

Leonardo da Vinci Pilot project CZ/06/B/F/PP-168007

Educational Materials for Designing and Testing of Timber Structures – TEMTIS



Education and Culture

Leonardo da Vinci

INSTRUCTION HANDBOOK TO ELABORATED CASE STUDIES



Guide to case studies for lecturers

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**EDUCATIONAL MATERIALS FOR DESIGNING AND TESTING OF TIMBER
STRUCTURES**

INSTRUCTION HANDBOOK TO ELABORATED CASE STUDIES

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EDUCATIONAL MATERIALS FOR DESIGNING AND TESTING OF TIMBER STRUCTURES

INSTRUCTION HANDBOOK TO ELABORATED CASE STUDIES

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Foreword

The Leonardo da Vinci Pilot project no. CZ/06/B/F/PP-168007 called “Educational Materials for Designing and Testing of Timber Structures” addresses the urgent need to implement timber and timber-based materials in the construction sector.

The outputs of the project should enable an effective implementation and application of the new methods for designing and verification of timber structures in all partner countries (Austria, Czech Republic, Denmark, Norway, Poland, Slovakia, Slovenia) as well as other EU countries.

Within the project there were two handbooks elaborated. One focuses on structural systems of timber structures, the second focuses on use of Eurocodes for designing of elements and structures made of timber and timber-based materials.

Further, case studies of successful and interesting realizations of timber structures and constructions were prepared including the template that would enable potential users to widen this set.

It was also the database of timber constructions in partner countries that was created. It contains data on location, type of construction, images, interesting details, costs accompanied by links for inquiring other information.

The main purpose of the Instruction handbook is to help teachers and lecturers to understand the breath of the subject accelerating their knowledge and interactive teaching methods in order they are able to deliver the product to students efficiently. The product can be used as a practical complementation to Handbook 1 and Handbook 2.

The educational aims of the Instruction handbook is to give teachers the expert awareness on the issue of timber structures and timber-based constructions and as good understanding of the elaborated case studies as possible. The product will include also questions for students, tasks for individual work.

A wide range of potential users of the handbooks and other training materials includes practicing engineers, designers, technicians, officers of public authorities, young people – high school and university students. The target groups come from all territorial regions of the partner countries.

I wish all users of the project products enjoyment of the acquired knowledge and good luck with its implementation in the designing work.

Assoc. Prof. Alois Materna, MSc., MBA

Dean of the Faculty of Civil Engineering of VSB-Technical University of Ostrava, Czech Republic

In Ostrava, 11.2007



Case study no. 1

MULTI PURPOSE SPORTS HALL BULLY ARENA

1. General information

Date: 2002

Price: 5 mil. CZK (only GLT part of roof)

Design studio: OSA Projekt s.r.o.

Construction company: Ingenia dřevostavby, Město Albrechtice, Czech Republic

Location: Kravaře, Czech Republic

Materials used: glued laminated timber (120 m³), steel (18000 kg), reinforced concrete

2. Investment design

The main purpose of Bully Arena is to serve as a training ice-hockey hall intended for ice-hockey youth. Now and then exhibition matches or tournaments in various kinds of sports may be organized there as well as different cultural and social events. The hall capacity is 1000 onlookers, while 650 seated on the main terraces. The icy area may be used for another 500 people.





Fig. 1 General view of Bully Arena

3. Bearing system

The main bearing structure of roofing consists of saddle timber roof truss from glued laminated timber in combination with steel rods and steel joints. The trusses are placed on the dead of concrete columns by joints; on one truss side there is hard jointed imposition, on the other side of the truss there is sliding jointed imposition with coefficient of friction $f=0,15$. The material of timber roof trusses is a glued laminated timber of CB class, steel S 235, steel of joints is galvanized by flame.

Longitudinal arc section of the hall comprises of variable height is timber columns of the main timber roof trusses. Height of location of root joints is the same for all roof trusses.

Spatial bracing of the bearing structure is secured by transversal steel bracings in lateral fields that go from trusses imposition on one side through roof level towards imposition of trusses on the other side. The material of bracings is steel pole, steel S 235, steel galvanized by flame. Trusses exceeding the hall gable (section 100/180/2500 – class SII) are supported in slude by the bearing structure of gables.



Fig. 2 Bearing system of the roof

4. Computational models used

The bearing system was computed by FEM programmes IDA NEXIS.



Used norms: ČSN 73 / 1701 Navrhování dřevěných stavebních konstrukcí (Design of timber structures, ČSN 73 / 1401 Navrhování ocelových konstrukcí (Design of steel structures).

5. Actions on structures

As actions on structures were selfweight of the roof, snow and wind according to ČSN 73 / 0035 Zatížení stavebních konstrukcí (Action on structures).

6. Project documentation, plans, and drawings

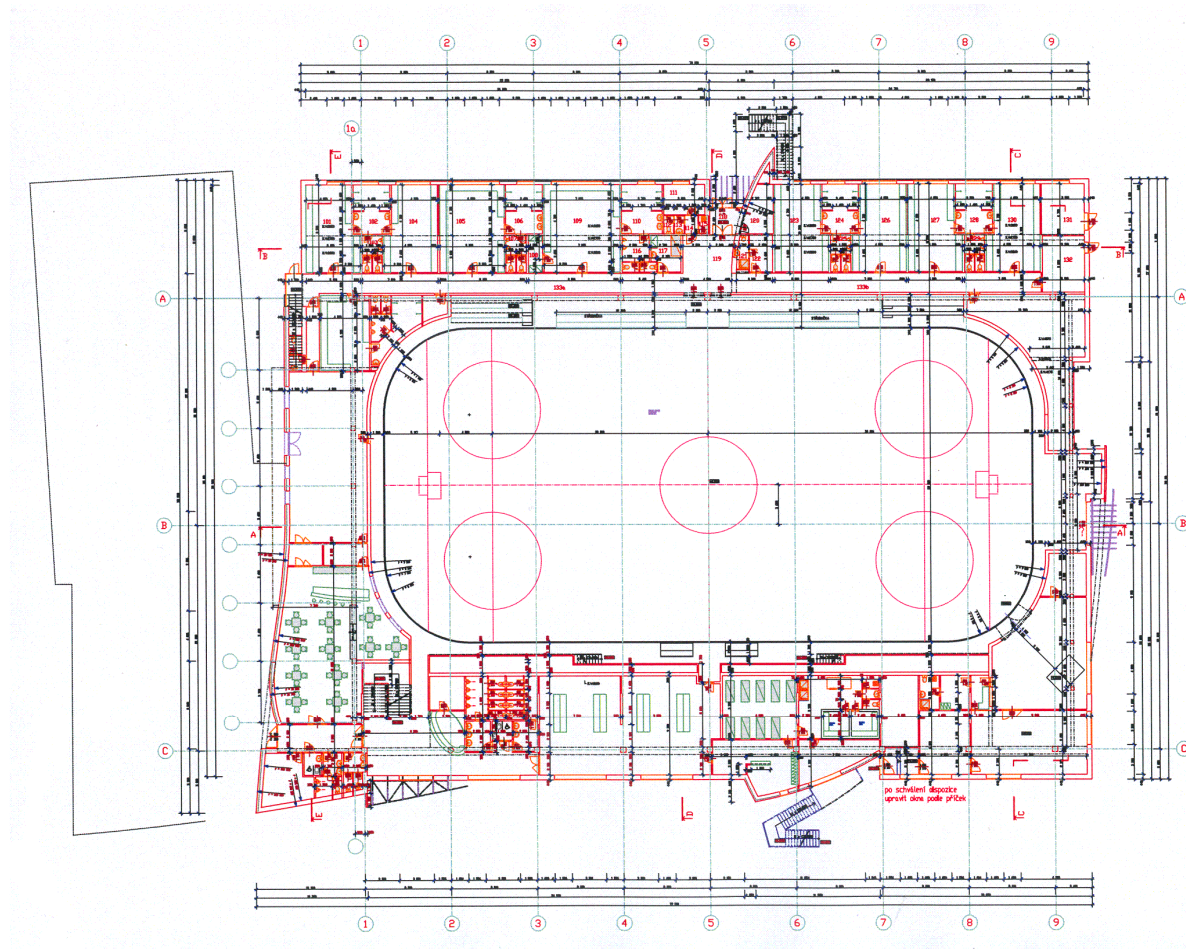


Fig. 3 Floor plan

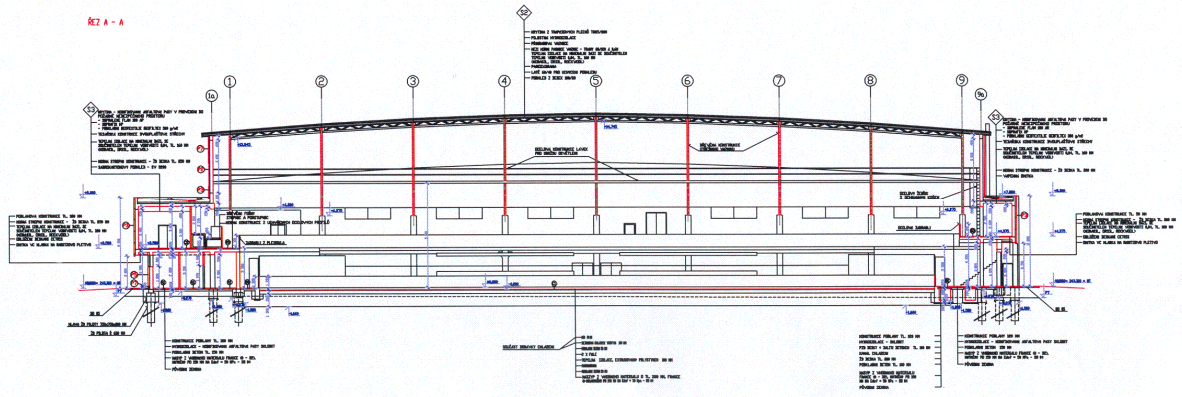


Fig. 4 Cross section A - A

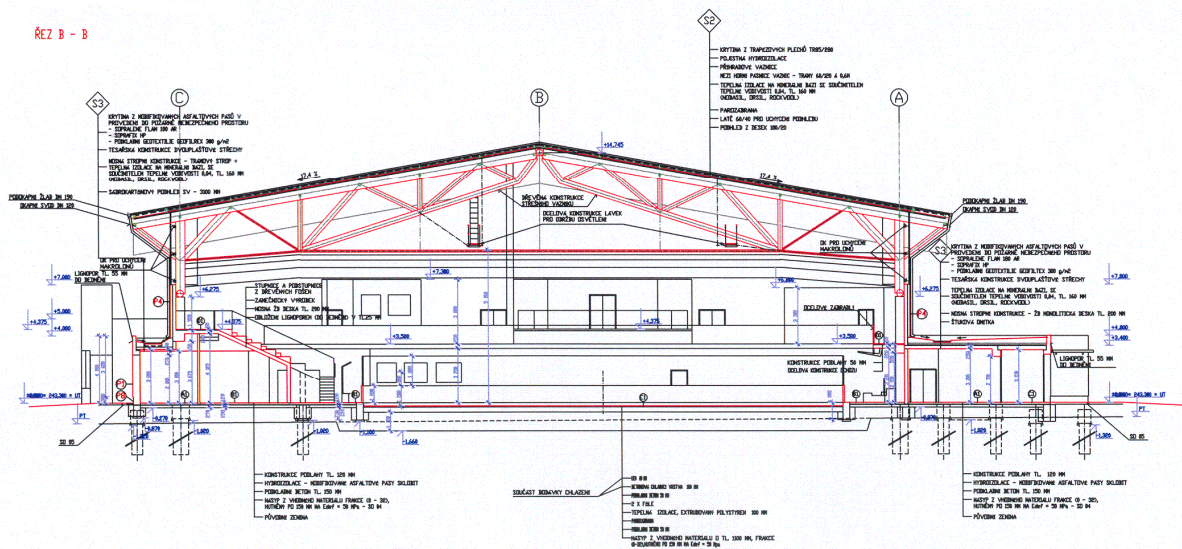


Fig. 5 Cross section B - B

7. Erection



Fig. 6 Erection of the roof





Fig. 7 Erection of the roof



Fig. 8 Erection of the roof



Fig. 9 Erection of the bearing system

8. Interesting construction details



Fig. 10 Detail of timber - steel bars joint



9. Protection from weather effects

The timber truss roof is covered with steel covering on thermo and water isolation layers. Protection of timber bearing structures was done with visible bearing structures with glazing paint, with hidden timber elements and trusses by impregnation.



Fig. 11 Detail of protecting timber parts against weathering

10. Economical and ecological aspects

The multi-purpose sports hall serves for sports and cultural utilization of about 80 000 inhabitants of the region of Opava, for training of young ice-hockey and skating talents.

Instructions and case study no 1 were prepared by Antonín Lokaj.



Case study no. 3

“RAABSTEG” FELDBACH (A)**1. General information**

Type of building	(Covered) Pedestrian and bicycle bridge
Structural system	Cable supported single-span girder with suspended bridge deck
Owner	City of Feldbach / Styria (A)
Location	Feldbach / Styria (A)
Used Materials (for the main structural parts) - Abutment and pylons - Deck - Columns - Tension bars - Suspension cable - Deck surface	Concrete C30/37 CLT-Elements glued with asymmetrically combined glulam beams (GL36c) acting as a T-section; wood species: Spruce Glulam GL24h; wood species: Larch Steel S235 Steel S235 Mastic asphalt
Erection date	08 / 1998
Investor	City of Feldbach and Government of the Province of Styria (A)
Architectural, structural and construction design	Lignum Consult / Graz (A) BM Ing. K. Angerer, DI J. Riebenbauer Collaboration: M. Augustin
Consultant Timber Engineering	Univ.-Prof. DI Dr. techn. G. Schickhofer / Graz (A)
Construction Companies: - Abutment - End columns - Timber structures - Mastic asphalt	City of Feldbach / Styria (A) Fa. Lieb-Bau-Süd GmbH & Co KG, Gleisdorf (A) Fa. Stingl GmbH, Trofaiach (A) Fa. Swietelsky, Feldbach (A)
Price - Abutment - Structure (incl. railing and superstructural parts) - Cost per square meter traffic area	€ 23.255,- € 118.457,- € / m ² : 1.138,-



2. Investment design

City development purposes caused the bridging of the river Raab by a pedestrian and bicycle bridge in the eastern part of the city of Feldbach in the Austrian province of Styria. In this area the river Raab has a width of about 20 m. The bridge connects the centre of the town with the new raised Centre for Healthiness and Culture and contributes to the expansion of the local bicycle network.

To find an appropriate solution for the given location three variants have been designed and analysed by students of Graz University of Technology, Faculty of Civil Engineering – a suspension structure, a fish-bellied girder and a cable supported plate – and have been presented in February 1997 to the major and some communal representatives.

Rapidly the discussion came to the result to build the present variant of a cable supported single-span girder with a suspended traffic deck (Fig. 1). After the detailed design and the clarification of the financing concept the bridge has been erected in August 1998 and could be given over to the traffic already one month later.



Fig. 1 Pedestrian and bicycle bridge „Raabsteg“ in Feldbach (A)

3. Structural system

The structural system of the roofed “Raabsteg” bridge is a cable supported single-span girder with a suspended traffic deck and a free span of 35,0 m and a clear width of 2,50 m (Fig. 2 and 3).

The bridge deck is composed of a cross-laminated timber plate (CLT-plate) which transfers the actions to glulam-beams at the edge of the plate. Those beams are glued with the CLT-plate so that the deck has the function of a T-beam.

Exactly the same structural system has been chosen for the roof construction to act as a stiffening beam for the tension chord. The BS18k-girder (GL36c in accord. to EN 1995) – an asymmetrical combined glulam-beam of the highest strength class in accordance to the Austrian National Standard at the time of erection – of the roof rests on the four bearing-areas consisting of reinforced concrete pylons, which lead the vertical and horizontal loads from the roof plane into the abutment.

Both the upper and the lower deck are manufactured with the wood species spruce.



Dead and traffic loads acting on the surface of the traffic deck are conducted by tension bars (ISTOR TX55) into the tension chord, further into the bearing points of the pylons and the upper plate respectively. The roof T-beam is loaded in compression and bending and is jointed with the road surface by vertical larch glulam-columns. The greater part of the roof-deck's dead load is carried in this way by the lower deck and loads are leaded further to the tension tie. Furthermore the columns are acting as lateral supports for the stiffening beam of the roof deck.

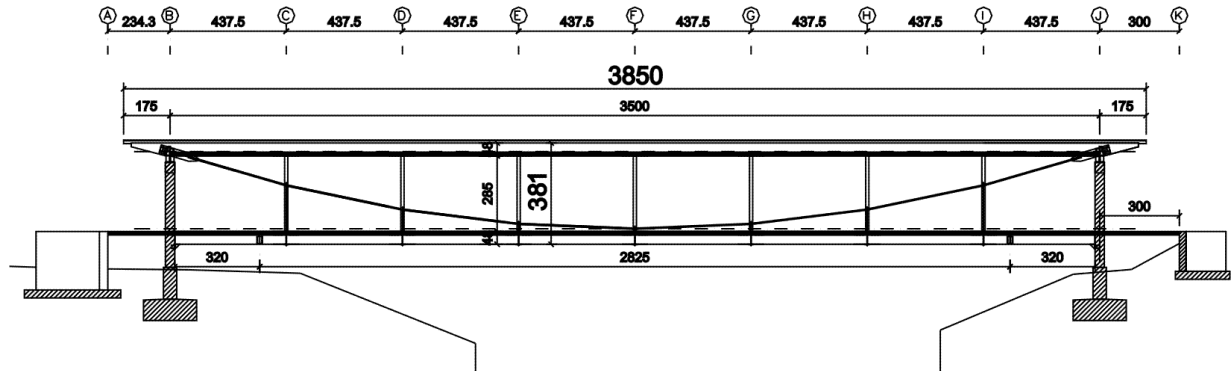


Fig. 2 Longitudinal section and structural system of pedestrian bridge „Raabsteg“ in Feldbach (A)

The cross-section of the bridge shows a structure clearance of 2,58 m width and 2,80 m height. It allows the crossing of vehicles for maintenance purposes up to a load of 6,6 tons. The roof and the traffic deck are consisting of two (twin-) glulam beams (200/350 mm; 200/480 mm). The deck is formed by a 135 mm thick 5-layered CLT-plate glued with both glulam beams and is therefore acting as a T-beam.

