNm}$ $V_{z,d} = A = B = \frac{q_d * l}{2} = \frac{2{,}09\mathrm{kN/m} * 4{,}0m}{2} = 4{,}18kN$	
Comparative E-modulus: $\mathrm{n_2} = \frac{\mathrm{E_{2(crosslayer)}}}{\mathrm{E_v}} = \frac{370\ \mathrm{m/mm^2}}{11000\mathrm{m/mm^2}} = 0{,}03$	
Effective cross-area: $\mathrm{A_{eff}} = 947\ cm^2$	
Gravity center of the cross area: $z_s = \frac{A_1 * \left(\frac{d_1}{2}\right) + 2 * A_{12} * \left(d_1 + \frac{d_{12}}{2}\right) * \mathrm{n_2}}{A_{eff}} + \frac{2 * A_{12} * \left(d_1 + d_{12} + \frac{d_2}{2}\right)}{A_{eff}}$ $z_s = 7{,}21cm$	
Compliance of γ-factor: $\gamma_1 = \frac{1}{1 + (\frac{\pi^2 * E_1 * A_1}{l^2} * \frac{d_{crosslayer}}{G * b})} = \frac{1}{1 + (\frac{\pi^2 * 11000 * 40000}{4000^2} * \frac{20}{50 * 1000})} = 0{,}902$	
Effective moment of inertia: $I_{eff} = I_1 + I_2 + I_3 = 7228{,}8\ cm^4$	
Resisting moment: $\mathrm{W_{eff}} = 1903{,}6cm^3$	
Static moment: $S_{eff} = d_1 * b * z_{1s} + d_2 * b * z_{1s} = 1643{,}85cm^3$	
Bending resistance along the fibers: $\mathrm{f_{c,0,k}} = 21\mathrm{N/mm^2}$ $\mathrm{k_{mod}} = 0{,}8$ $\gamma_\mathrm{m} = 1{,}25$	

$\mathrm{f_{c,0,d}} = \frac{21\mathrm{N/mm^2} * 0{,}8}{1{,}25}$=13,44 $\mathrm{N/mm^2}$ **Bending stress:** $\sigma_{m,d} = \frac{M_d}{W} = \frac{418\ kN/cm}{1903{,}6cm^3}$ $= 0{,}22\ kN/cm^2 = 2{,}2\ N/mm^2$ **Allowable stress:** $\mathrm{f_{m,k}} = 24\mathrm{N/mm^2}$ $\mathrm{k_{mod}} = 0{,}9$ $\gamma_\mathrm{m} = 1{,}25$ $\mathrm{k_l} = 1{,}1$ $\mathrm{f_{m,d}} = \frac{24\mathrm{N/mm^2} * 0{,}9}{1{,}25} * 1{,}1$ $= 19{,}00\ \mathrm{N/mm^2}$ **Checking:** $\frac{\sigma_{m,d}}{\mathrm{f_{m,d}}} = \frac{2{,}2\ N/mm^2}{19{,}00\mathrm{N/mm^2}} = 0{,}12\ (12\%)$	
Shearing stress: $\tau_{v,d} = \frac{V_d * S_{eff}}{I_{eff} * b} = \frac{4{,}18kN * 1643{,}85cm^3}{7844{,}91cm^4 * 100cm}$ $= \frac{0{,}009kN}{cm^2} = 0{,}09N/mm^2$ **Allowable shear:** $\mathrm{f_{v,k}} = 1{,}25\mathrm{N/mm^2}$ $\mathrm{k_{mod}} = 0{,}9$ $\gamma_\mathrm{m} = 1{,}25$ $\mathrm{f_{v,d}} = \frac{1{,}25\mathrm{N/mm^2} * 0{,}9}{1{,}25} = 0{,}9\mathrm{N/mm^2}$ **Checking:** $\frac{\tau_{v,d}}{\mathrm{f_{v,d}}} = \frac{0{,}09N/mm^2}{0{,}9\mathrm{N/mm^2}} = 0{,}10\ (10\%)$	

Calculation of the roof slab

Dimensions:

- L_g = 4,0 m - span
- L = 4,8m - length
- w = 1,5 m - width
- h = 140 mm (CLT 140L5s)
- The roof angle $\alpha=34^o$
- strength class – C24

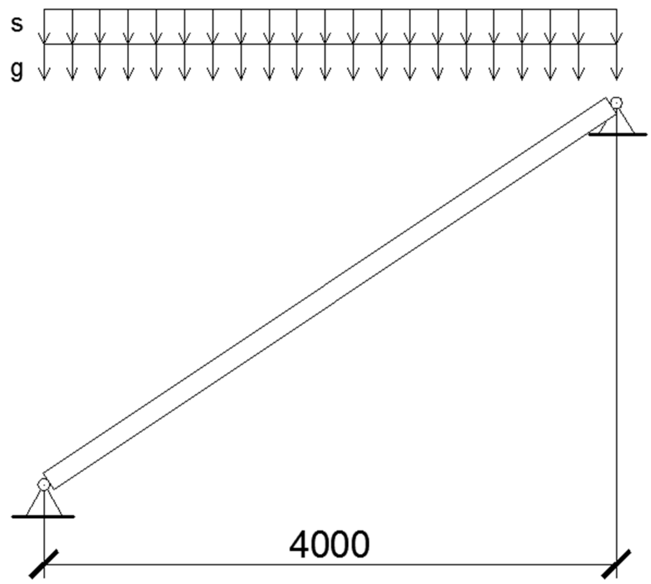


Figure A2.1 Static model of the roof slab

Loads and impacts were taken from SNiP for calculation according Russian rules. The slab can be calculated like a beam if ratio of length to width is more than 2:

$$\frac{l}{w} = \frac{4,8}{1,5} = 3,2 > 2$$

Roof structure is shown in the figure:

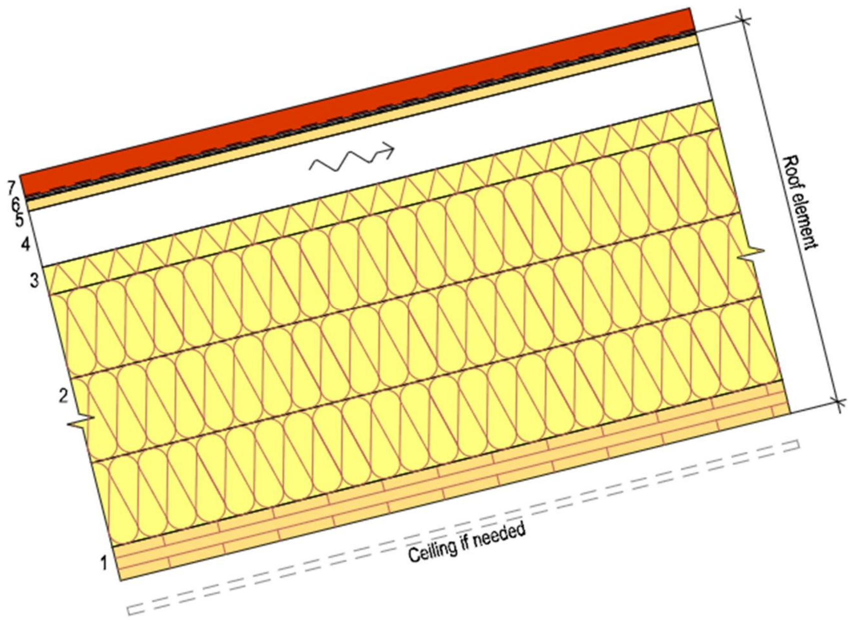


Figure A2.2 Roof structure with numbers

The numbers are:

1. Metal sheet – 0.7 cm
2. Bitumen – 0.3 cm
3. OSB board – 1.8 cm
4. Mineral wool (wind barrier) – 5 cm
5. Mineral wool (thermal insulation) – 45 cm
6. Load-bearing structure (60cm x 5 cm) step – 60 cm
7. CLT L5s - 14cm

Loads were collected according Finnish and Russian rules. Wind load was not taken into account.

Loads for SNiP calculation are shown on the next table:

Proof load, kN/m^2	γ_f	Design loads, kN/m^2
Metal sheet $\frac{0{,}0007m*78{,}5\ kN/m^3}{cos\alpha} = 0{,}065\ kN/m^2$	1,05	0,069
Bitumen $\frac{0{,}003m*14\ kN/m^3}{cos\alpha} = 0{,}050\ kN/m^2$	1,3	0,065

OSB board $\frac{0{,}018m*10\ kN/m^3}{cos\alpha} = 0{,}214\ kN/m^2$	1,2	0,257
Mineral wool (wind barrier) $\frac{0{,}05m*2\ kN/m^3}{cos\alpha} = 0{,}119\ kN/m^2$	1,2	0,143
Mineral wool (thermal insulation) $\frac{0{,}45m*1\ kN/m^3}{cos\alpha} = 0{,}536\ kN/m^2$	1,2	0,640
Load-bearing structure (glued beams) $\frac{0{,}6m*0{,}05m*5\ kN/m^3}{0{,}6m*cos\alpha} = 0{,}30\ kN/m^2$	1,1	0,33
CLT 140L5s $\frac{0{,}14m*5\ kN/m^3}{cos\alpha} = 0{,}70\ kN/m^2$	1,1	0,663
Snow load $S_0 = 0{,}7 * c_e * c_t * \mu * S_g = 0{,}7 * 1 * 1 * 1{,}4 * 1{,}8\ \ kN/m^2 = 1{,}76\ kN/m^2$	1,4	2,47kN/m^2
Sum: 3,644 kN/m^2		**Sum:** 4,637 kN/m^2

Live load and γ-coefficient are taken from SNiP 2.01.07-85* “Loads and Impacts” par.7, 8.2, table 8.3.

The calculation steps:

Roor slab	
Eurocode example	**SNiP example**
Impacts: Loads from structure G were taken from table. Loads for 1m of the slab: $q_k = \mu_i * s_k = 0{,}75 * 2{,}75\ kN/m = 2{,}06\ kN/m$ $q_g = 1{,}25 * K_{FI} * G_{kj,CLT} + 1{,}15 * K_{FI} * G_{kj} + 1{,}5 * K_{FI} * Q_{k,1} + 1{,}5 * K_{FI} * \sum_{i>1} \Psi_{0,i} * Q_{k,i} = 1{,}25 * 0{,}9 * 0{,}7\ kN/m + 1{,}15 * 0{,}9 * 1{,}284\ kN/m + 1{,}5 * 0{,}9 * 2{,}06\ kN/m = 4{,}9\ kN/m$ For this calculation a special programm was used. The programm provided by Stora Enso on www.clt.info. The main formulas for calculation will be shown, but the result value will be taken from the programm.	**Design loads for 1m of the slab (width is 1,5m):** $q^k = P^k * w = 3{,}644\ kN/m^2 * 1{,}5m = 5{,}466 kN/m$ $q^d = P^d * w = 4{,}637\ kN/m^2 * 1{,}5m = 6{,}956 kN/m$
Bending moment and cross-axis force: $\mathrm{M_{y,d}} = \frac{\mathrm{q_d} \times \mathrm{l}^2}{8} = \frac{4{,}9\ \mathrm{kN/m} \times 4{,}8^2 \mathrm{m}^2}{8} = 14{,}1\ \mathrm{kNm}$ $V_{z,d} = A = B = \frac{q_d * l}{2} = \frac{4{,}9\mathrm{kN/m} * 4{,}8\mathrm{m}}{2} = 11{,}8 kN$	**Bending moment in the middle:** $M_{max} = \frac{q^d * l^2}{8} = \frac{6{,}956 \frac{kN}{m} * 4{,}8^2 m^2}{8} = 20{,}03 kNm$ **Cross-axis force on the supports:** $Q_{max} = \frac{q^d * l}{2} = \frac{6{,}956 \frac{kN}{m} * 4{,}8m}{2} = 16{,}69 kN$
Comparative E-modulus: $\mathrm{n_2} = \frac{\mathrm{E_{2(crosslayer)}}}{\mathrm{E_v}} = \frac{370\ \mathrm{m/mm^2}}{11000 \mathrm{m/mm^2}} = 0{,}03$	**Reduction coefficient:** $\mathrm{n_{red}} = \frac{\mathrm{E_{(crosslayer)}}}{\mathrm{E}} = \frac{370\ \mathrm{Pa}}{11000\mathrm{Pa}} = 0{,}034$
Effective cross-area: $\mathrm{A_{eff}} = 1000\ cm^2$ Cross layers are not taken into account.	**Reduction cross-area:** $\mathrm{A_{red}} = A_1 + A_{12} * \mathrm{n_{red}} + A_2 + A_{23} * \mathrm{n_{red}} + A_3 = 4 * 100 + 2 * 100 * 0{,}034 + 2 * 100 + 2 * 100 * 0{,}034 + 4 * 100 = 1013{,}6 cm^2$
Gravity center of the cross area: $z_s = \frac{A_1 * \left(\frac{d_1}{2}\right) + 2 * A_{12} * \left(d_1 + \frac{d_{12}}{2}\right) * \mathrm{n_2}}{A_{eff}} + \frac{2 * A_{12} * \left(d_1 + d_{12} + \frac{d_2}{2}\right)}{A_{eff}}$ $z_s = 7cm$	**Gravity center of the cross area relative to the lower edge:** $y_{c.g.} = \frac{A_1 * y_1 + A_2 * y_2 + A_3 * y_3 + A_{12} * y_{12} * n}{A_{red}} = \frac{400 * 2 + 200 * 7 + 400 * 12 + 200 * 0{,}03}{813{,}6} = 7cm$
Compliance of γ-factor:	Nothing similar has been found.