The upper deck system, which sustains the roof, has been designed and produced in the same way as the lower plate is also glued with two BS18k-twin beams (GL36c) at the edges of the plate. The tension bars (steel $\text{\O}24$ mm) conduct the loads from the lower deck-plate into the tension chord (flat steel 40/200 mm, ST 510 C). To perform an upper completion of the roof a slightly curved three-layer wood panel with a sheet metal is responsible for the lead-away of rain and snow.

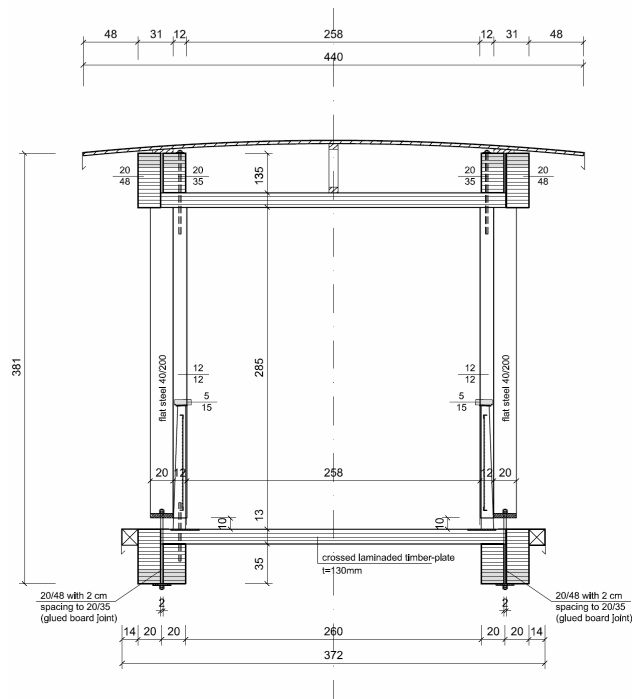


Fig. 3 Cross-section

4. Computational models used

Structural analysis has been done with the programme package “APL” (developed by Zenkner and Handel, Graz (A)) which allows the analysis of structural systems using Theory of 2. Order. All calculations have been carried out with the planar structural system given in Fig. 4.

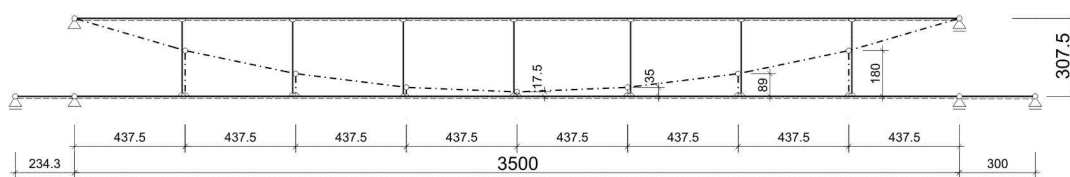


Fig. 4 Structural system

Analysis work showed that the mechanical behavior of this kind of structural system is dominated by the stiffness of the tie bar. As a consequence serviceability limit states (deformation, vibration) has been decisive for the design during the optimization process. For the design of the columns apart from their load carrying capacity an adequate stiffness to reach the second eigenform for the roof member has been considered.

Vibration analysis has been also done on the planar system. The calculated eigenfrequency during the design of about 3 Hz has been checked by in-situ test which resulted in a good conformity with the results from the analysis.



5. Actions on structures

The Austrian Standard ÖNORM B 4002 which has been valid at the time of the design of the bridge is providing a basis for the design actions. The load specifications in longitudinal direction are listed in the following table (Tab. 1).

dead load	deck-plate roof-plate	g_1 g_2	6,3 3,7	kN/m kN/m
snow		s	0,85	kN/m ²
traffic load	uniformly distributed load vehicle for maintenance puposes	p_k P_k	5,0 66,0	kN/m ² kN

Tab. 1 Design Actions

The relevant load case is reached by full load (dead load, traffic load, snow). The design forces have been calculated by means of a computer program and are shown in Tab. 2.

	N_{min}	N_{max}	$M_{y,max}$	$M_{z,max}$	V_{max}	H_{max}
roof-plate	-939,7 kN		92,5 kNm	189,9 kNm		
column	-34,4 kN					
upper support					155,9 kN	10,9 kN
tie bar		978,5 kN				
deck-plate			100,9 kNm	346,1 kNm		
suspension post		88,8 kN				
lower support					46,8 kN	19,8 kN

Tab. 2 Design loads for the main members of the bridge

6. Project documentation, plans, and drawings

Plans and drawings of the "Raabsteg Feldbach" are given in Fig. 2, 3 and 4.

7. Erection

The bridge has been prefabricated and compiled in the production hall of the timber construction company Stingl GesmbH in Trofaiach (A) and has then been transported by means of a low loading trailer all-in-one piece from Trofaiach to Feldbach (A) (about 130 km distance). On-site the structure has been attached on the pylons by means of three mobile cranes. Finally the roof membrane, the coating of the deck and the pipes for the district heat and electricity cables have been mounted.



Fig. 5 Transportation of the bridge



Fig. 6 Assembly of the bridge

8. Interesting construction details

8.1. Deck Construction

The deck is glued with both glulam- (twin-) beams at the edge of the CLT-plate and has therefore the function of a T-beam. For the lay-up a five-layer crossed laminated timber-plate (17/32/32/32/17 mm) made by the company Stingl, with a thickness of 13 cm. On the upper surface of the deck a two layer sealing and on it a 5 cm mastic asphalt layer as mechanical protective layer and weathering coat (Fig. 6) has been applied.

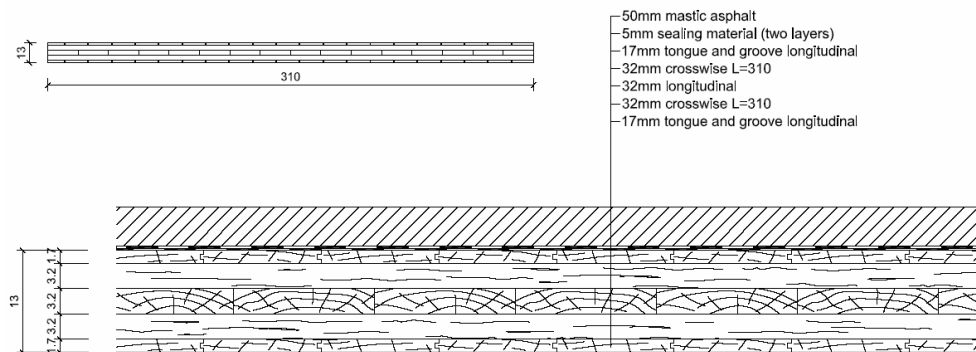


Fig. 7 Cross-section of the deck-plate

8.2. Connection Suspension Bar on Main Girder

To connect the glulam-columns (larch) with the decks a steel-plate angle has been slotted into the column and has been connected by means of steel dowels and wood screws respectively. The tension bars are arranged in the center of the twin glulam-beams and were inserted through them to load them on compression perpendicular to the grain at the lower side by means of a steel plate and threads with nuts. On the upper side a transverse steel pole with an inside thread has been welded on the tension tie. The point of penetration has been realized using a plug sleeve. To protect the main construction against driving rain a square-sawn timber on the outside of the gluelam beam has been screwed on them. Finally the edge area has been covered by a zinc sheet (Fig. 7).

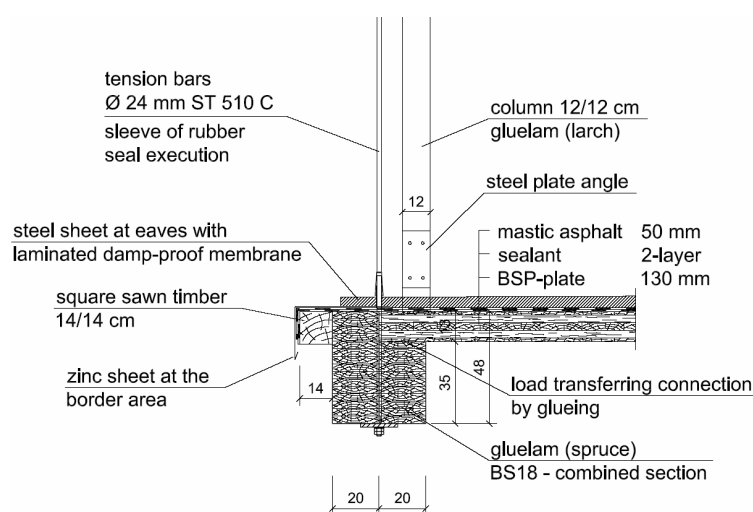


Fig. 8 Detail at the connection between the suspension bar the main girder

8.3. Support Detail – Connection Tie Bar

The tie bar consists of a flat (40/200 mm) of steel ST 360 C and has been welded with a steel sword, which leads the loads into a complex steel part. This part - which is connected with the supporting pylons by means of self-fixing screws - introduces longitudinal loads with a contact joint into the roof deck and is leading it's loads into the reinforced concrete columns (Fig. 8).

The final form of this detail has been already manufactured and mounted in the production hall of the manufacturer.

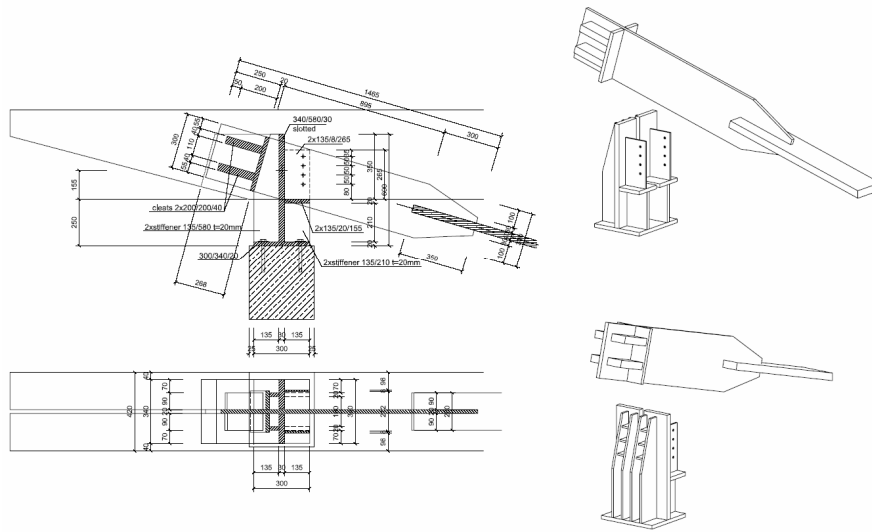


Fig. 9 Supporting detail

8.4. Railing System

The railing is made up of eight fields and is located between the sections of the columns. Single fields are separated on one hand by the timber columns and on the other hand by steel posts (ST 360 C). In the fields steel grids are situated which are welded on gentle steel angles and fixed with simple screw connections on the columns. The easy to change glulam (larch) handrail is forming the upper limit of the railing system (Fig. 8).

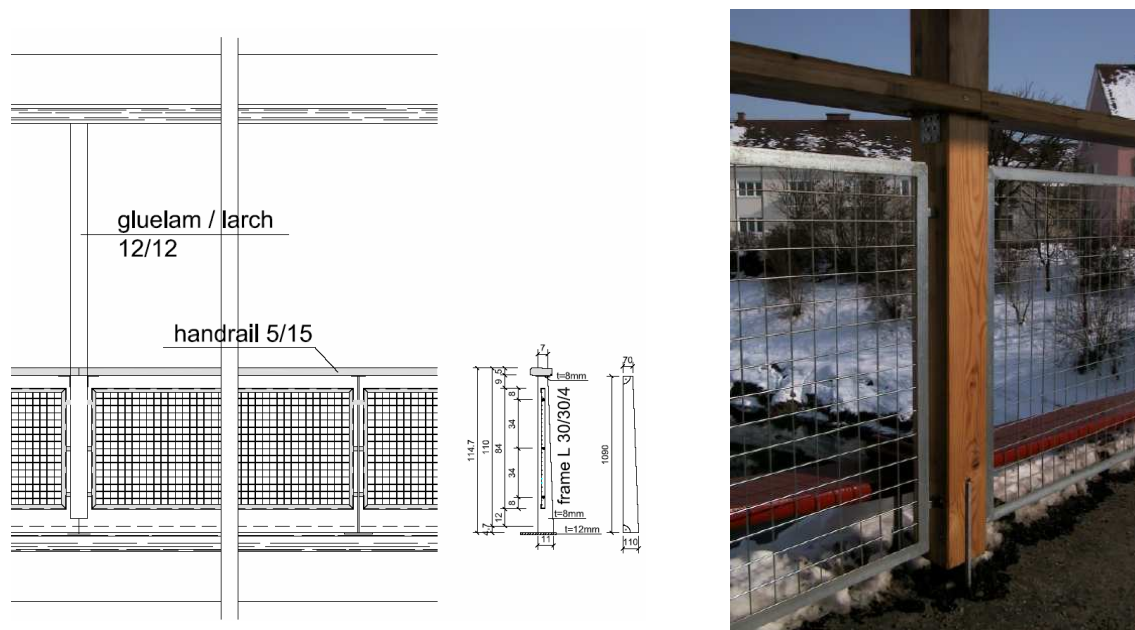


Fig. 10 Railing and protective construction

9. Protection from weather effects

During the design process of the structure primarily constructive principles of weather effect protection have been considered. Since the bridge is canopied the main protection from weather effects is done by the roof. In addition the twin glulam-beams of the traffic deck are protected by square-sawn structural timbers covered by a zinc sheet. The deck-plate has a two layered sealant with an slightly inclined 50 mm thick mastic asphalt layer. For the weather exposed columns and the handrail the resistant wood species larch has been used.

In addition all wooden parts were treated three times with the wood-preservative glaze "Danske Vakuummattpe".

The tension-tie which is highly exposed to rain and snow has been covered with a plumbiferous corrosion coating covered by a three times top painting. All other steel parts are provided with a zinc coating.



Leonardo da Vinci

WP6 – Case studies



10. Economical and ecological aspects

From the economical point of view this bridge has been a relative cheap solution for the given challenge. Abutment and parts of the pylons have been manufactured by the owner. Since the bridge has been manufactured in the production hall of the producer for the production process the stationary equipment of the company (cranes, tools etc.) could be used. In comparison to an in-situ assembling of the load carrying members the costs of the 120 km transport between the production hall and the building site and the lifting to the end-position by means of three mobile cranes has been cheaper and more time effective.

Concerning to ecological aspects it has to be mentioned that about 2/3 of the province of Styria are covered with forests. Because of this the use of wood and timber but also because of the natural scenery in the city of Feldbach a wooden bridge was rated as the appropriate material for this building.

Instructions and case study no 3 were prepared by the Institute of Timber Engineering and Wood Technology at Graz University of Technology.



Case study no. 4

PEDESTRIAN BRIDGE RÁDLO

1. General information

Date: March 2004

Price: 4 000 000 CZK

Investor: Liberec county

Design studio: Design office VANER

Construction company: Stavby silnic a železnic, ZAKLÁDÁNÍ STAVEB, TESKO

Location: Road I/5 close to village Rádlo in the Czech Republic

Materials: glulam , steel

2. Investment design

Pedestrian bridges are mainly used by pedestrians and cyclists and only occasionally by maintenance vehicles or ambulances. Due to their lower loadings, pedestrian bridges are mostly lighter than road bridges and are often seen to be more suited to the use of a low modulus material like timber.

With regard to appearance and also to structure, open and covered bridges are distinguished as two main types of bridge. The choice of the best structural form of a bridge depends on several parameters:

- topography and landscape;
- span;
- loading;
- clearance and clear width;
- soil conditions;
- architectural features.

Another principal distinction concerns the position of the deck plate relative to the main structure: the deck plate may be on top or at the base of the main structure.

Pedestrian bridge Rádlo is designed as open bridge with the deck plate on top of the main structure.

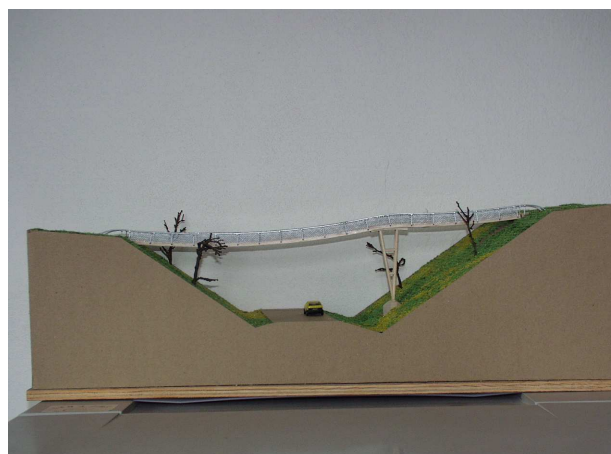


Fig. 1 Model of the bridge

3. Bearing system

For the bridge structure itself, a large number of bearing systems are possible to be used. Most bridges consist of one of the following basic forms: beams on two or more supports, trussed systems, kings and queens post trusses, strut frame systems, frame systems, arch systems, suspended and cable-stayed systems, chainlike structure. Pedestrian bridge Rádlo is designed as chainlike structure.

4. Computational models used

The simplified models and methods were used. The simplified method was based on an equivalent constant amplitude fatigue loading, representing the fatigue effects of the full spectrum of loading events.

The stress was determined by an elastic analysis under the specified action.

The fatigue loading from traffic was obtained from the project specification in conjunction with EN 1991-2.

The number of constant amplitude stress cycles per year was taken from EN 1991-2.

5. Actions on structures

The design of bridge was in accordance with EN 1990.

Actions used in design of bridge were obtained from the relevant parts of EN 1991:

- EN 1991-1-1 Densities, self-weight and imposed loads
- EN 1991-1-3 Snow loads
- EN 1991-1-4 Wind loads
- EN 1991-1-5 Thermal actions
- EN 1991-1-6 Actions during execution
- EN 1991-1-7 Accidental actions due to impact and explosions
- EN 1991-2 Traffic loads on bridges.

Variable actions due to the passage of vehicular and pedestrian traffic were regarded as short-term actions.

6. Project documentation, plans, and drawings

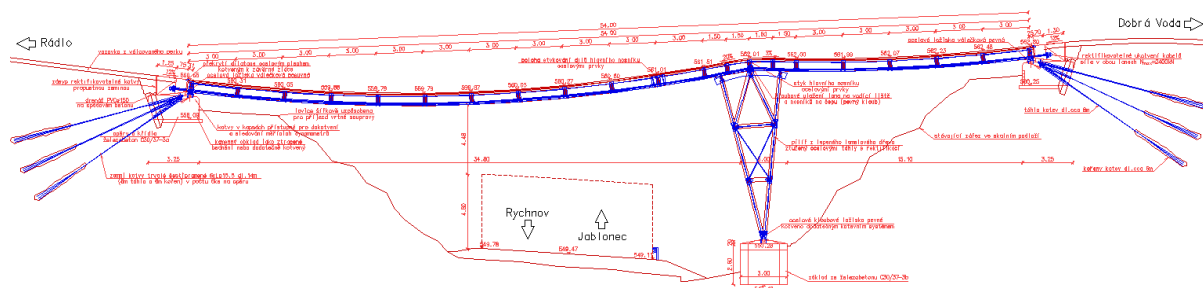


Fig.2 View of the bridge

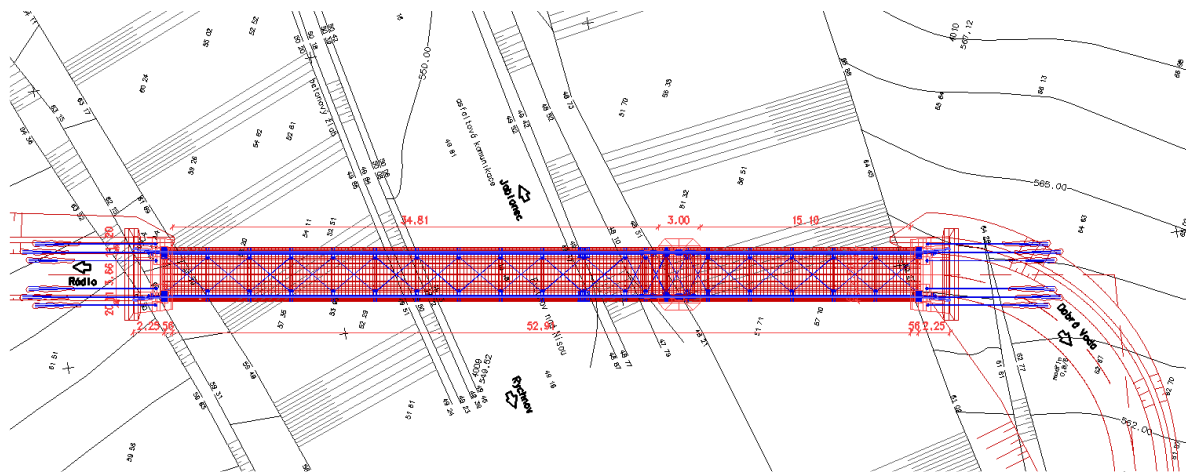


Fig. 3 Floor plan of the bridge

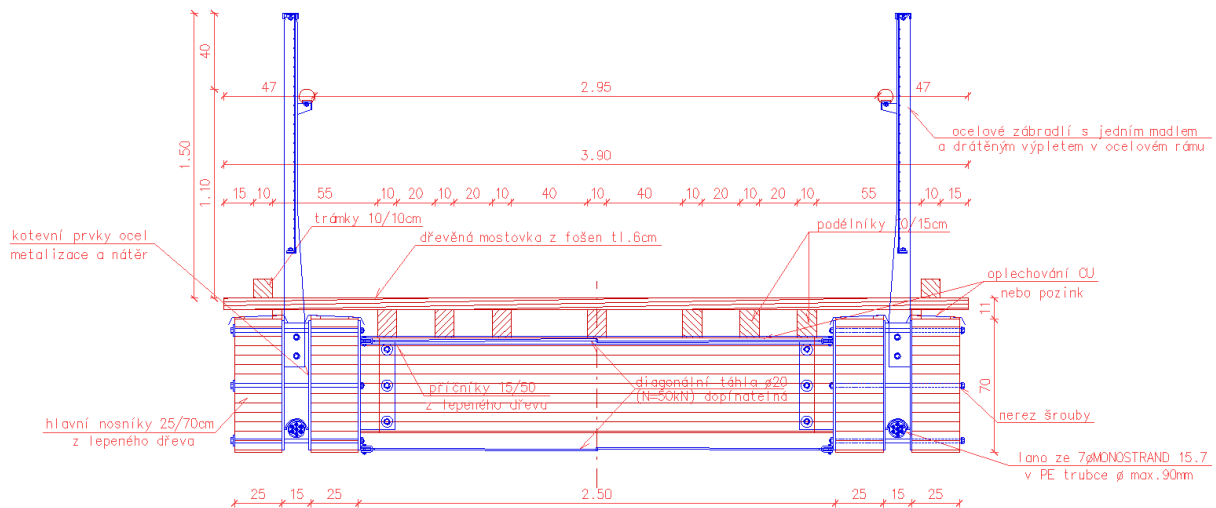


Fig. 4 Cross section of the bridge

7. Erection

The final phases in the provision of a timber bridge are transport and erection. These may appear insignificant in the realisation of a project but they require the same attention as the preceding phases, in that together they can influence not only the design but also the budgeting and the management of the project.

Erection represents, in the construction of a timber structure, the moment in which all the previous stages are verified. A well executed assembly is a primary condition to achieve a good building but it is not a sufficient condition. It is necessary that all the previous phases (design, engineering, fabrication, machining and transportation) are correctly executed, to be followed by skilled erection of the structure. Workmen have to be skilled, with experience in timber construction and with complete and efficient tools and machines. The site must be ready for receiving the timber structural elements in order to allow workmen to operate easily and with safety.

Erection of a timber structure is usually carried out by placing first the main columns and beams and then the secondary elements. Due to the fact that these frequently have a role in bracing the structure, provisional bracing must be provided. Assembly procedure depends on the type of structural system.



Fig. 5 Bridge erection sequence



8. Interesting construction details

The reason for decay in timber bridges is nearly always poor detailing for durability and neglected maintenance. All aspects of timber protection and maintenance should therefore be considered even during the planning phase of bridge.

Timber as a natural product is part of a life cycle of growing and decomposition. One method to break this cycle and hence preserve the timber is to keep the wood material constantly dry. This is a very effective method to preserve the load carrying capacity and the functioning of the bridge during its planned life time. This goal can be achieved using a timber protection plan relating to the elements shown in Tab. 1.

Element	Objective	Measure
Conceptional design	Prevention or decrease of intense weather exposure	Roof or covering of the main structure
Choice of material	Prevention of damage through adequate choice of materials	Use of either naturally durable or preservatively treated timbers; low moisture content during erection
Design of details	Prevent unfavourable consequences of shrinkage and swelling due to water contact	Covering of horizontal surfaces, of joints and of end grain; enable quick drying out of wet parts
Preservative treatment	Prevention of fungi or insect attack	Pressure treatment using chemical solutions
Surface treatment	Prevent weathering of surfaces, achieve dimensional stability and avoid cracks; limited protection against fungi or insect attack	Several layers of pigmented coating

Tab. 1 Timber protection plan

9. Protection from weather effects

The deck protects the main structure from moisture and mechanical damage from traffic. Apart from the timber members the metal fasteners and fittings have to be protected against corrosion. Especially from the use of salt to keep the roads free from ice and snow in the winter and the use of salts for treating the timber which leads to accelerated corrosion of steel parts. Because fasteners in timber connections are not accessible after erection of the structure, they have to be protected permanently. Hot-dip galvanizing and eventually additional layers of protective coating lead to a prolonged lifetime of fasteners and metal fittings. In more aggressive environments stainless steel is preferred.

10. Economical and ecological aspects

During recent years a real renaissance of timber bridges has taken place. One reason is the increasing interest in using such a durable and ecologically sound building material as timber. Apart from that, technological developments have contributed to new and more efficient jointing techniques and the use of wood-based materials. Timber bridges are thus shown to be effective, economic and durable and to allow innovative and aesthetic solutions.

Instructions and case study no 4 were prepared by Petr Kuklík.



Case study no. 5

APARTMENT HOUSES CHÝNĚ

1. General Information

Period of construction:	2006 – 2007
Price:	7,4 million CZK
Investor:	OXES, s.r.o. Praha 2, Španělská 742/6, PSČ 120 00
Project:	Jindřich Sporek, Valašské Klobouky, Cyrilometodějská 301, PSČ 766 01
Construction company:	RD Rýmařov, s.r.o. Rýmařov, 8. května 1191/45, PSČ 795 01
Location:	Chýně
Materials used:	Timberwork (timber, mineral and glass fiber insulation, gypsum wood-fiber board, gypsum plasterboard, concrete roofing, ceramics, contact thermo facade ...)

2. Investment design

It is a locality construction of 32 timber-based multistoried detached and terrace houses. The delivery is turn-key including groundwork, house connections, ground completion and fencing.



Pic. 1 Apartment houses in Chýně

3. Bearing system

The timber-based houses are made of platform frame. The carrying bars of the vertical construction have a profile of 120 x 120 mm and are located in a module distance of 600 mm. Gypsum wood-fiber boards are used for static sheathing. The horizontal construction is made of beams with a dimension 60 x 240 mm, closed with DTD 22 mm. The roof construction is a purlin system. Moreover, it is made of wooden beams for a maximum snow load of up to 1,5 kNm⁻² in agreement with the static calculations. The house can be situated to the elevation above sea-level up to 600 m. The overlap of



the saddle roof is approximately 600 mm on the eaves and gable side. The roof covering is made of concrete roof tiles.

4. Computational models used

The program IDA NEXIS is used for the computation of the building static.

5. Actions on structures

The individual structural parts are made in the factory as a platform frame. The dimension of the vertical structural parts is the whole story height with a length up to 11 000 mm. The horizontal structures are made in form of ceiling elements with the maximum dimension of 2 400 x 12 000 mm. The roof purlin construction is completely prepared in the factory in the form of individual machined members. The production documentation is run by means of the graphic program Cadwork.

6. Project documentation, plans, drawings

The apartment houses in Chýně are designed for detached and terrace house-buildings. The houses are built on slab-on-ground foundation bases. They have two stories above ground and an attic. The apartments are designed as houses with six or ten flats. The dimensions of the ground plan of the house are 16,96 x 10,63 m. Characteristics of the building are shown in Fig.1:

Ground plan size	16,96 x 10,63 m
Number of above-ground stories	3
Number of dwelling units	6 (10)
Type of roof construction	purlin system 38°
Construction of external walls	framework
Thermal resistance for external walls	$R = 4,195 \text{ m}^2\text{K W}^{-1}$
Coefficient of thermal transmittance for external walls	$U = 0,229 \text{ W m}^{-2}\text{K}^{-1}$
External wall fire resistance	REI 90, REW 60
External wall airborne sound insulation	$R_w = 44 \text{ dB}$
Impact sound insulation for ceiling with covering	$L'_{n,w} = 52 \text{ dB}$
Airborne sound insulation for flat to flat walls	$R'_w = 59 \text{ dB}$

Fig. 1

6.1. Structure of single components

- External wall and gable from exterior:
- Stopper with stiffening network 3 mm
 - Facade polystyrene 60 mm
 - Gypsum wood-fiber board 15 mm
 - frame construction with mineral insulation 120 mm
 - Moisture stop
 - Gypsum wood-fiber board 12,5 mm
 - Gypsum plasterboard 12,5 mm
 - Structural wallpaper
 - Interior paint

Ceiling structure top down:



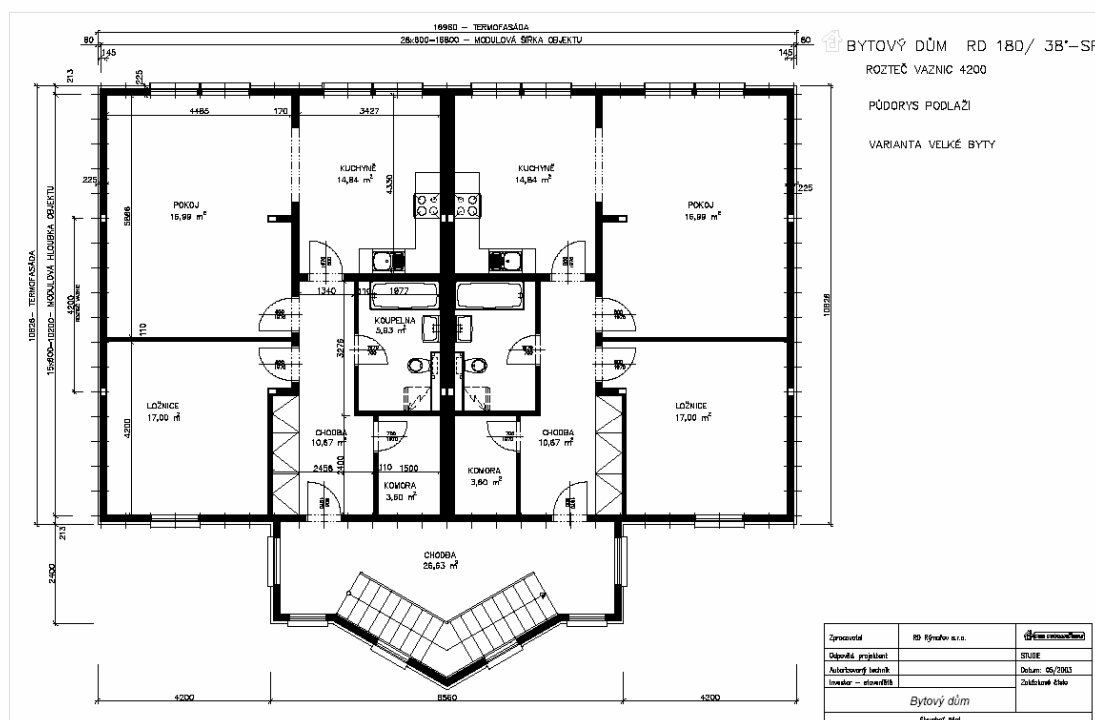
- Floor covering (carpet, tiles)
- Anhydrite compound 45 mm
- Sound insulation layer of mineral wool
- Ceiling covering DTD 22 mm
- Ceiling beams 60 x 240 mm with min. insulation 120 mm
- spread lathing 30 x 60 mm
- 2 x gypsum plasterboard GKF 12, 5 mm

The internal bearing walls have a bearing construction of wooden beams. The covering is made of gypsum wood-fibre boards and gypsum plasterboards. The interior space of the framework is filled with mineral felt. The total thickness of one internal bearing wall including covering with gypsum plasterboards 2 x 12,5 mm is approximately 170 mm.

The dividing bars are a framework construction with a gypsum wood-fibre board and a gypsum plasterboard covering. The interior of the framework is filled with mineral felt – thickness approximately 60 mm. Dividing bars are used with a total thickness of approximately 110, 157, 170 mm. Installation walls are used according to the constructional requirements – thickness approximately 87 – 219 mm.

Stairs between the floors are made of metal, in accordance with the project documentation without risers. To make the loft accessible (loft above the attic), RD houses are equipped with a trap door.