$\gamma_1 = \frac{1}{1+(\frac{\pi^2 * E_1 * A_1}{l^2} * \frac{d_{crosslayer}}{G * b})} = \frac{1}{1+(\frac{\pi^2 * 11000 * 40000}{4800^2} * \frac{20}{50 * 1000})} = 0{,}93$	
Effective moment of inertia: $I_{eff} = I_1 + 2 * I_2$ $I_1 = \frac{b * h^3}{12} = \frac{100 * 2^3}{12} = 66{,}667\ cm^4$ $I_2 = \frac{b * h^3}{12} + \gamma_1 * A_2 * a^2 = \frac{100 * 4^3}{12} + 0{,}93 * 400 * 5^2 = 9833{,}33\ cm^4$ $I_{eff} = 66{,}667 + 2 * 9833{,}33 = 19732\ cm^4$	**Reductive moment of inertia relative to the c.g.:** $I_{red} = I_2 + 2 * \left(I_{12} + A_{12} * \left(\frac{d_2}{2} + \frac{d_{12}}{2}\right)^2\right) * n_{red} + 2 * \left(I_3 + A_3 * \left(\frac{d_2}{2} + d_{23} + \frac{d_3}{2}\right)^2\right) = \frac{100 * 2^3}{12} + 2 * \left(\frac{100 * 2^3}{12} + 2 * 100 * (1+1)^2\right) * 0{,}034 + 2 * \left(\frac{100 * 4^3}{12} + 100 * 4 * (1+2+2)^2\right) = 66{,}667cm^4 + 58{,}933cm^4 + 21066{,}666cm^4 = 21192{,}266cm^4$
Resisting moment: $\mathrm{W_{eff}} = \frac{\mathrm{I_{eff}}}{\gamma_1 * \mathrm{a_1} + \frac{\mathrm{d_1}}{2}}$ $\mathrm{W_{eff}} = 2667cm^3$	**Reduction resisting moment:** $\mathrm{W_{red}} = \frac{\mathrm{I_{red}}}{y_{c.g.}} = \frac{21192{,}266cm^4}{7cm} = 3027{,}46cm^3$
Static moment: $S_{eff} = d_1 * b * z_{1s} + d_2 * b * z_{1s} = 2050cm^3$	**Reduction static moment of the half cross-area:** $S_{\frac{1}{2},red} = A_1 * y_1 + A_{12} * y_{12} * n_{red} + \frac{A_2}{2} * y_2 = 100 * 4 * (1+2+2) + 100 * 2 * 0{,}034 + 100 * \frac{1}{2} * \frac{2}{2} = 2000cm^3 + 6{,}8cm^3 + 50cm^3 = 2056{,}8cm^3$
Bending resistance along the fibers: $\mathrm{f_{c,0,k}} = 21\mathrm{N/mm^2}$ $\mathrm{k_{mod}} = 0{,}8$ $\gamma_\mathrm{m} = 1{,}25$	**Bending strength:** $\frac{M_{max}}{W_{red}} \leq m_m * f_{m,k}$ m_Φ – depends on material, $m_\Phi = 0{,}8$

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$\mathrm{f_{c,0,d}} = \frac{21\mathrm{N/mm^2}*0{,}8}{1{,}25}$=13,44 $\mathrm{N/mm^2}$

Bending stress:

$$\sigma_{m,d} = \frac{M_d}{W} = \frac{1410\ kN/cm}{2967cm^3}$$
$$= 0{,}475\ kN/cm^2 = 4{,}75\ N/mm^2$$

Allowable stress:

$\mathrm{f_{m,k}} = 24\mathrm{N/mm^2}$
$\mathrm{k_{mod}} = 0{,}9$
$\gamma_\mathrm{m} = 1{,}25$
$\mathrm{k_l} = 1{,}1$

$$\mathrm{f_{m,d}} = \frac{24\mathrm{N/mm^2} * 0{,}9}{1{,}25} * 1{,}1$$
$$= 19{,}00\ \mathrm{N/mm^2}$$