Pic.2 - The ground plan



PDF byl vytvořen zkušební verzí FinePrint pdfFactory <http://www.fineprint.cz>

Pic. 2

7. Assembly

The vertical construction parts of the first storey are brought down on the prepared concrete foundation base by crane (walls and bars) and fixed with the help of anchors and expansion screws. The cross-connection of the parts is done through screws and drywall screws. The ceiling elements are laid on the balanced walls and **mutually** connected with screws. The whole ceiling board is fixed with spiral nails to the walls. Beam riders are fixed on the ceiling on which the external walls of the



second above ground storey are put. Bars and carrying walls are put into the object. The cross-connection is similar to the assembly of the first above ground storey, the same is for the assembly of the roof including the beam riders of the attic floor. The external walls of the attic floor and the bottom part of the gable are put on the beams. In between the walls and the external walls of the attic floor inclined walls are assembled. After the settlement of the purlin roof spars are fixed with the help of the BMF profiles, spiral nails and stepped nails. Roof and gable lower ceilings, diffuse folio, contra rods, roof rods and roof cover are settled on the roof spar. The external thermo façade is finished in the areas, where due to assembly reasons the production could not be finished and the visual plaster is extended. At the same time the interior is completed. The electricity is distributed. The central heating, the inner canalization, gas and sanitary conveniences are finished. Further, the floor construction is laid. The interior facing of the wall is completed with plasterboard and the gypsum plasterboard lower

ceilings are assembled. The walls and the ceilings are affixed with a structural wall paper and white paint. The floor coverings, paving and facings are laid, heaters, lights, blinds, fixtures and fittings for bathrooms, toilets and the kitchen are assembled. The entrance doors for each flat and interior doors without door steps with doorframes are assembled.

8. Interesting construction details

The requirement of the investor to increase the fire resistance of the gable wall of the apartment houses to REI 90 was fulfilled by implementing a MULTIPOR board 600x390x80 into the construction. The MULTIPOR boards were glued to the gable wall directly in the fabric and integrated into the areas of the connecting parts after the assembly.



Pic. 3 Glueing of Multipor



Pic. 4 Gable wall with Multipor

9. Protection from weather effects

The building parts are produced and loaded in protected tempered spaces. At the construction site trailers are transported under the protecting cover. The assembly is carried out directly from the transporters without an in-process store. In case of bad weather and stopped work, the object in the process of construction is protected with a cover. The assembly of building shells is done in a short time if possible and is finished with the roof covering and the completion of the thermo façade including the surface works.

10. Economical and ecological aspects

The use of wood for the construction of apartment houses in terms of the economy and environment is very useful. It is a matter of the most significant natural material. It is a resource, which positive aspects are especially good effects on the atmosphere, fragrance, regulated humidity, increased sense of warmth and emerging physical building characteristics. In consequence of current requirements of long-term sustainable growth, wood as a building material gains new perspectives. The fact, that wood as building material is prioritized has many reasons:

- its harvesting amount is increasing in the Czech Republic
- its use for the building of houses has historical roots in the Czech Republic
- the energy intensity of the harvesting of wood, its processing into the object and the disposal of the object after the termination of its lifetime is three to five times lower as materials like concrete, brick etc.
- the whole object from the floor to the roof covering can be built out of wood
- a wood construction of the whole object is represented by less than 2 % in the Czech Republic.

The wood can therefore be used to build family houses, apartment houses and in future even whole building blocks.



Leonardo da Vinci

WP6 – Case studies



Instructions and case study no. 5 were prepared by Ing. Miroslav Jindrák.





Case study no. 6

PRODUCTION BUILDING

1. General information



Fig. 1 The building seen from the north

Date:	Sept.2006 – April 2007
Price:	Approx. 3 Mill. EUR
Investor, design, construction and production:	Palsgaard Træ A/S, Denmark
Location:	Palsgaardvej 5, DK-7362 Hampen
Materials used:	Timber in the main structure
Surrounding:	The building is a new part of an existing production company.



Fig. 2 The building seen from the inside

2. Investment design

The new 5000 m² fabrication building is for production of prefabricated trusses. Together with investment in new machinery and flexible production methods it gives a more cost effective production of high quality trusses.

The building design gives small costs for maintenance of the building.

In the production area the staff meets good atmosphere with timber construction, daylight, good noise reduction and the surfaces held in light colours.

3. Bearing system

3.1. General description

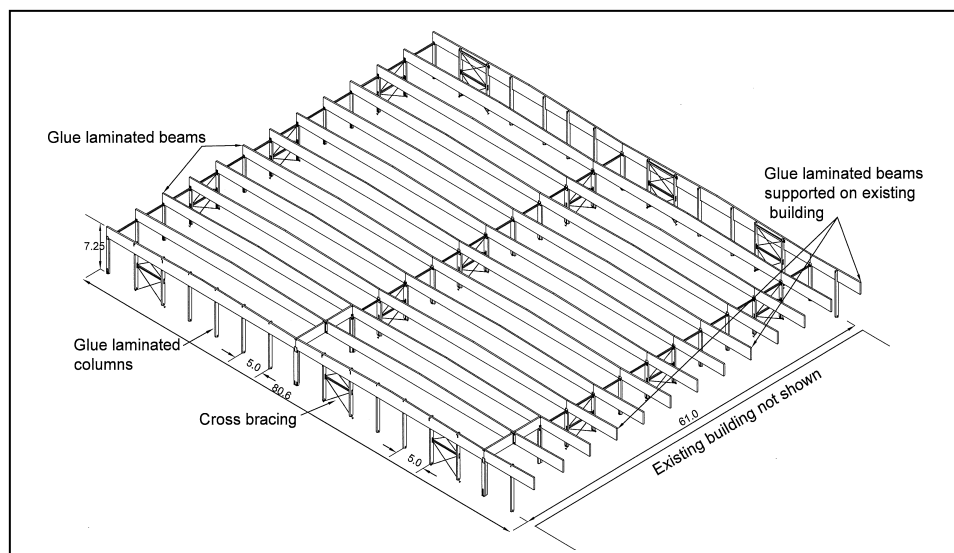


Fig. 3 3D model of the bearing system

The building is in one level with the overall dimensions of 80.6 m x 61 m. The internal height is 7.25 to 7.60 m and the height of the facades is 8.02 m from the floor level.

The main beams are glue-laminated wood with taper. Columns are glue-laminated wood. The cross bracings are with horizontal members in glue-laminated wood and inclined tension members in steel.

The roof is used as a structural diaphragm. It is made of prefabricated elements with timber beams covered with plywood for horizontal bracing. The connections between the roof elements are with nails.

The facades are with an upper part of prefabricated elements with timber beams and a lower part of prefabricated concrete elements.

The foundation and the floor are in reinforced concrete.



3.2. Vertical loads transferred to the foundation

The vertical loads are from self-weight, imposed load, snow and wind.

The roof element transfers the loads to the glue-laminated beams. From the beams the loads are transferred to the columns and then to the foundation.

The facades are directly supported on the foundation.

3.3. Horizontal loads transferred to the foundation

The most important horizontal loads on this building are the wind loads. Other loads are brake forces from the cranes and forces from stabilization of members in compression.

The facades transfer the most part of the horizontal wind loads to the columns. The pin joint columns transfer the loads to the roof and the foundation. A smaller part of the wind loads on the top of the facades is transferred directly to the roof.

Now the roof acts like a diaphragm. It transfers the loads to the vertical cross bracing. From the cross bracing the loads are transferred to the foundation.

4. Computational models used

Beams, columns, façade elements and roof elements are calculated as simply supported elements with the supplier's computer programs. The global stability analysis of the building is documented by hand calculations.

5. Actions on structures

Actions on the structures are according to the Danish Code DS 410:1998.

The actions from cranes are based upon information from the supplier.

The characteristic maximum velocity pressure q_{\max} is 0.80 kN/m^2 with basic wind velocity at $v_b = 24 \text{ m/s}$ and terrain category II (farmland).

The basic value for the characteristic snow load on the ground is $s_{k,0} = 0.90 \text{ kN/m}^2$.

In Denmark the mass loads come from small earth quakes, structures out of plumb, etc.

The calculation for this project shows, that it isn't necessary to use the mass loads, because they are smaller than the wind loads.

5% of the roofs area consists of windows used as fire ventilation. According to the Danish Building Regulation (BR-82) there are no requirements for the fire protection of the main construction in the building.

Collision actions from the internal traffic are taken by a separate construction of steel cantilevered from the foundation.

6. Project documentation, plans, and drawings

The main drawings are the ground floor plan, the foundation plan, the construction plan, facades, cross sections and details.



There is a full documentation with static calculations according to the Danish Building Regulation.

Element drawings, element plans and an isometric model of the main constructions are used for the fabrication and erection of the building.

There are also detailed working descriptions.

7. Erection



Fig. 4 Erection of the building

The erection of the building is done by cranes. The roof elements are delivered with one layer of bitumen felt. It is important with a quick covering with bitumen felt of the joints between the roof elements to protect them against rain.

8. Interesting construction details

8.1. Roof elements

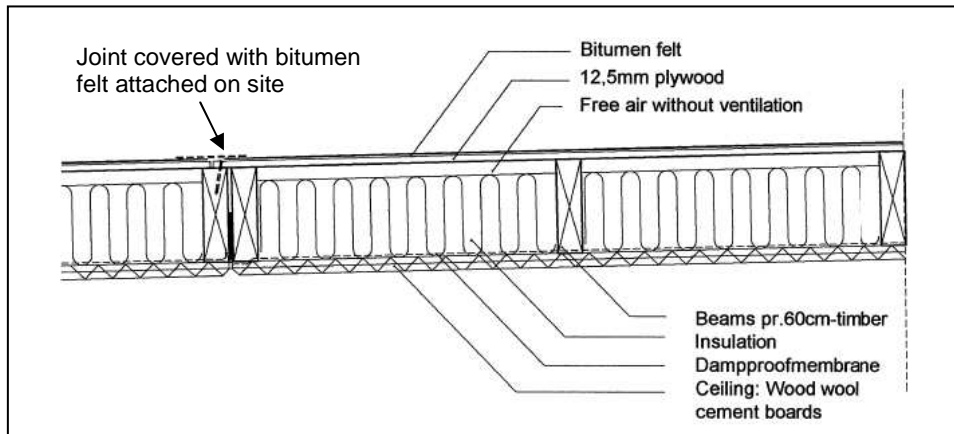


Fig. 5 Cross section in roof elements

The roof elements are PT-elements type 1 from Palsgaard Træ A/S. They are without air ventilation and can be used for room climate class 1, because the production does not generate much moisture.

The damp proof membrane is made with a special filter. It can drain possible water to the downside of the membrane.

The differences in moisture in the elements give the roof elements vertical deformations from winter to summer. These deformations may be larger than the deformations from snow.

8.2. Roof element connections

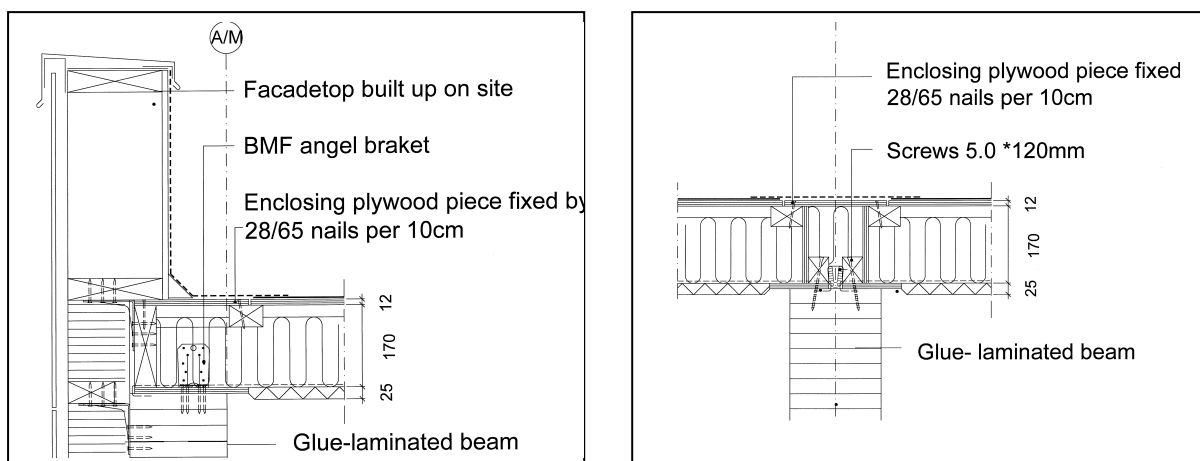


Fig. 6 Roof connections at the laminated beams

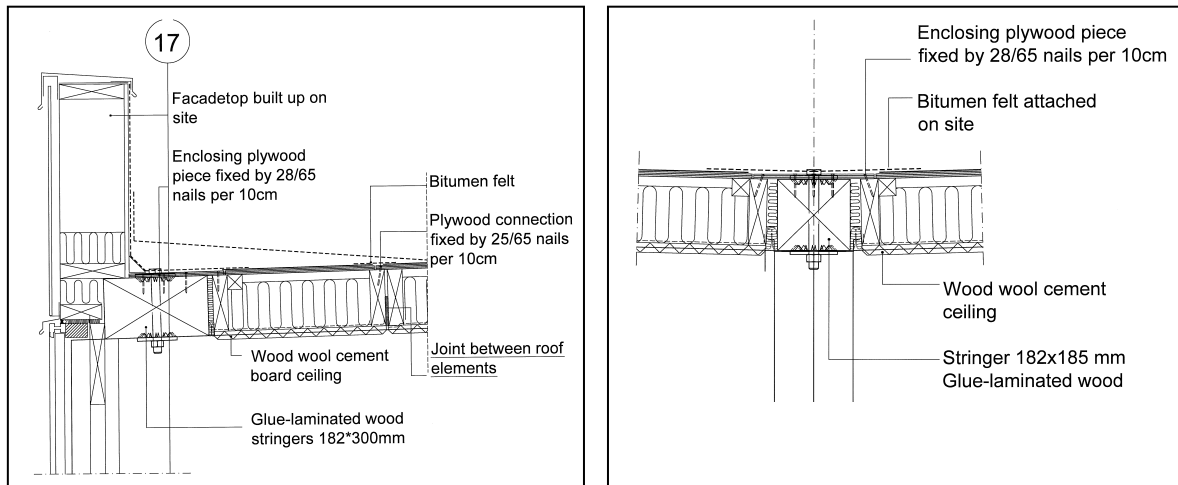


Fig. 7 Roof connections at the stringers

8.3. Facade



Fig. 8 The facade seen from the outside and inside

Fig. 8 shows from inside the upper wall construction covered with wood wool cement boards as a part of the facade elements and the lower wall construction with concrete elements.