Checking:

$$\frac{\sigma_{m,d}}{\mathrm{f_{m,d}}} = \frac{4{,}75\ N/mm^2}{19{,}00\mathrm{N/mm^2}} = 0{,}25(25\%)$$

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$$\frac{20{,}03kNm}{3027{,}46cm^3 * 10^{-6}} = 6016\frac{kN}{m^2}$$
$$= 6{,}02MPa < m_m * f_{m,k}$$
$$= 0{,}8 * 24MPa = 19{,}2\ MPa$$
$$\frac{6{,}02MPa}{19{,}2\ MPa} * 100\% = 31\%$$

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Shearing stress:

$$\tau_{v,d} = \frac{V_d * S_{eff}}{I_{eff} * b} = \frac{11{,}8kN * 2050cm^3}{19732cm^4 * 100cm}$$
$$= \frac{0{,}012kN}{cm^2} = 0{,}12N/mm^2$$

Allowable shear:

$\mathrm{f_{v,k}} = 1{,}25\mathrm{N/mm^2}$
$\mathrm{k_{mod}} = 0{,}9$
$\gamma_\mathrm{m} = 1{,}25$

$$\mathrm{f_{v,d}} = \frac{1{,}25\mathrm{N/mm^2} * 0{,}9}{1{,}25} = 0{,}9\mathrm{N/mm^2}$$

Checking:

$$\frac{\tau_{v,d}}{\mathrm{f_{v,d}}} = \frac{0{,}12N/mm^2}{0{,}9\mathrm{N/mm^2}} = 0{,}13\ (13\%)$$

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Shearing stress:

$$\tau_{v,d} = \frac{Q_{max} * S_{1/2,red}}{I_{red} * b}$$
$$= \frac{16{,}69kN * 2056{,}8cm^3}{21192{,}266cm^4 * 100cm}$$
$$= 0{,}016\frac{kN}{cm^2} = 0{,}16MPa$$
$$< m_m * \mathrm{f_{v,k}}$$
$$= 0{,}8 * 1{,}25\mathrm{MPa} = 1\mathrm{MPa}$$
$$\frac{\tau_{v,d}}{0{,}8 * \mathrm{f_{v,d}}} = \frac{0{,}16MPa}{0{,}8 * 1{,}25MPa} * 100\% \approx 16\%$$

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Shearing between the layers:

$$\tau_{R,d} = \frac{V_d * S_{R,eff}}{I_{eff} * b} = \frac{11{,}8kN * 2050cm^3}{19732cm^4 * 100cm}$$
$$= \frac{0{,}012kN}{cm^2} = 0{,}12N/mm^2$$

Allowable shear:

$\mathrm{f_{R,k}} = 1{,}25\mathrm{N/mm^2}$
$\mathrm{k_{mod}} = 0{,}9$
$\gamma_\mathrm{m} = 1{,}3$

$$\mathrm{f_{v,d}} = \frac{1{,}25\mathrm{N/mm^2} * 0{,}9}{1{,}25} = 0{,}9\mathrm{N/mm^2}$$

Checking:

$$\frac{\tau_{R,d}}{\mathrm{f_{R,d}}} = \frac{0{,}12N/mm^2}{0{,}9\mathrm{N/mm^2}} = 0{,}13\ (13\%)$$

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Fire safety calculation:

Load in cause of fire:

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Fire safety:

Fire calculations can be done for proving

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$q_g = G_{kj} + \Psi_{1,i} * Q_{k,1} = (0{,}7\ kN/m + 1{,}284\ kN/m) + 0{,}5 * 2{,}06\ kN/m = 3{,}01\ kN/m$	fire safety of the house, but it is not necessary. SNIP does not require that calculation. Fire endurance of the main structures can be proved in the laboratory. According SP 2.13130.2009 **par.6.5.8.3.** There are no demands for fire resistance and structural class of fire risk for **two-store buildings**. **Par.6.5.8.4.** There are several demands for main structures of three-store houses: • Load-bearing structures – R45 • Floor structures – REI45 • Non load-bearing structures – RE15 • Built-up roof – RE15 • Trusses, beams, summers – R15 • Participle walls – no rules If the total floor area is more than 150m^2 it is possible to take fire resistance rating for load bearing structures at least R30, floor structures – REI30.
Geometrical characteristics including fire damage: Fire speed for floors $\beta_0 = 0{,}65\ mm/min$ After 30th minutes: $d_{char} = 0{,}65 \frac{mm}{min} * 30min + 7mm = 26{,}3mm$ $d_{eff} = 40mm - 26{,}5mm = 13{,}5mm$	
Bending moment and cross-axis force: $\mathrm{M_{y,d}} = \frac{\mathrm{q_d} \times \mathrm{l}^2}{8} = \frac{3{,}01\mathrm{kN/m} \times 4{,}8^2\mathrm{m}^2}{8} = 8{,}7\ \mathrm{kNm}$ $V_{z,d} = A = B = \frac{q_d * l}{2} = \frac{3{,}01\mathrm{kN/m} * 4{,}8\mathrm{m}}{2} = 7{,}2kN$	
Comparative E-modulus: $\mathrm{n_2} = \frac{\mathrm{E_{2(crosslayer)}}}{\mathrm{E_v}} = \frac{370\ \mathrm{m/mm^2}}{11000\mathrm{m/mm^2}} = 0{,}03$	
Effective cross-area: $\mathrm{A_{eff}} = 735\ cm^2$	
Gravity center of the cross area: $z_s = \frac{A_1 * \left(\frac{d_1}{2}\right) + 2 * A_{12} * \left(d_1 + \frac{d_{12}}{2}\right) * \mathrm{n_2}}{A_{eff}} + \frac{2 * A_{12} * \left(d_1 + d_{12} + \frac{d_2}{2}\right)}{A_{eff}}$ $z_s = 6{,}4cm$	
Compliance of γ-factor: $\gamma_1 = \frac{1}{1 + (\frac{\pi^2 * E_1 * A_1}{l^2} * \frac{d_{crosslayer}}{G * b})} = \frac{1}{1 + (\frac{\pi^2 * 11000 * 40000}{4000^2} * \frac{20}{50 * 1000})} = 0{,}93$	
Effective moment of inertia: $I_{eff} = I_1 + I_2 + I_3 = 9007\ cm^4$	
Resisting moment: $\mathrm{W_{eff}} = 1461cm^3$	
Static moment: $S_{eff} = d_1 * b * z_{1s} + d_2 * b * z_{1s} = 1182cm^3$	
Bending resistance along the fibers: $\mathrm{f_{c,0,k}} = 21\mathrm{N/mm^2}$ $\mathrm{k_{mod}} = 0{,}8$ $\gamma_\mathrm{m} = 1{,}25$	

$\mathrm{f_{c,0,d}} = \frac{21\mathrm{N/mm^2} * 0{,}8}{1{,}25}$=13,44 $\mathrm{N/mm^2}$ **Bending stress:** $\sigma_{m,d} = \frac{M_d}{W} = \frac{870\ \ kN/cm}{1461cm^3}$ $= 0{,}59\ \ kN/cm^2 = 5{,}9\ N/mm^2$ **Allowable stress:** $\mathrm{f_{m,k}} = 24\mathrm{N/mm^2}$ $\mathrm{k_{mod}} = 0{,}9$ $\gamma_\mathrm{m} = 1{,}25$ $\mathrm{k_l} = 1{,}1$ $\mathrm{f_{m,d}} = \frac{24\mathrm{N/mm^2} * 0{,}9}{1{,}25} * 1{,}1$ $= 19{,}00\ \mathrm{N/mm^2}$ **Checking:** $\frac{\sigma_{m,d}}{\mathrm{f_{m,d}}} = \frac{5{,}9\ N/mm^2}{19{,}00\mathrm{N/mm^2}} = 0{,}31\ (31\%)$	
Shearing stress: $\tau_{v,d} = \frac{V_d * S_{eff}}{I_{eff} * b} = \frac{7{,}2kN * 1182cm^3}{9007cm^4 * 100cm}$ $= \frac{0{,}009kN}{cm^2} = 0{,}09N/mm^2$ **Allowable shear:** $\mathrm{f_{v,k}} = 1{,}25\mathrm{N/mm^2}$ $\mathrm{k_{mod}} = 0{,}9$ $\gamma_\mathrm{m} = 1{,}25$ $\mathrm{f_{v,d}} = \frac{1{,}25\mathrm{N/mm^2} * 0{,}9}{1{,}25} = 0{,}9\mathrm{N/mm^2}$ **Checking:** $\frac{\tau_{v,d}}{\mathrm{f_{v,d}}} = \frac{0{,}09N/mm^2}{0{,}9\mathrm{N/mm^2}} = 0{,}10\ (10\%)$	

Calculation of the wall panel

Dimensions:

- h = 2,90 m
- l_k = 2,90 m
- a = 100 mm (CLT 100C3s)
- b_{eff} = 1,0 m

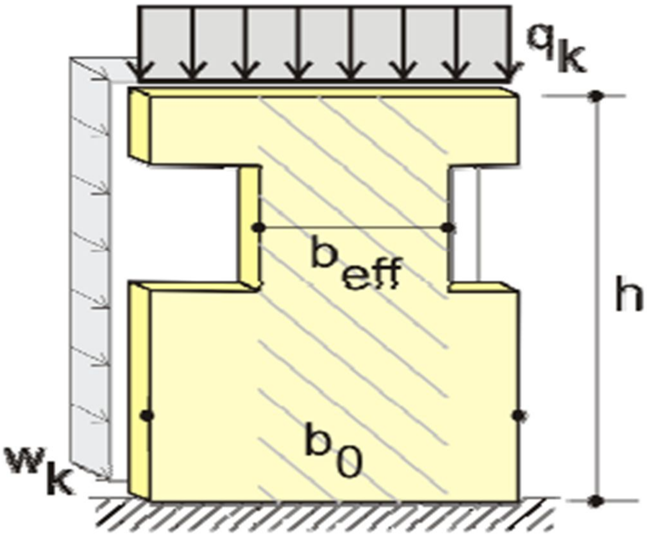

Figure A3.1 Static model of the wall element

Fire resistance – R30

For this case loads are calculated according to Floor and Roof calculations. The self-weight of these structures is taken into account. The case is a two-storey building. The panel is situated on the first floor and the load area is assumed 3,2 m x 2,9 m=9,28m^2.

Proof loads are shown in the next table:

Proof load, kN
Roof and snow $3{,}644\,kN/m^2 * 9{,}28m^2 = 33{,}82kN$
Floor slab and live load $2{,}587\,kN/m^2 * 9{,}28m^2 = 24{,}01kN$
Wall panel (2nd floor) $1{,}45\,kN/m^2 * 2{,}9m * 2{,}9m = 12{,}20kN$
Wall panel (1st floor) $1{,}45\,kN/m^2 * 2{,}9m * 2{,}9m = 12{,}20kN$
Sum: 82,23

The calculation steps:

Wall panel	
Eurocode example	**SNiP example**
Impacts: Collected from other calculations, load area is the same. $N_d = q_{g,roof} * A + q_{g,floor} * A + 2 * q_{wallpanel} * l = 4{,}9\frac{kN}{m^2} * 9{,}28\,m^2 + 5{,}01\frac{kN}{m^2} * 9{,}28\,m^2 + 2 * 1{,}45\frac{kN}{m} * 2{,}9 = 100{,}37\,kN$ Wind load: $q_w = c_f * q_k(h) = 1{,}5 * 0{,}45\,\,kN/m = 0{,}68\,\,kN/m$ **Bending moment of wind impact:** $\mathrm{M_d} = \frac{\mathrm{w_d \times h^2}}{8} = \frac{0{,}68\mathrm{kN/m} \times 2{,}9^2\mathrm{m}^2}{8} = 0{,}71\,\mathrm{kNm}$	**Proof wind load:** $w_p = w_0 * k(z_e) * c = 0{,}3\,\,kN/m^2 * 0{,}95 * 0{,}8 = 0{,}23\,\,kN/m^2$ **Design wind load:** $w_d = w_p * 1{,}2 = 0{,}23\,\,kN/m^2 * 1{,}2 = 0{,}276\,\,kN/m^2$ For wall panel with width 2,9m: $w = 0{,}276\,\,kN/m^2 * 2{,}9m = 0{,}8\,kN/m$ **Bending moment from wind load:** $\mathrm{M} = \frac{\mathrm{w * h^2}}{8} = \frac{0{,}8\,kN/m * 2{,}9^2\mathrm{m}^2}{8} = 0{,}84\,\mathrm{kNm}$ $\mathrm{N} = 82{,}23\,\mathrm{kN} - \text{taken from the table}$
Comparative E-modulus: $\mathrm{n_2} = \frac{\mathrm{E_{2(crosslayer)}}}{\mathrm{E_v}} = \frac{370\,\mathrm{m/mm^2}}{11000\mathrm{m/mm^2}} = 0{,}03$	**Reduction coefficient:** $\mathrm{n_{red}} = \frac{\mathrm{E_{(crosslayer)}}}{\mathrm{E}} = \frac{370\,\mathrm{Pa}}{11000\mathrm{Pa}} = 0{,}034$
Effective cross-section: $\mathrm{A_{eff}} = 2 * \mathrm{d_1} * \mathrm{b_{eff}} = 2 * 3\mathrm{cm} * 100\mathrm{cm} = 600\mathrm{cm}^2$	**Reduction cross-area:** $\mathrm{A_{red}} = A_1 + A_{12} * \mathrm{n_{red}} + A_2 = 3 * 100 + 4 * 100 * 0{,}034 + 3 * 100 = 613{,}6\,\mathrm{cm}^2$
Compliance of γ-factor:	Nothing similar has been found

$\gamma_1 = \frac{1}{1+(\frac{\pi^2 * E_1 * A_1}{l^2} * \frac{d_{crosslayer}}{G * b})} = \frac{1}{1+(\frac{\pi^2 * 11000 * 30000}{2900^2} * \frac{20}{50 * 1000})} = 0{,}953$	
Effective moment of inertia: $I_{eff} = 2 * I_1$ $I_1 = \frac{b * h^3}{12} + \gamma_1 * A_1 * a^2 = \frac{100 * 3^3}{12} + 0{,}910 * 300 * 3{,}5^2 = 3727{,}28\ cm^4$ $I_{eff} = 2 * 3727{,}28 = 7454{,}55\ cm^4$	**Reductive moments of inertia:** $I_{1,red} = I_{12} * \mathrm{n_{red}} + 2 * \left(I_1 + A_1 * \left(\frac{d_1}{2} + \frac{d_2}{2}\right)^2\right) = \frac{100 * 4^3}{12} * 0{,}034 + 2 * \left(\frac{100 * 3^3}{12} + 100 * 3 * \left(\frac{4}{2} + \frac{3}{2}\right)^2\right) = 18{,}13cm^4 + 7800cm^4 = 7818{,}13\ cm^4$ $I_{y,red} = I_1 + I_{12} * \mathrm{n_{red}} + I_2 = \frac{3 * 100^3}{12} + \frac{4 * 100^3}{12} * 0{,}034 + \frac{3 * 100^3}{12} = 511333{,}33cm^4$
Resisting moment: $\mathrm{W_{eff}} = \frac{\mathrm{I_{eff}}}{\gamma_1 * \mathrm{a}_1 + \frac{\mathrm{d}_1}{2}}$ $\mathrm{W_{eff}} = 1490{,}91\ cm^3$	**Reduction resisting moment:** $\mathrm{W_{red}} = \frac{\mathrm{I_{red}}}{y_{c.g.}} = \frac{7818{,}13cm^4}{5cm} = 1563{,}63cm^3$
Radius of gyration: $\mathrm{i} = \sqrt{\frac{\mathrm{I_{eff}}}{\mathrm{A_{eff}}}} = \sqrt{\frac{7454{,}55\mathrm{cm}^4}{600\mathrm{cm}^2}} = 3{,}52\mathrm{cm}$	**Radiuses of gyration:** $\mathrm{i}_1 = \sqrt{\frac{\mathrm{I_{1,red}}}{\mathrm{A_{red}}}} = \sqrt{\frac{7818{,}13\mathrm{cm}^4}{613{,}6\mathrm{cm}^2}} = 3{,}56\mathrm{cm}$ $\mathrm{i}_y = \sqrt{\frac{\mathrm{I_{y,red}}}{\mathrm{A_{red}}}} = \sqrt{\frac{511333{,}33\mathrm{cm}^4}{613{,}6\mathrm{cm}^2}} = 28{,}86\mathrm{cm}$
Flexibility: $\lambda = \frac{\mathrm{l_{eff}}}{\mathrm{i}}$ $l_{eff} = \beta * \mathrm{l} = 1{,}0 * 2{,}9 = 2{,}9\mathrm{m}$ $\lambda = \frac{2{,}90\mathrm{m}}{0{,}0352\mathrm{m}} = 82{,}38$	**Flexibility for component elements:** $\lambda = \sqrt{(\mu_y * \lambda_y)^2 + \lambda_1^2}$ $l_{eff} = \mu * \mathrm{l} = 1 * 2{,}9 = 2{,}9\mathrm{m}$ $\mu = 1$ – for two-pin structures $\lambda_1 = \frac{l_{eff}}{\mathrm{i}_1} = \frac{290cm}{3{,}56cm} = 81{,}46$ $\lambda_y = \frac{l_{eff}}{\mathrm{i}_y} = \frac{290cm}{28{,}86cm} = 10{,}05$ $\mu_y = 1$ – for glued jointing $\lambda = \sqrt{(1 * 10{,}05)^2 + 81{,}46^2} = 82{,}08$
Related flexibility:	Nothing similar has been found