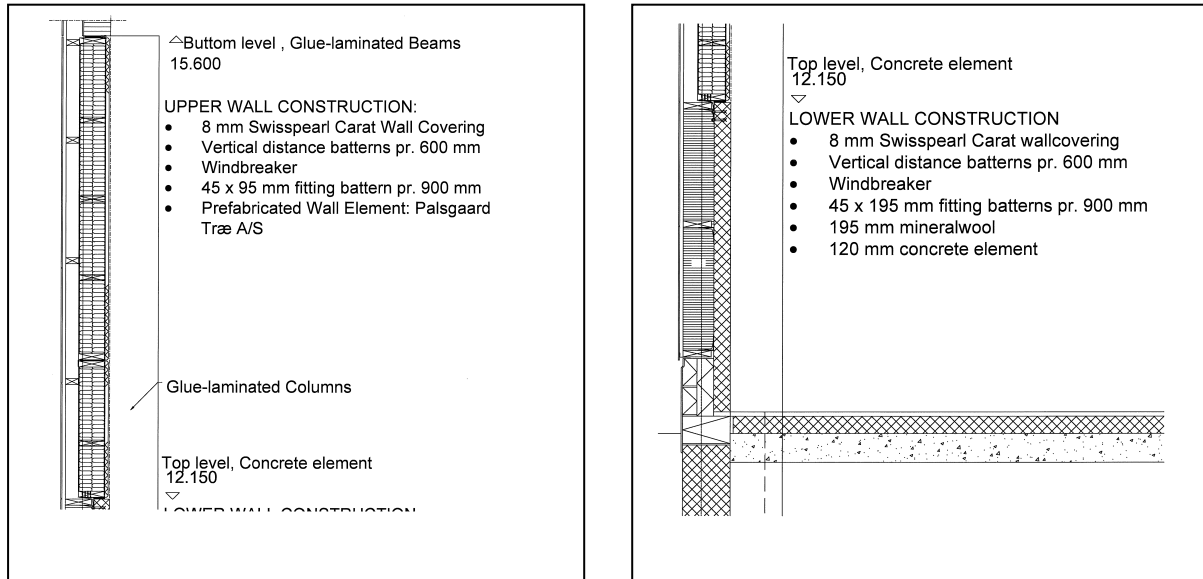


Fig. 9 Cross section in the facade

8.4. Details in the main construction

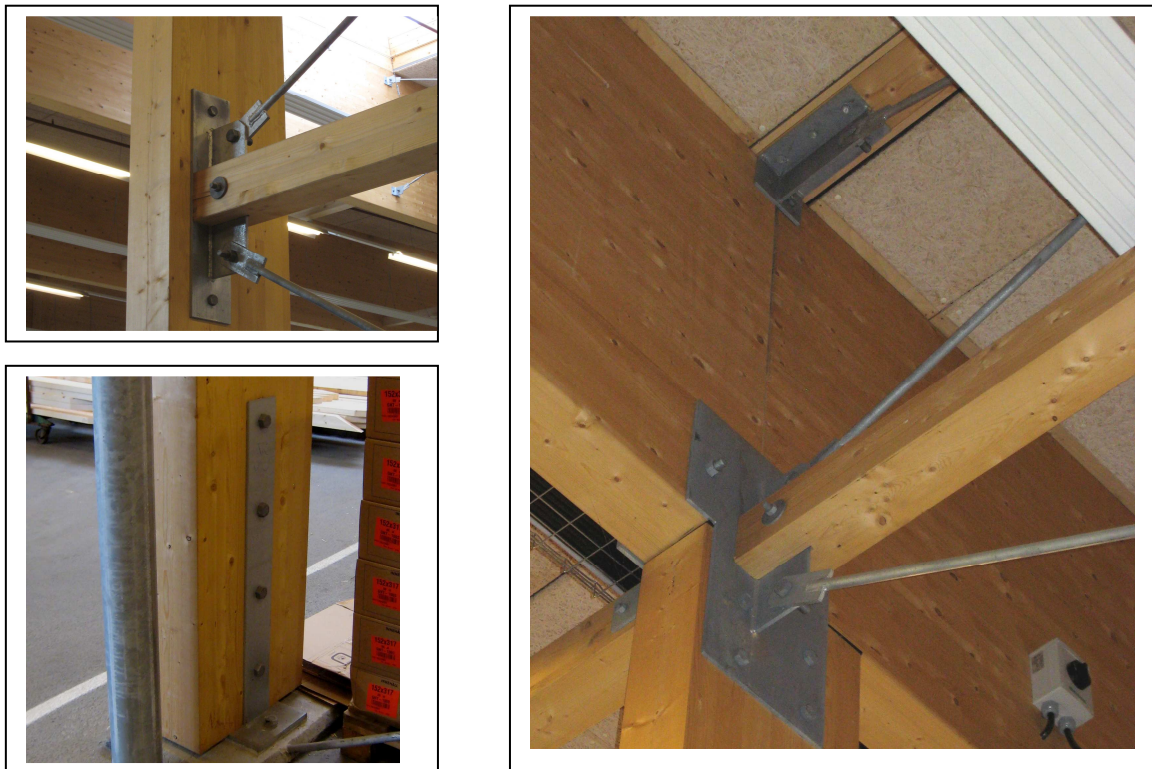


Fig. 10 Details in the wind bracing

8.5. The roof diaphragm

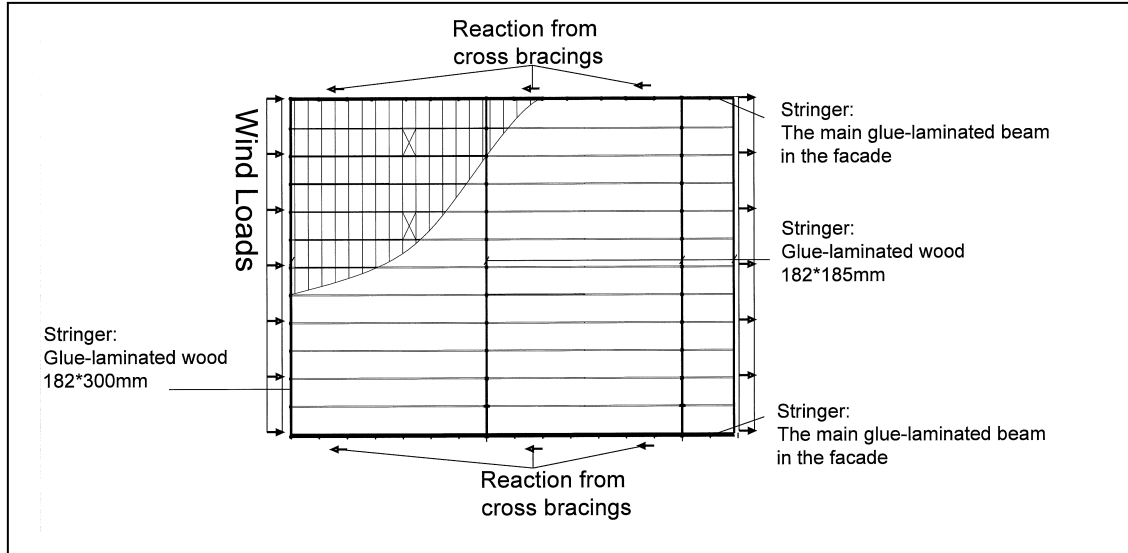


Fig. 11 Plan: Roof diaphragm with wind loads in the longitudinal direction

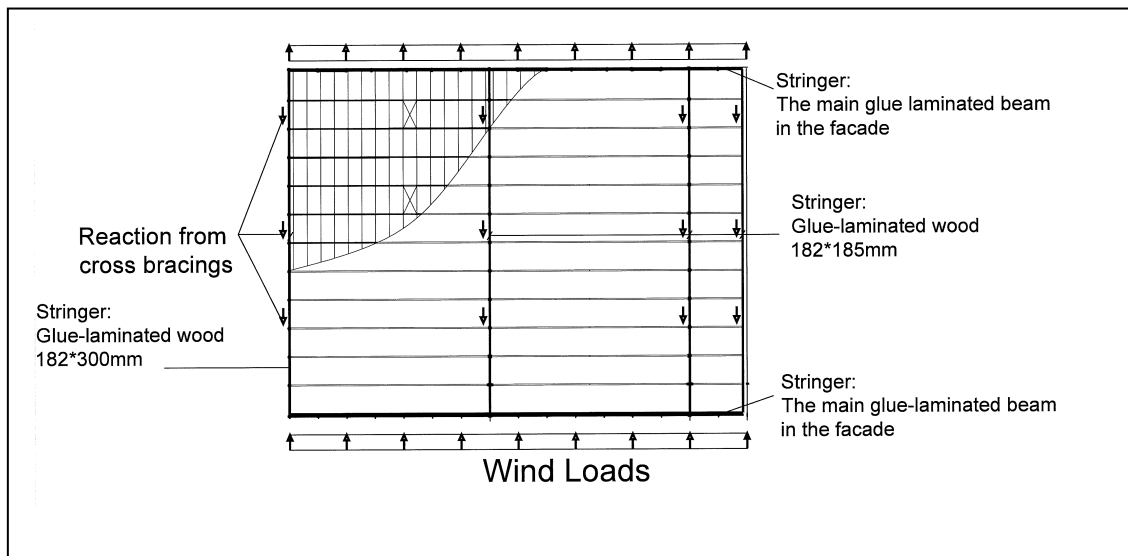


Fig. 12 Plan: Roof diaphragm with wind loads in the transverse direction

The structural system of the roof diaphragm is

- 1) The plywood boards nailed to the beams in the elements. They take the shear forces in the diaphragm.
- 2) The stringers are made of glue-laminated wood. They take the moments in the diaphragm by compression and tension. The connections in the stringers shall take compression and tension. The stringers are also used to transfer the forces from the diaphragm to the cross bracing.

8.6. Cranes

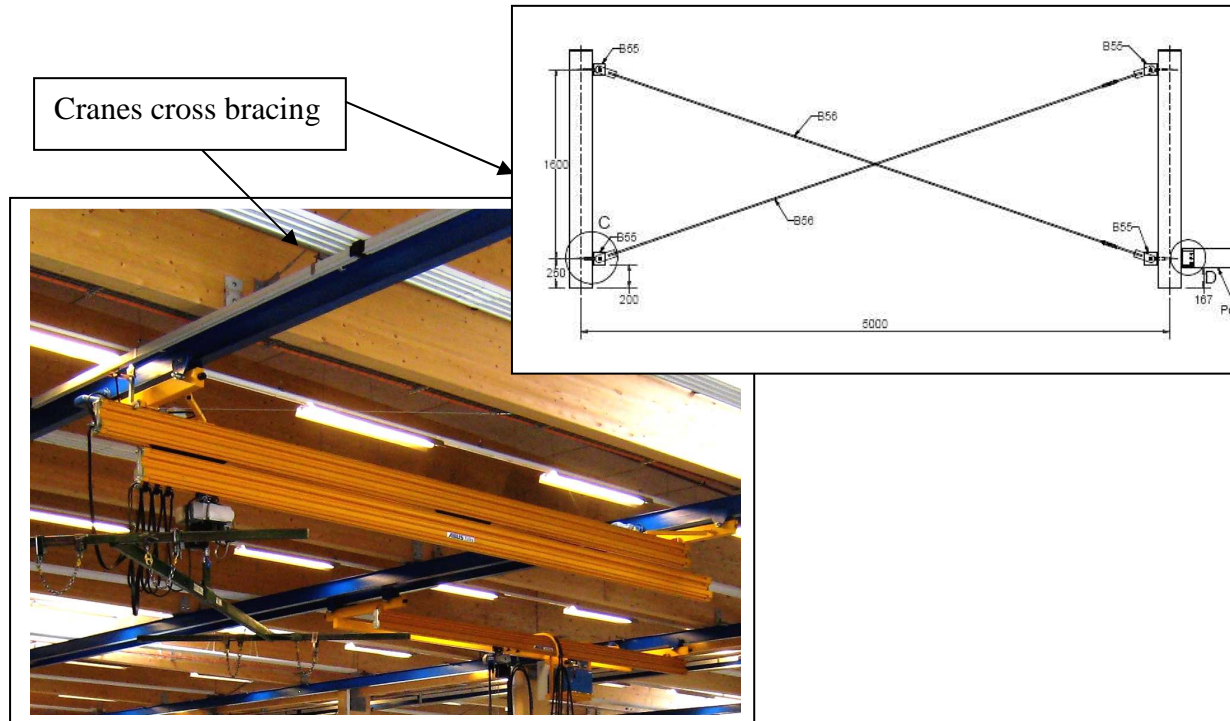


Fig. 13 Cranes and the drawing of the cross bracing to the roof.

The crane system is fixed at the bottom of the main beams. When the cranes stop, horizontal braking forces will develop. To avoid vibration in the construction the support beams of the cranes are braced to the roof.

9. Economical and ecological aspects

According to the investor the building system gives a competitive price, because it consists of standard products on the market.

The main building material is wood and the roof and facades are well insulated. It is known that wood used in a correct way gives a good ecological profile. In this case, all the wood is unprotected, because it is placed inside the building. The good insulation gives low consumption of energy to heat up the building.

Instructions and case study no 6 are prepared by Senior Lecturer, Civil Engineer MSc, Anders Soevsoe Hansen.



Case study no. 7

FURNITURE SALON

1. General information

- date: 04.04.2007,
- price: ca. 2 000 000PLN, within ca. 450 000PLN for timber structure,
- investor: KOMFORT Sp. z o.o. Szczecin,
- design studio: PPB – Pracownia Projektowania Budowlanego s.c. Opole,
- construction company: Holzbau Wehmeyer sp. z o.o., Ciecierzycze 89, 66-446 Deszczno
- location: Poland, Opole, ul. Horoszkiewicza,
- surroundings: general service buildings,
- materials used: glued timber, multilayered casing, concrete elements, brick-made walls

2. Investment design

The building is oriented for the salon of furniture trading network. The network shops are located in most of big cities in Poland. In connection with this, there was a need to provide a large working space suitable for specified object character.

3. Bearing system

3.1. Foundation

The building is founded on marl soil, very often occurring at the Opole region. The foundation is designed as the system of spot footings for the columns (**Fig. 1, 2**) and continuous footing under the brick walls and ground beams.

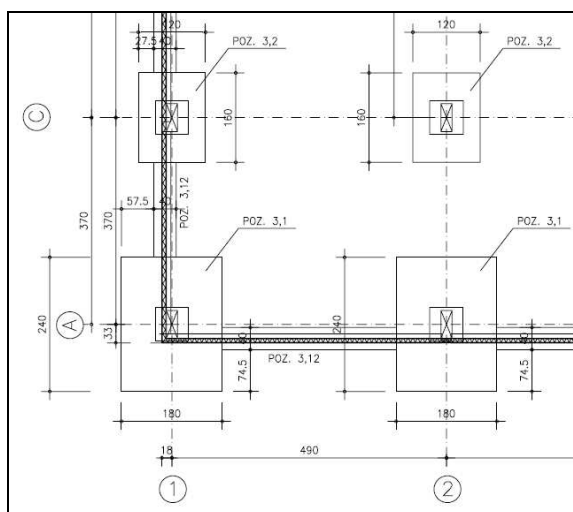


Fig. 1 Plan view of spot footing

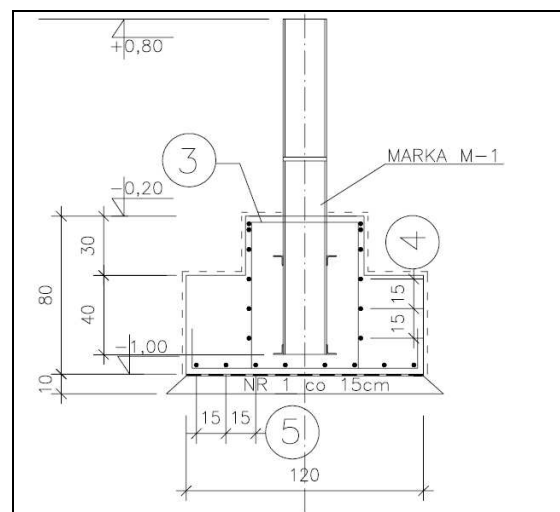


Fig. 2 Footing detail



The joint between column and spot footing is made with the help of steel basket and M20 (5.6) bolts (Fig. 3).



Fig. 3 Column support joint

3.2. Carrying elements

The main carrying elements are made as the single-storey frames, fabricated from glued timber of GL-28h class (Fig 3, 5). The additional elements, such as mezzanine, are mounted directly to the frame (Fig. 4)

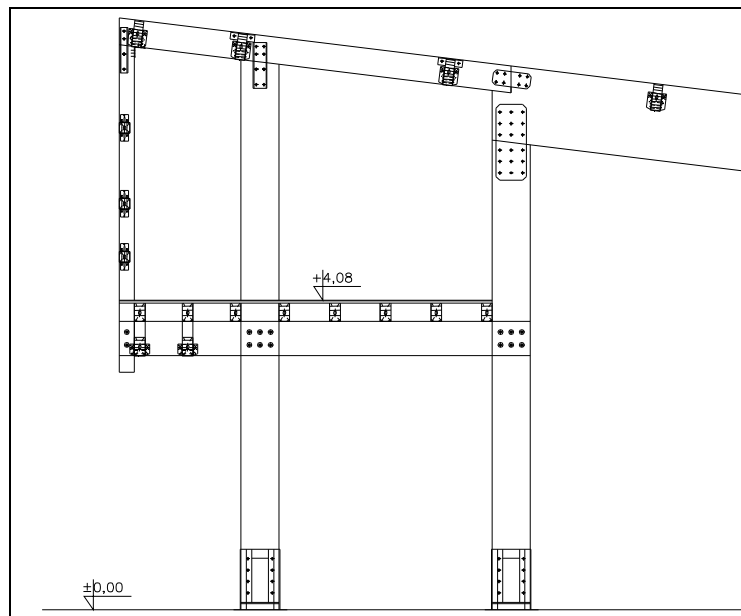


Fig. 4 Additional frame elements – mezzanine

3.3. Casing elements

The roof cover is made from trapezoid roofing sheet TR50/260 type, insulated with mineral wool. As the outer walls casing the light, multilayered and internally insulated panels were used. The casing is completed with large glass surfaces (Fig. 5).



Fig. 5 The building facade

4. Computational models used

The construction of the building is based on plane frames braced with the help of steel sway bracings. According to very useful carrying properties of marl soils it was possible to assume the static model as a frame with rigid joints (Fig. 6). Therefore it was possible to model the roof beam as a single-span free-ends beam, and as a result, to simplify their connection with columns (Fig. 7)

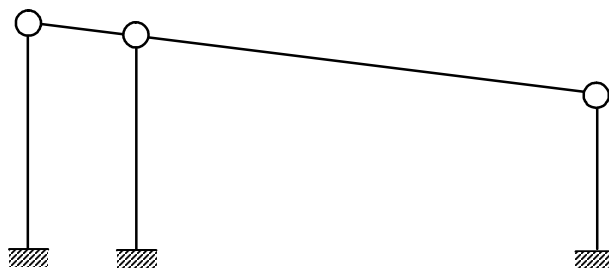


Fig. 6 Computational model of the main frame

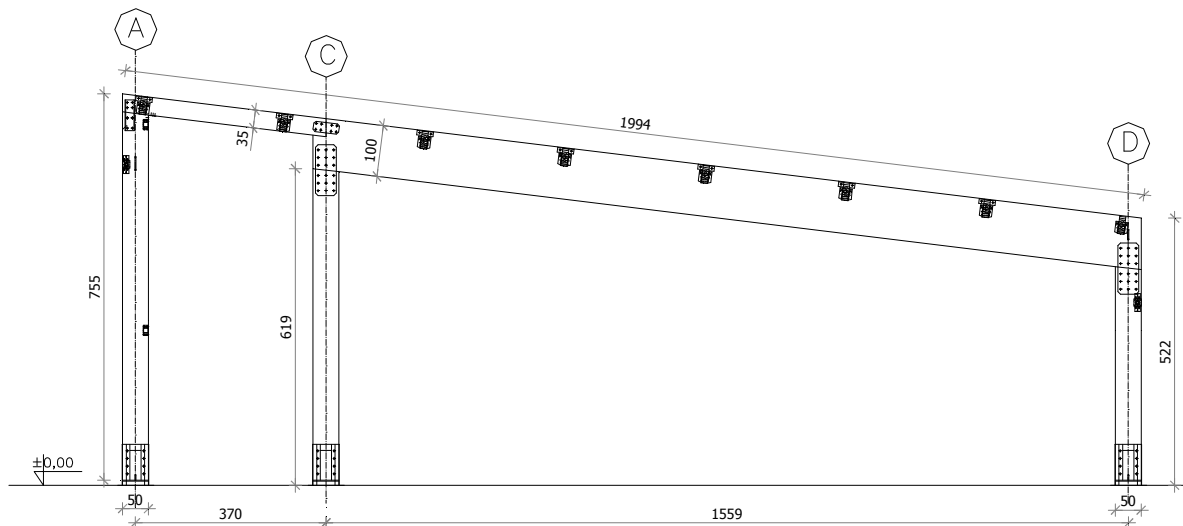


Fig. 7 The main frame plan view

5. Actions on structure

The construction is loaded with typical set of forces, according to polish standards. It is grouped into few parts:

- snow: $S_k=0,56\text{kPa}$,
- wind at 1st area according to PN (polish standard): $p_k=0,25\text{kPa}$,
- constant loading of roof (including ventilation devices), floors and walls casing,
- variable loading of mezzanine: $q_k=2,5\text{kPa}$.