$\lambda_{rel,c} = \frac{\lambda}{\pi} * \sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{82,38}{\pi} * \sqrt{\frac{21}{7333}} = 1,4$	
Coefficient for glued timber: $k = 0,5 * (1 + \beta_c * (\lambda_{rel,c} - 0,3) + \lambda_{rel,c}{}^2) = 0,5 * (1 + 0,1 * (1,4 - 0,3) + 1,4^2) = 1,53$ $\beta_c = 0,1$ for glued timber $k_{c,y} = \frac{1}{k + \sqrt{(k^2 - \lambda_{rel,c}^2)}} = \frac{1}{1,53 + \sqrt{1,53^2 - 1,4^2}} = 0,46$	μ_y – this coefficient has the same meaning $\mu_y = \sqrt{1 + k_c \frac{b * h * n_j}{l_0^2 * n_c}}$ $k_c = 0$ – for glued timber, this parameter considers flexibility of the glued connection
Compressing stresses: $\sigma_{c,0,d} = \frac{N_d}{A_{eff}} = \frac{100,37kN}{600cm^2} = 0,167kN/cm^2$	**Compressive resistance:** $\frac{N}{A_{red}} \leq R_c * m_o * m_m$ $m_o = 0,85$ – operation coefficient, for envelop structures has this value $m_m = 0,8$ – coefficient considers type of material (pine) $\frac{82,23kN}{613,6cm^2} = 0,134\frac{kN}{cm^2} = 1,34MPa \leq 21MPa * 0,85 * 0,8 = 14,28MPa$ $\frac{1,34\frac{kN}{cm^2}}{14,28MPa} * 100\% = 7\%$ **Buckling resistance:** $\frac{N}{\varphi * A_{red}} \leq R_{c,0,d} * m_o * m_m$ $\varphi = \langle \lambda > 70, \frac{A}{\lambda^2} \rangle$ $A = 3000$ – for timber boards $\varphi = \frac{3000}{82,08^2} = 0,44$ $\frac{82,23kN}{0,44 * 613,6cm^2} = 0,30\frac{kN}{cm^2} = 3,0MPa \leq 21MPa * 0,85 * 0,8 = 14,28MPa$ $\frac{3,0\frac{kN}{cm^2}}{14,28MPa} * 100\% = 21\%$
Bending resistance along the fibers: $f_{c,0,k} = 21N/mm^2$ $k_{mod} = 0,8$ $\gamma_m = 1,25$ $f_{c,0,d} = \frac{21N/mm^2 * 0,8}{1,25}$=13,44 N/mm^2 **Allowable bending:** $f_{c,0,k} = 24N/mm^2$ $k_{mod} = 0,8$	Similar coefficients are used in this formula: $\frac{N}{A_{red}} \leq R_{c,0,d} * m_o * m_m$

$\gamma_m = 1{,}25$ $k_1 = 1{,}1$ $f_{m,d} = \frac{24N/mm^2 * 0{,}8}{1{,}25} * 1{,}1 = 16{,}9N/mm^2$ **Checking of compressing stresses:** $\frac{\sigma_{c,0,d}}{f_{c,0,d} * k_{c,y}} = \frac{1{,}67N/mm^2}{13{,}44 * 0{,}46cm^2} = 0{,}27 < 1$	
Bending stresses: $\sigma_{m,y,d} = \frac{M_d}{W_{eff}} = \frac{71kNcm}{1490{,}91cm^3} = \frac{0{,}047kN}{cm^2} = 0{,}47N/mm^2$ **Checking of bending stresses:** $\frac{\sigma_{m,y,d}}{f_{m,d}} = \frac{0{,}47N/mm^2}{16{,}9N/mm^2} = 0{,}028 < 1$	**Bending resistance:** $\frac{M}{W_{red}} \leq R_{m,k} * m_o * m_m$ $\frac{84kNcm}{1563{,}63cm^3} = 0{,}053\frac{kN}{cm^2} = 0{,}53MPa < 24MPa * 0{,}8 * 0{,}85 = 16{,}32\ MPa$ $\frac{0{,}53MPa}{16{,}32\ MPa} * 100\% = 3\%$
Checking with eccentric compression formula: $\frac{\sigma_{c,0,d}}{f_{c,0,d} * k_{c,y}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} = \frac{0{,}167kN/cm^2}{1{,}34\ kN/cm^2 * 0{,}46} + \frac{0{,}047kN/cm^2}{1{,}69kN/cm^2} = 0{,}28 < 1{,}0$	**Eccentric compression:** $\frac{N}{A_{red}} + \frac{M_d}{W_{red}} \leq R_{c,0,d} * m_o * m_m$ $M_d = \frac{M}{\xi}$ – for two-pin static model $\xi = 1 - \frac{N}{\varphi * R_{c,0,d} * m_o * m_m * A_{red}} = 1 - \frac{90{,}45kN}{0{,}44 * 1428\frac{kN}{cm^2} * 613{,}6cm^2} = 0{,}99$ $M_d = \frac{0{,}84}{0{,}99} = 0{,}85\ kNm$ $\frac{82{,}23\ kN}{613{,}6 * 10^{-4}m^2} + \frac{0{,}85\ kNm}{1563{,}63 * 10^{-6}m^3} = 1883{,}73\frac{kN}{m^2} = 1{,}9MPa < 14{,}28\ MPa$ $\frac{1{,}9MPa}{14{,}28\ MPa} * 100\% = 13\%$
	Buckling: $\frac{N}{\varphi * A_{red} * R_{c,0,d}} + (\frac{M_d}{\varphi_m * R_{m,k} * W_{red}})^n \leq 1$ $n = 2$ – for elements with fixing tension zone $\varphi_m = 140 * \frac{b^2}{l_{eff} * h} * k_d$ $k_d = 1{,}13$ – depends on bending moment diagram (taken from SNiP's table) $\varphi_m = 140 * \frac{1^2}{2{,}90 * 0{,}1} * 1{,}13 = 545$ $\frac{90{,}45\ kN}{0{,}44 * 613{,}6 * 10^{-4}m^2 * 14280\ kN/m^2} + \frac{0{,}85\ kNm}{545 * 16320\frac{kN}{m^2} * 1563{,}63 * 10^{-6}m^3} = 0{,}78 < 1$

Fire safety calculation:
Impacts:
Loads are collected from other calculations in fire cause, load area is the same.

$$N_d = q_{g,roof} * A + q_{g,floor} * A + 2 * q_{wallpanel} * l = 3{,}01\frac{kN}{m^2} * 9{,}28\ m^2 + 2{,}09\frac{kN}{m^2} * 9{,}28\ m^2 + 2 * 1{,}45\frac{kN}{m} * 2{,}9 = 55{,}74\ kN$$

Wind load:

$$q_{w,fire} = \Psi * q_w = 0{,}3 * 0{,}68 = 0{,}2\ kN$$

Bending moment of wind impact:

$$\mathrm{M_d} = \frac{\mathrm{w_d} \times \mathrm{h}^2}{8} = \frac{0{,}2\mathrm{kN/m} \times 2{,}9^2\mathrm{m}^2}{8} = 0{,}21\ \mathrm{kNm}$$

Comparative E-modulus:

$$\mathrm{n_2} = \frac{\mathrm{E_{2(crosslayer)}}}{\mathrm{E_v}} = \frac{370\ \mathrm{m/mm^2}}{11000\mathrm{m/mm^2}} = 0{,}03$$

Effective cross-section:

$$\mathrm{A_{eff}} = 341\ cm^2$$

Compliance of γ-factor:

$$\gamma_1 = \frac{1}{1 + (\frac{\pi^2 * E_1 * A_1}{l^2} * \frac{d_{crosslayer}}{G * b})} = \frac{1}{1 + (\frac{\pi^2 * 11000 * 30000}{2900^2} * \frac{20}{50 * 1000})} = 0{,}953$$

Effective moment of inertia:

$$I_{eff} = 1357\ cm^4$$

Resisting moment:

$$\mathrm{W_{eff}} = \frac{\mathrm{I_{eff}}}{\gamma_1 * \mathrm{a_1} + \frac{\mathrm{d_1}}{2}}$$

$$\mathrm{W_{eff}} = 269\ cm^3$$

Radius of gyration:

$$\mathrm{i} = \sqrt{\frac{\mathrm{I_{eff}}}{\mathrm{A_{eff}}}} = \sqrt{\frac{1357\mathrm{cm}^4}{341\mathrm{cm}^2}} = 2\mathrm{cm}$$

Flexibility:

$$\lambda = \frac{\mathrm{l_{eff}}}{\mathrm{i}}$$

$$l_{eff} = \beta * \mathrm{l} = 1{,}0 * 2{,}9 = 2{,}9\mathrm{m}$$

$$\lambda = \frac{2{,}90\mathrm{m}}{0{,}02\mathrm{m}} = 145$$

Related flexibility:

Fire safety:
Fire calculations can be done for proving fire safety of the house, but it is not necessary.
According SP 2.13130.2009 **par.6.5.8.3.** There are no demands for fire resistance and structural class of fire risk for two-store buildings.
Par.6.5.8.4. There are several demands for main structures of three-store houses:

- Load-bearing structures – R45
- Floor structures – REI45
- Non load-bearing structures – RE15
- Built-up roof – RE15
- Trusses, beams, summers – R15
- Participle walls – no rules

If the total floor area is more than $150m^2$ it is possible to take fire resistance rating for load bearing structures at least R30, floor structures – REI30.

$\lambda_{rel,c} = \frac{\lambda}{\pi} * \sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{145}{\pi} * \sqrt{\frac{21}{7333}} = 2,48$	
Coefficient for glued timber: $k = 0,5 * \left(1 + \beta_c * \left(\lambda_{rel,c} - 0,3\right) + {\lambda_{rel,c}}^2\right) = 0,5 * (1 + 0,1 * (2,48 - 0,3) + 2,48^2) = 3,7$ $\beta_c = 0,1$ for glued timber $k_{c,y} = \frac{1}{k + \sqrt{(k^2 - \lambda_{rel,c}^2)}} = \frac{1}{3,7 + \sqrt{3,7^2 - 2,48^2}} = 0,16$	
Compressing stresses: $\sigma_{c,0,d} = \frac{N_d}{A_{eff}} = \frac{55,74kN}{341cm^2} = 0,163kN/cm^2$	
Bending resistance along the fibers: $f_{c,0,k} = 21N/mm^2$ $k_{mod} = 0,8$ $\gamma_m = 1,25$ $f_{c,0,d} = \frac{21N/mm^2 * 0,8}{1,25} = 13,44\ N/mm^2$ **Allowable bending:** $f_{c,0,k} = 24N/mm^2$ $k_{mod} = 0,8$ $\gamma_m = 1,25$ $k_1 = 1,1$ $f_{m,d} = \frac{24N/mm^2 * 0,8}{1,25} * 1,1 = 16,9N/mm^2$ **Checking of compressing stresses:** $\frac{\sigma_{c,0,d}}{f_{c,0,d} * k_{c,y}} = \frac{1,63N/mm^2}{13,44 * 0,16cm^2} = 0,76 < 1$	
Bending stresses: $\sigma_{m,y,d} = \frac{M_d}{W_{eff}} = \frac{20kNcm}{269cm^3} = \frac{0,07kN}{cm^2} = 0,7N/mm^2$	
Checking of bending stresses: $\frac{\sigma_{m,y,d}}{f_{m,d}} = \frac{0,7N/mm^2}{16,9N/mm^2} = 0,04 < 1$	
Checking with eccentric compression formula: $\frac{\sigma_{c,0,d}}{f_{c,0,d} * k_{c,y}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} = \frac{0,163kN/cm^2}{1,34\ kN/cm^2 * 0,16} + \frac{0,07kN/cm^2}{1,69kN/cm^2} = 0,8 < 1,0$	