Moreover, the ground-floor was designed for variable operational loading $q=15\text{kPa}$.

6. Project documentation, plans, and drawings

At the below pictures one can see respectively: plan view of the structure at roof level, the stairs leading to mezzanine and roof bracing.

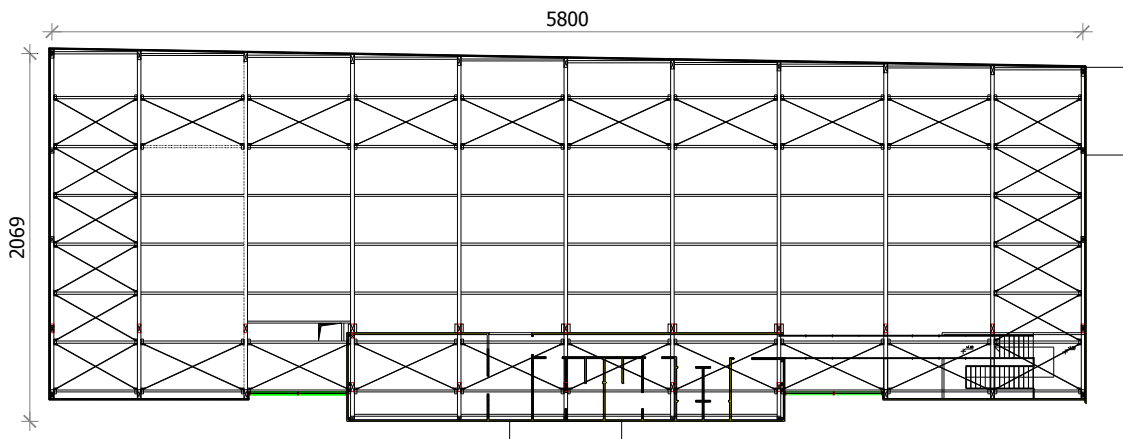


Fig. 8 Plan view of construction at roof level

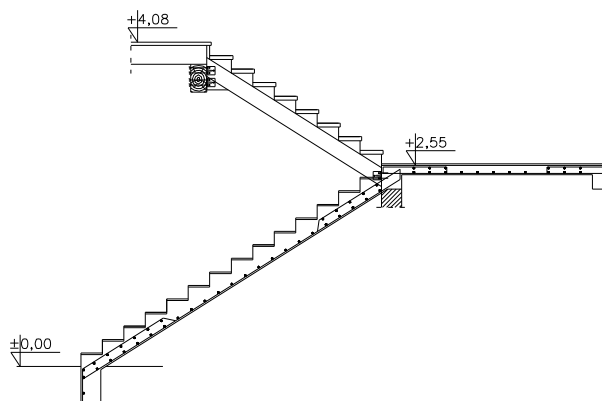


Fig. 9 Stairs cross-section

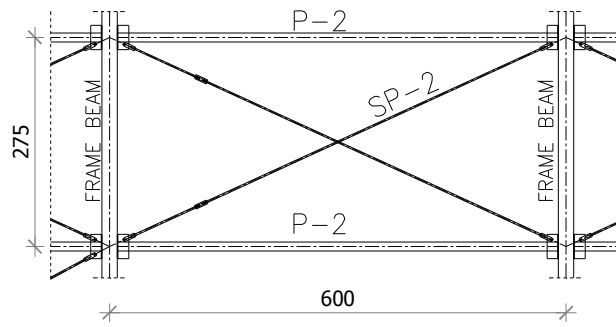


Fig. 10 Roof bracing



7. Erection

The erection of structure was led from 10.2006 to 05.2007. A sequence of works was typical for this type of constructions:

- earth work – foundation digging
- spot and continuous footings
- columns and its supports
- frame beams
- brick-made staircase and concrete stairs
- roof covering
- light-walls casing
- finishing work

8. Interesting construction details

The main interesting points of described structure were mentioned above, but one should pay attentions especially at:

- connection of columns with spot footings,
- connections between timber elements (made with nailed plates),
- bracings.

9. Protection from weather effects

As a target solution the typical, commonly available protective fungicide and insecticide media were used. Additionally, during the erection some of the elements were protected in the simple way against weather influence (**Fig.11**).



Fig. 11 Weather dumping protection of a column element

10. Economical and ecological aspects

From the economical point of view a structure made from glued timber elements is not profitable. Now in Poland exists too few factories producing this kind of composite materials and this is the main reason of theirs relatively high prices. The analogical structure made from steel would cost approx. 40% less. But if we consider ecological and esthetical aspect we will see, that timber has unquestionable values. Moreover, the designed function of the building – being furniture shop – causes that using of timber structure is most suitable for that design and can emphasize its appropriation.

Instructions and case study no 7 were prepared by Andrzej Marynowicz and Kamil Pawlik.



Case study no. 8

TERME ZREČE, HOTEL DOBRAVA

1. General information

Date:	5.7.1999
Price:	approx. 12 mil. EUR
Investor:	Unior,d.d., Kovaška c. 21, Zreče, Slovenia
Design studio:	Karlovšek d.o.o., ul. Antona Skoka 7, Domžale, Slovenia
Construction company:	Lumar Hiše d.o.o., Šmatevž 26, Gomilsko, Slovenia
Location:	Zreče, Slovenia
Materials used:	timber, reinforced concrete

2. Investment design

Hotel for approx. 300 people.

3. Bearing system

3.1. General description

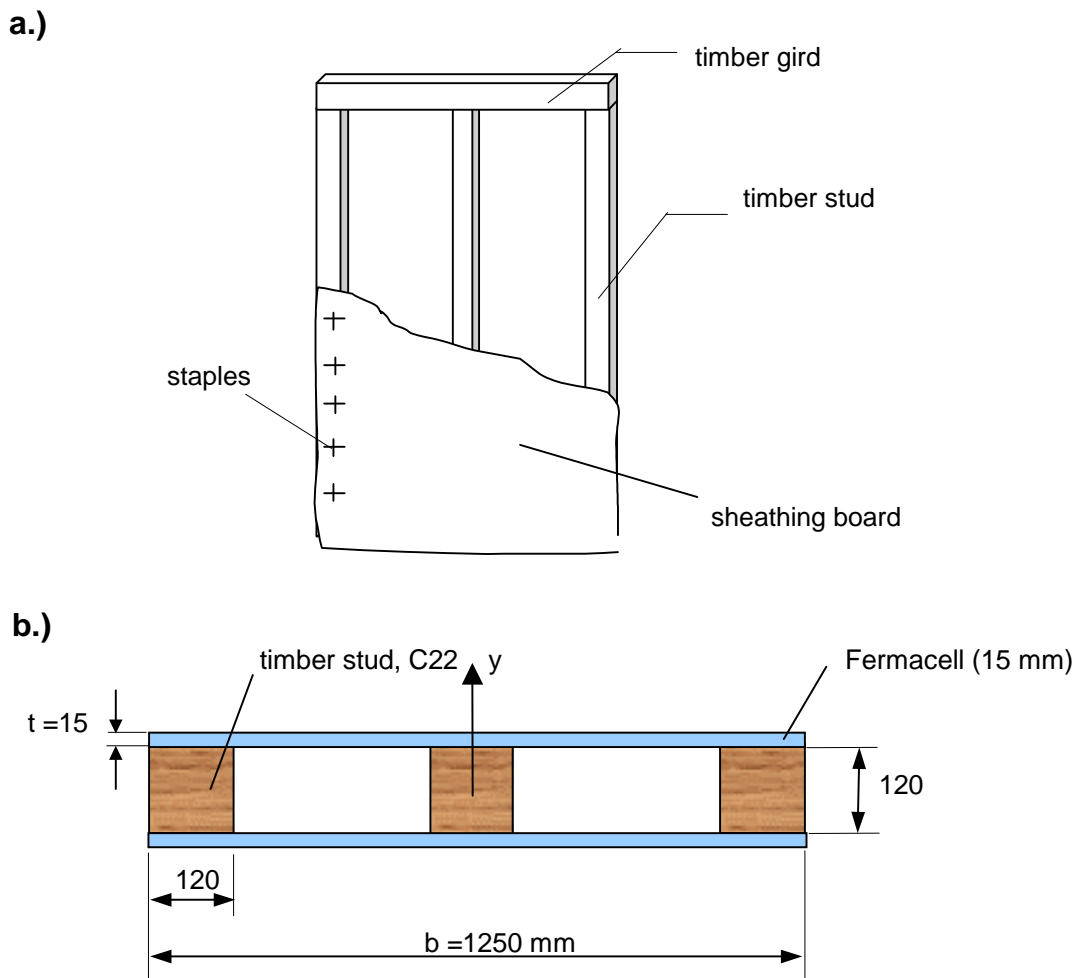
The structure is 6-level building with overall ground-plan dimensions of 38 m x 18,60 m. The first two levels are classical - made from reinforced concrete, while the upper four consist of prefabricated timber elements (**Fig. 1**).



Fig. 1: Photo of the hotel from the east side.

3.2. Prefabricated wall elements

Prefabricated timber walls as main vertical bearing capacity elements of actual dimensions $h=2760\text{ mm}$ and $b=1250\text{ mm}$ are composed of a timber frame and of sheets of board-material fixed by mechanical fasteners to the both sides of the timber frame (**Fig. 2a,b**). The timber frame consists of three studs with dimensions of $120 \times 120\text{ mm}$ and two girders with dimensions of $120 \times 120\text{ mm}$. The sheathing boards of the Fermacell type and thickness of $t=15\text{ mm}$ are fixed to the timber frame using staples of $\Phi 1.53\text{ mm}$ at an average spacing of $s = 60\text{ mm}$ in the both edge studs and at an average spacing of $s = 120\text{ mm}$ in the middle stud (**Fig 2a**).



3.3. Reinforcing of wall elements in the first and second level

Although gypsum is a healthy material and assures a good fire protection, in a structural view its tensile strength is very low, approximately 10-times lower than the compressive one, and cannot be compared with the strength of the timber frame at all. Since the walls by horizontal force acting at the top of the wall actually behave like deep composite elements, the fiber-plaster boards (FPB) are usually a weaker part. Thus, especially in multi-level buildings located in seismic or windy areas, cracks in FPB usually appear. Therefore, each side of the wall in the first and in the second level was

reinforced with two BMF steel diagonals of a cross-section $60 \times 2 \text{ mm}$ with the module of elasticity $E_s = 210.000 \text{ N/mm}^2$ (Fig. 3).

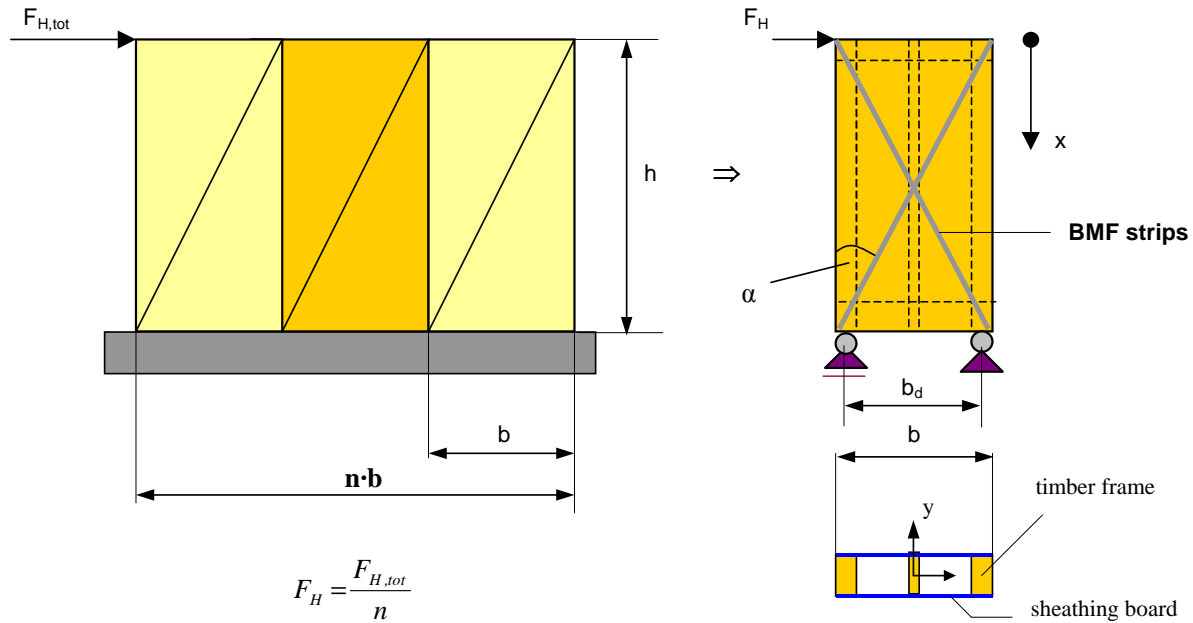


Fig. 3: Reinforcing of the walls with BMF steel strips.

3.4. Prefabricated floor elements

Prefabricated floor elements of actual wide of 1250 mm consist of three timber beams with dimensions of $80 \times 220 \text{ mm}$. They are covered with a 19 mm thick plywood at the top and with a Fermacell fibre-plaster board of thickness 15 mm at the bottom (Fig. 4).

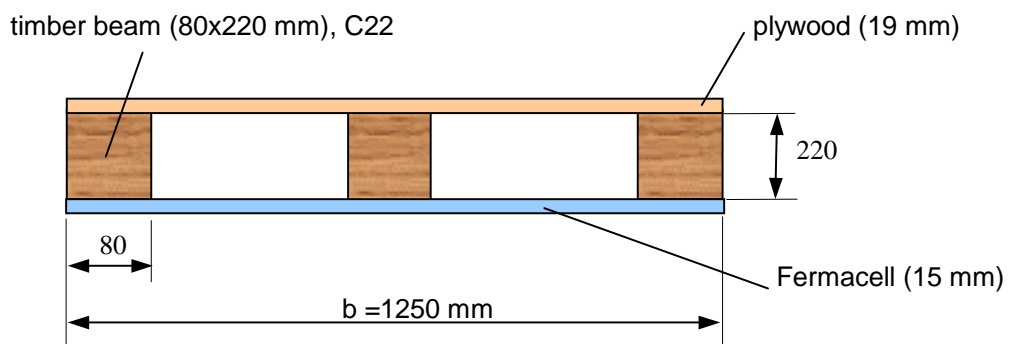


Fig. 4: Cross-section Dimensions of the prefabricated timber floor elements.

Properties of the used materials are listed in Table 1.

	$E_{0,m}$ [N/mm ²]	G_m [N/mm ²]	$f_{m,k}$ [N/mm ²]	$f_{t,0,k}$ [N/mm ²]	$f_{c,0,k}$ [N/mm ²]	$f_{v,k}$ [N/mm ²]	ρ_m [kg/m ³]
Timber C22	10000	630	22	13	20	2.4	410
Fermacell boards	3000	1200	4.0	2.5	20	5.0	1050
BMF steel strips	210000	/	/	400	/	/	7850

Table 1. Properties of used materials.

4. Computational models used

4.1. Static design for the floor elements

By a static design of the floor elements the continuous system with a constant beam span of 3800 mm was used (Fig 5).

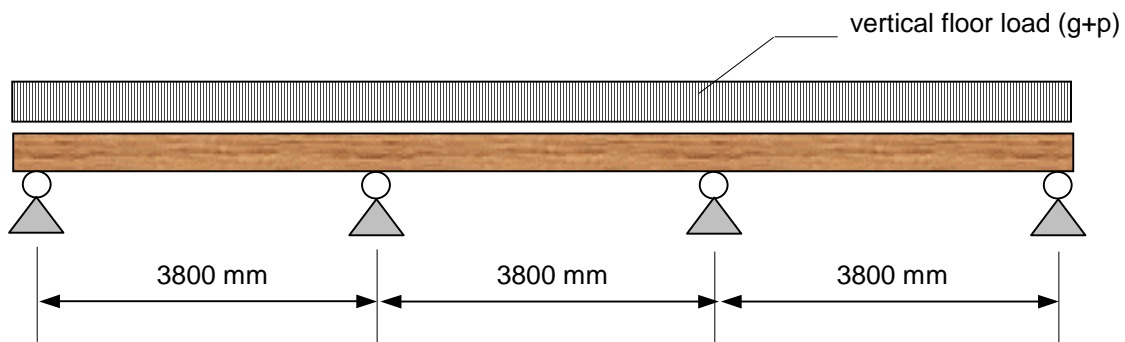


Fig. 5: Static design of the prefabricated floor elements.

4.2. Static design for the wall elements

Horizontal force distribution on walls was calculated according to the shear stiffness ratio between the walls. For walls in y-direction the following static design (Fig. 6) was used to calculate the axial forces, shear forces and bending moment due to vertical and horizontal loads.

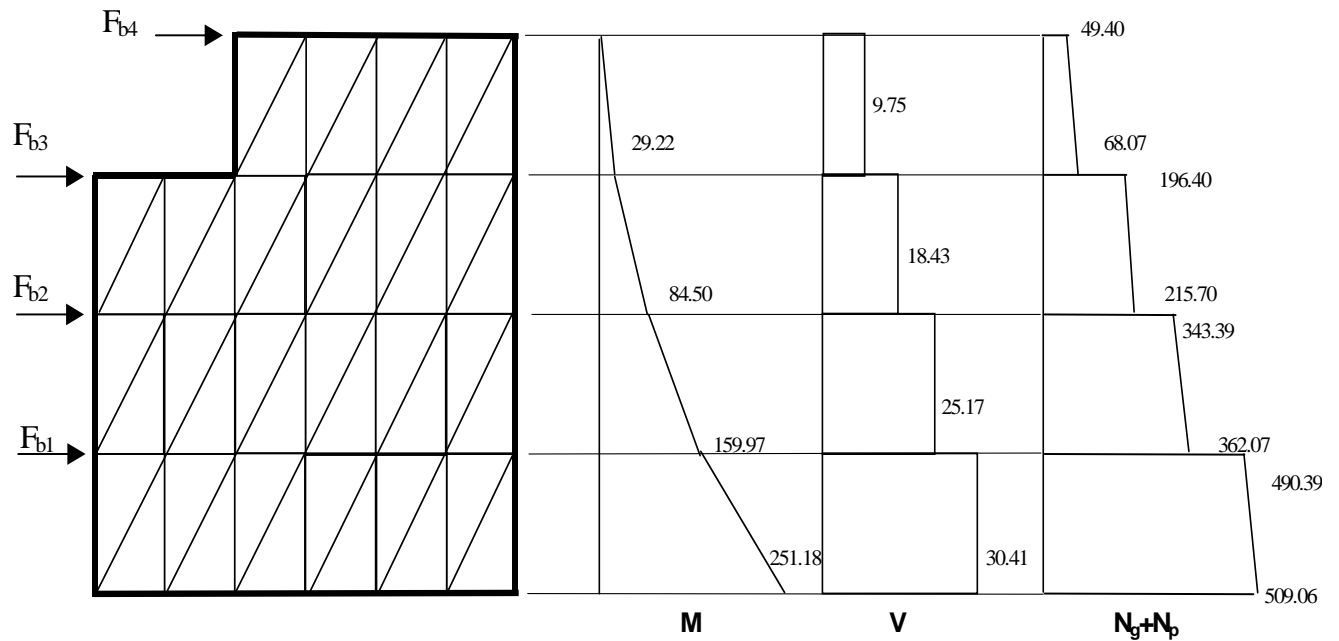


Fig.6: Static design of the prefabricated wall elements in the y-direction.

5. Actions on structure

Actions on structures according to in year 1999 valid Slovenian standards.

1. Dead load
2. Live load $p = 1.50 \text{ kN/m}^2$
3. Snow $s = 1.25 \text{ kN/m}^2$
4. Wind $w_0 = 0.60 \text{ kN/m}^2, c_{pe} = 0.80, -0.40$
5. Seismic force VII. MCS

Actions of vertical and horizontal loads are presented on **Fig. 7** and **Fig. 8**.

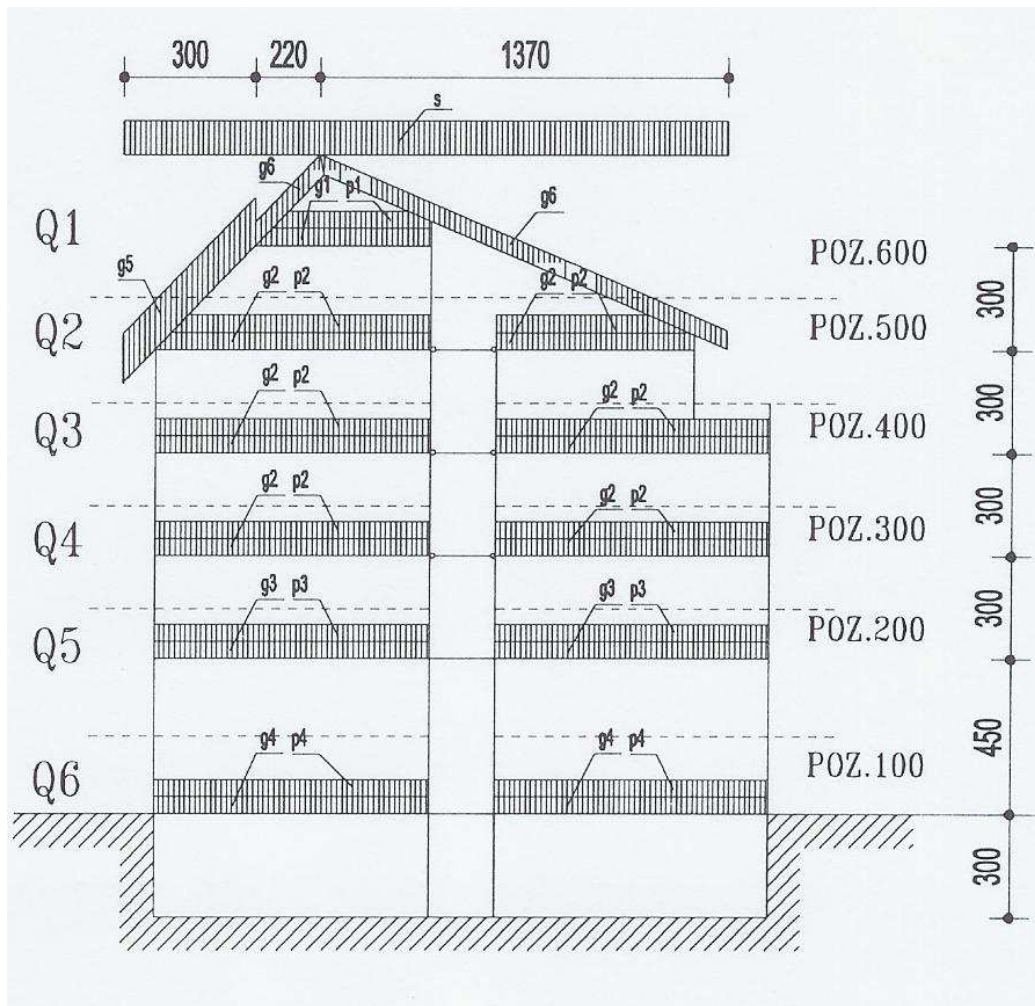


Fig. 7: Vertical load actions on the structure.

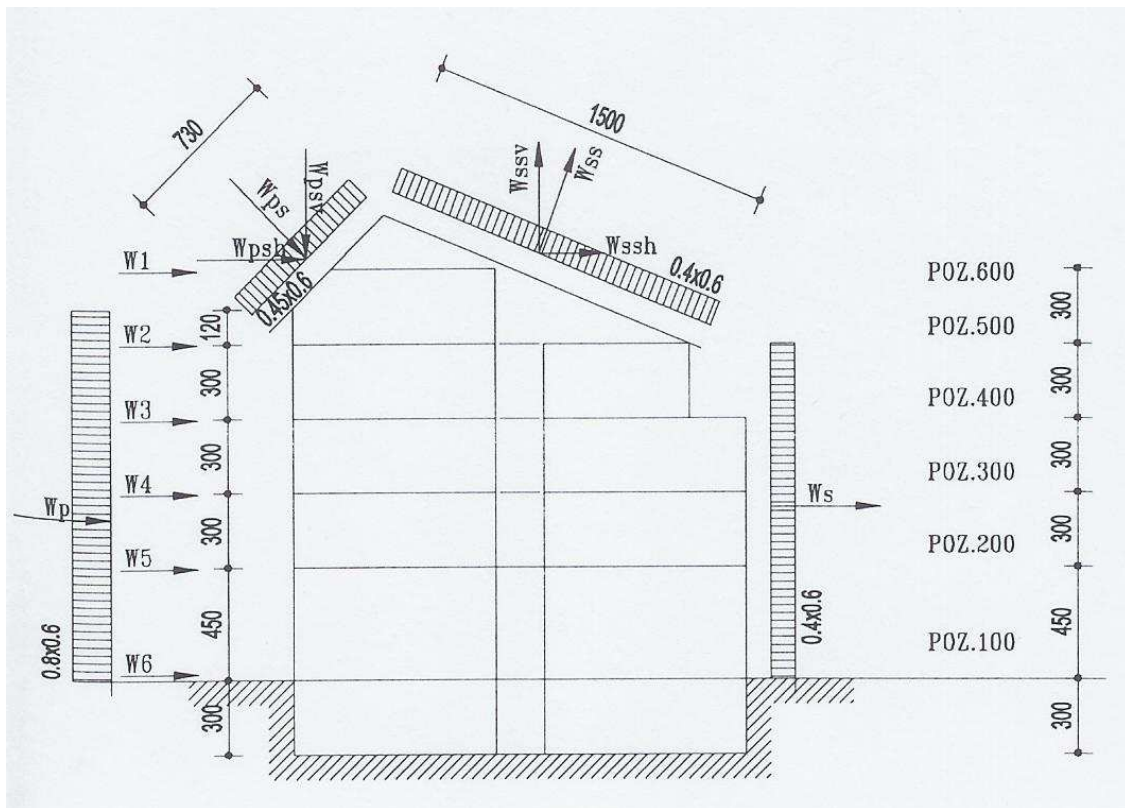


Fig. 8: Horizontal load actions on the structure in the y-direction.

6. Project documentation, plans, and drawings

6.1. Project documentation

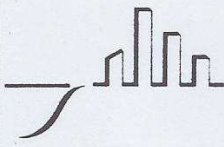
 karlovšek d.o.o.	
PODJETJE ZA PROJEKTIRANJE IN INŽENIRING Domžale, Antona Skoka 7, tel. / fax. / 061-721-286 Slovenija	
investitor	UNIOR d.d. ZREČE
objekt	PRIZIDEK HOTELA - I. FAZA
projekt	STATIKA - POZICIJSKI NAČRT
faza	PGD, PZI št. proj. 11/99
odg. vodja proj.	M. KARLOVŠEK, udig. <i>M. Karlovšek</i>
odg. projektant	S. ŠPEGELJ, gr.ing.
obdelal	S. ŠPEGELJ, gr.ing. <i>S. Špegelj</i>
pregledal	GREGOR GREGORC, udig.
datum	feb. 99

Fig. 9: General project documentation.

6.2. Ground plan

Ground-plan of the first four levels with overall dimensions of 38 x 18,60 m is presented on **Fig. 10**.

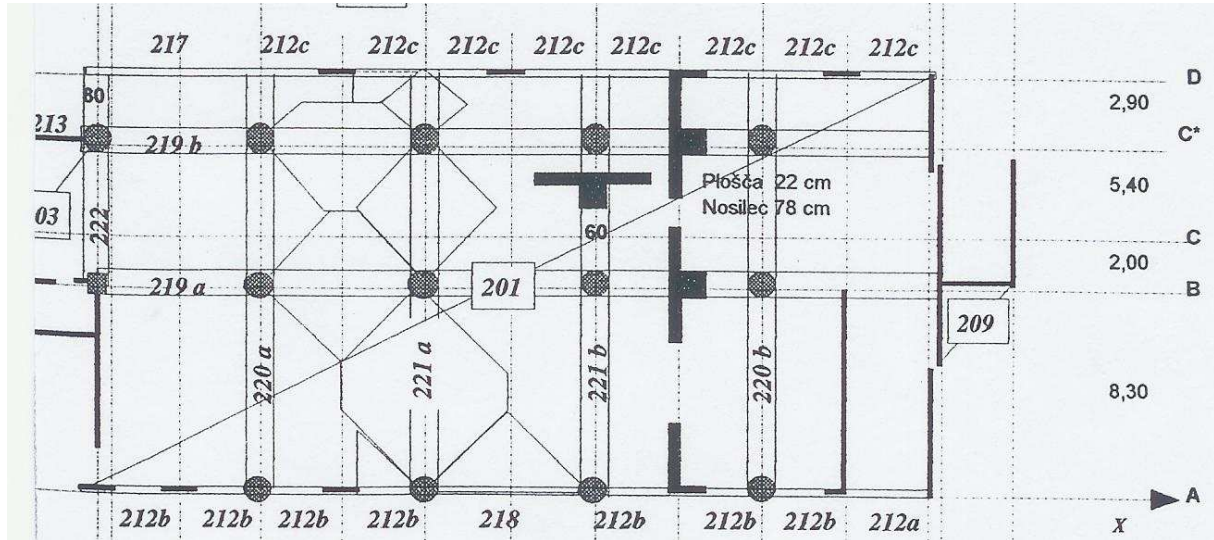


Fig. 10: Ground plan of the first four levels.

7. Erection

The first part of the building with the underground level and the ground-floor was built completely classical with a reinforced concrete of a strength class C20/25 and steel class S400 and S500.

The second part of the building, the rest four levels, were constructed using s.c. prefabricated platform timber system with the timber-framed walls (**Fig. 2** and **Fig. 3**) and the floor elements (**Fig. 4**). They were completely constructed in the assembly-plant (**Fig. 11**) and then as final products transported to the building-site.



Fig. 11: Construction of the wall elements in the assembly-plant.

8. Interesting construction details

a.) Vertical connection between the walls is presented on **Fig. 12**. Connection of the upper wall element to the floor beam is made with BMF angle element type 90 with spiral nails 4/60 mm. The floor beam is connected to the lower wall element with one additional BMF spiral nail 6/300 mm.

b.) Connection of the lowest timber wall element to the concrete wall with special steel plates and two bolts is shown on **Fig. 13**.

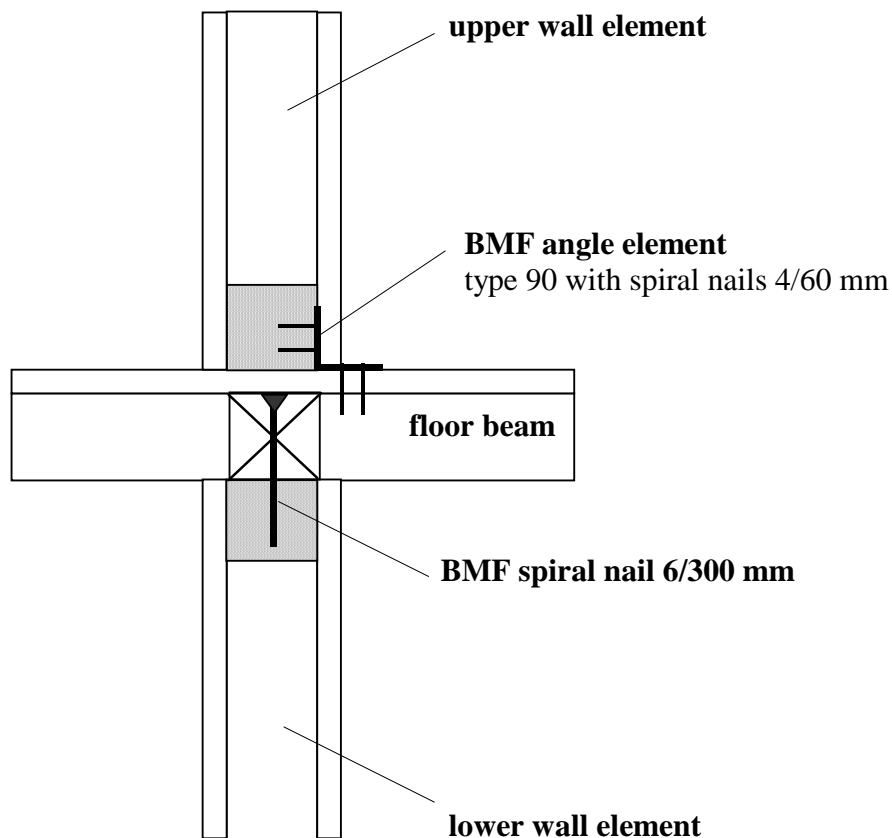


Fig. 12: Vertical connection between the walls.

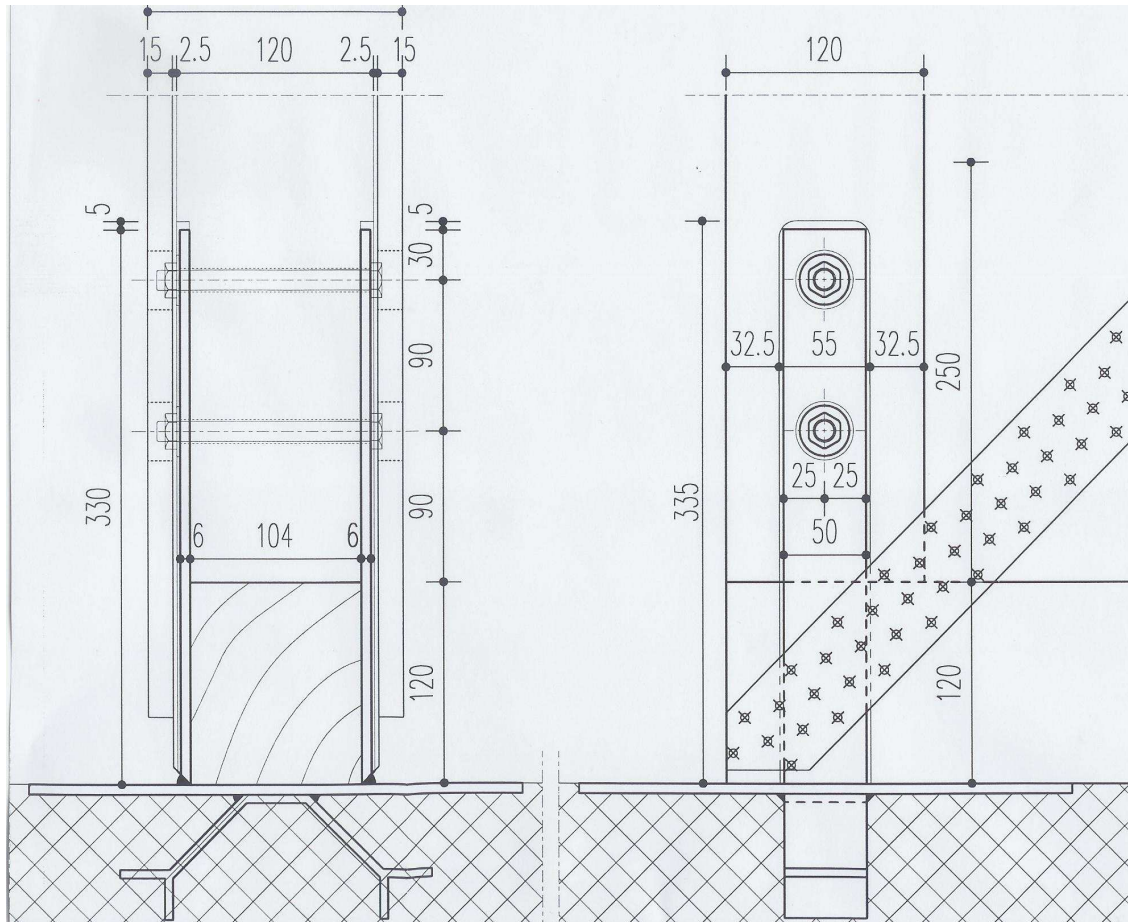


Fig. 13: Connection of the wall element reinforced with BMF diagonal to the lower concrete wall.

9. Protection from weather effects

To assure a horizontal protection of the building (for example strong wind effects) each side of the wall in the first and in the second prefabricated timber level was reinforced with two BMF steel diagonals of a cross-section $60 \times 2 \text{ mm}$ with the module of elasticity $E_s = 210.000 \text{ N/mm}^2$ (Fig. 3).

10. Economical and ecological aspects

As presented in Fig. 1 the building is very undisturbing incorporated in a beautiful green Pohorje mountain landscape. Additionally, gypsum used as a sheathing material by timber-framed walls and floor elements is a healthy natural material and is consequently particularly desired for residential buildings.

Instructions and case study no 8 were prepared by Assoc.Prof.Dr. Miroslav Premrov.



Case study no. 9

SPORTS HALL – ČESKÝ TĚŠÍN

1. General information

Date: September 2007
Price: 7 458 277 CZK, incl. VAT
Investor: private investor
Design studio: DELTA Třinec, s.r.o.
Location: Český Těšín, Street: Svojsíkova alej
Surrounding: Karviná district, Moravian-Silesian region
Materials used: concrete, timber, masonry material

2. Investment design

The principle aim and intention of the municipality is to provide better conditions for recreational and top level sports, to create good conditions for high-quality life in the town of Český Těšín.

The sports hall internal dimensions: 25,2 x 44,8 m, height in the highest point is 12,2 m, exploitable sports area is 968 m². The sports hall is intended for indoor games: badminton, basketball, indoor football, handball, indoor hockey, volleyball and tennis.

3. Bearing system

The object is founded on drilled piles on which foundation girders connected by transverse reinforced-concrete ribs are located.

External filling masonry and internal bearing walls are made of burnt shaped bricks POROTHERM P+D and Ytong shaped bricks.

Floor structure of the hall is projected to be from arch timber glue laminated trusses in dimensions 180/900, 160/900 mm and gable timber trusses 100/600 mm and with internal radius of 11 640 mm. Between the trusses purlins into BOVA straps are located.

Wind bracing of the roof level is provided by steel drawbars in two lateral fields and by timber bracings of 120/240 mm along the whole object. The roof of the hall is single-shelled with thermal insulation above the bonds. Asphalt roofing paper is used. Ceiling is covered by timber battening with spaces. Shields of the hall is designed as ventilated walls made of timber glued columns anchored on brick backing covered by plasterboards from internal and external sides.

Floor of the sports hall is universal cladding of thickness 4 – 6 mm, in nearby rooms the floor is made of ceramic tiles. In shield walls tipping glassy brightening areas are designed into plastic profiles.

4. Computational models used

Structure of the arch glued plain girded was modelled as a 3D frame structure. It was solved as a geometrically non-linear computational model in IDA NEXIS 32 programme.

5. Actions on structures

Single loads were calculated according to EC 1, according to its single parts for calculation of permanent load, snow loads and wind actions.

ČSN EN 1991-1-1 Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight and imposed loads for buildings

ČSN EN 1991-1-3 Eurocode 1: Actions on structures - Part 1-3: General actions – Snow loads

ČSN EN 1991-1-4 Eurocode 1: Actions on structures - Part 1-4: General actions – Wind actions.

ČSN EN 1995-1-1 norm was used for designing of the sports hall made of glue laminated timber connected by mechanical joining parts. The norm comprises principles and requirements related to safety and serviceability of structures and principles for designing and testing according to the theory of limit states.

6. Project documentation, plans, and drawings

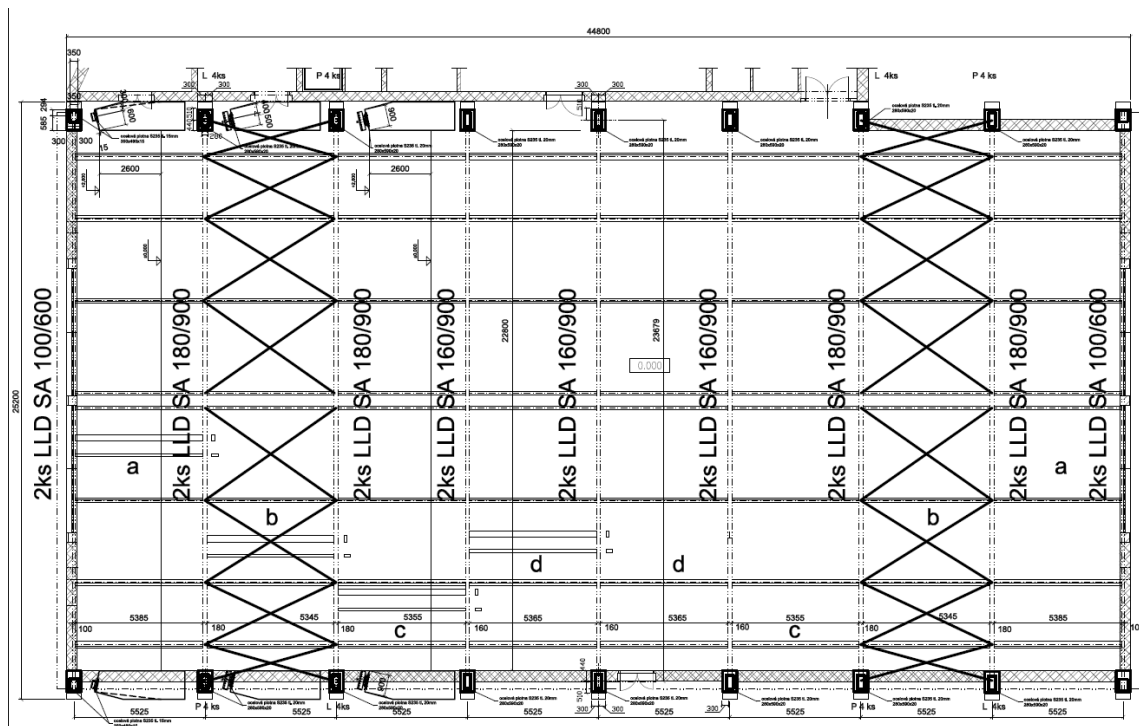


Fig. 1 Floor plan of the sports hall

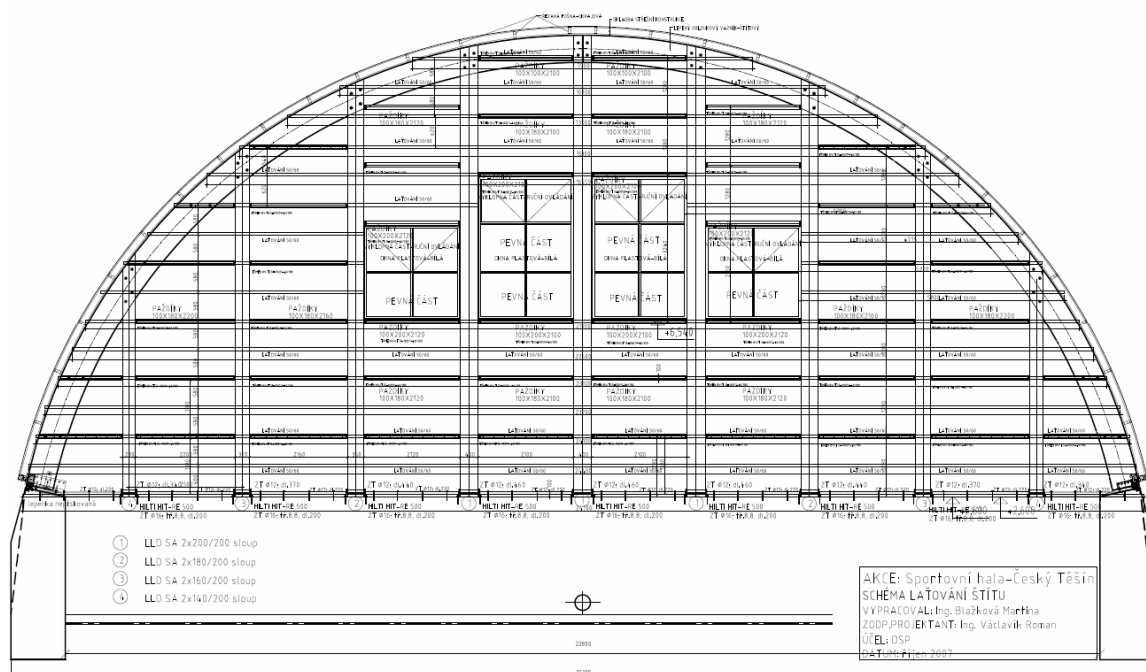


Fig. 2 Cross section of the shield wall

7. Erection



Fig. 3 Setting of the purlins into BOVA straps between glue laminated arches



Fig. 4 Arch truss frames with oblong bracing and steel drawbars



Fig. 5 Gradual roofing of the soffite





Fig. 6 View at timber battening with spaces



Fig. 7 Roofed sports hall with external filling masonry



Fig. 8 Shield wall

8. Interesting construction details



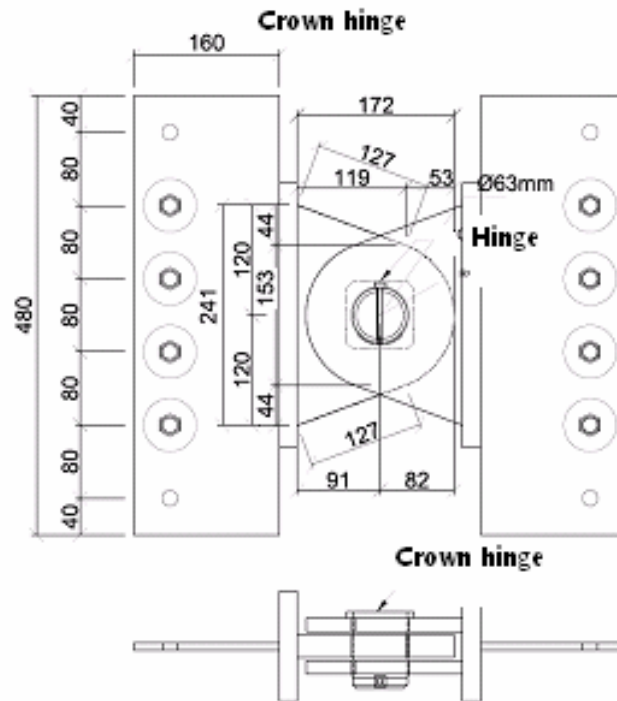


Fig. 9 Apical joint of arch truss frames





Fig. 10 Detail of the foot base of the arch timber truss with foundation structure

9. Protection from weather effects

Roof covering is single layered and it is designed by building-structural measures which assure that timber will be protected and ventilated. The edge of the roofing is provided with slots to provide air flow into the structures. Timber structures are located the way they are constantly exposed to free air flow. There was an edge created which should prevent leakage of rain water and condensation of air humidity.

10. Economical and ecological aspects

Towards the indisputable economic effect of the structure is necessary to be added a very positive economic circumstance. The sports facilities for non-organized public, which should be on the first place in the conception of priorities of investment building of physical training facilities in all towns, are not unprofitable and after relatively short time of returnability of invested resources it is possible to count on even economically profitable operation.

The main ecological aspect of the constructions is the use of the glued timber itself as the main bearing structural material. In the area where steel variants of structural roofing have been used on the past and present is the variant from glue timber energetically less demanding from the aspect of acquiring and operation.

Materials used in the construction process are characterized by lifetime span, minimal requirements on maintenance and treatment.



Leonardo da Vinci

WP6 – Case studies



Instructions and case study no. 9 were prepared by Antonín Lokaj.



Case study no. 10

“CENTRE FOR BUILDING TECHNOLOGY (CBT)” / Graz (AT)**1. General information**

Type of building	Laboratory (hall) with office buildings
Structural system (timber structure)	Boxed cross-section (walls), suspended CLT-plate (roof above laboratory hall), ribbed CLT-plate (floor above office buildings)
Owner	BIG – Federal Building Agency, Vienna (AT); Graz University of Technology (hirer)
User	Institutes and labs of the Faculty of Civil Engineering Sciences at Graz University of Technology (TUG), Graz (AT)
Location	Graz / Styria (AT)
Used Material (for the main structural parts) - Wall elements - Roof elements above the office “towers” - Roof above the laboratory hall - Façade	- 5-layered CLT-panels and 3-layered laminboards (spruce) with glulam ribs (GL24h) and OSB-boards for covering; boxed cross-section) - 5-layered CLT-panels and glulam ribs (GL32h) with OSB-boards for covering; T-beam cross-section - 5-layered CLT-panels (spruce) with steel suspension system - 3-layered laminboards (larch)
Erection date	1999 - 2001
Investor	BIG – Federal Building Agency, Vienna (AT)
Architectural design - Arch. and conceptional design - Design of details and construction management	Arch. G. Nussmüller, Graz (AT) Arch. W. Kampits, Graz (AT)
Structural and constructive design: - Concrete and reinforced concrete - Steelwork - Timber Engineering and Wood Technology - Building physics	Institutes of the Faculty of Civil Engineering Sciences at TUG, Graz (AT) - Institute for Concrete and Masonry Structures - Institute for Steel and Shell Structures - Institute for Timber Engineering and Wood Technology - Institute for Structural Design, Laboratory for Building Physics
Construction Companies: - Foundations and reinforced concrete - Timber structure	Fa. Granit Bau GmbH, Graz (AT) Fa. Stingl GmbH, Trofaiach (AT)



2. Investment design

Until the year 2001 the Faculty of Civil Engineering – in particular the institutes for structural analysis, concrete-, steel- and shell structures, timber engineering and wood technology and structural design – at Graz University of Technology (TUG) had limited possibilities to perform tests on full size elements. With the decision taken in 1998 to erect a “Centre for Building Technology” at the Inffeldgründe in Graz an almost 30 years long period of discussion has been completed and enables the mentioned institutes to perform tests in a contemporary environment now.

In the first erection step at the beginning of 1998 including the central situated testing laboratory and hall respectively and three office “towers” at the southern side of the building, containing labs for the preparation of test specimens and bounteous offices, have been designed and erected. According to the scheduled development plan of the faculty in a second step further three “towers” on the north side of the laboratory hall have been built during 2007. With the attachment of further “towers” and the enlargement of the testing hall in the future building activities for this centre will be finished. By then the faculty’s goals to focus all labs regarding material tests and tests on structural members at the Faculty for Civil Engineering at TUG in one central building will have come true.

Since central activities for the erection have been initiated by representatives of the – then – Chair for Timber Engineering at TUG (the erection of a testing centre for timber products was aimed by several members of different pressure groups and companies of the local wood industry at this time) it has been decided to design as many members as possible with timber and wood based products. This has then been a novelty in the course of the erection of public buildings and buildings for academic use in Austria and was an important sign “pro timber” by the responsible persons in the “wood-region” Styria.

Based on the design – for the already mentioned Timber Products Testing Centre – from an origin student project, an architectural design competition was initiated which gave the erected building it’s appearance. Apart from the cellar rooms and some rooms on the ground and first floor – erected with reinforced concrete and in parts even as a prestressed concrete structure, the crane structure of the lab and the roof to protect the façade of the office “towers” – the CBT is built with timber and wood engineered products as the main material.



Fig. 1 Laboratory hall and offices of the “Centre for Building Technology (CBT)” at Graz University of Technology (AT)



3. Project documentation, plans, and drawings

As already mentioned the CBT will be built in three steps. In the following this documentation is limited to step 1 since no documents are available at the moment for step 2 (finished in March 2008). This doesn't matter because step 2 and step 3 will be based on the same type of elements and erection methods.

As can be seen from the plan in Fig. 2 the CBT (erection step 1) consist of a central laboratory hall with dimensions of 19,30 x 75,92 m and three, two floors high, office "towers", each with dimensions of 16,07 x 14,02 m. Between the towers sanitary and house technique rooms are arranged.

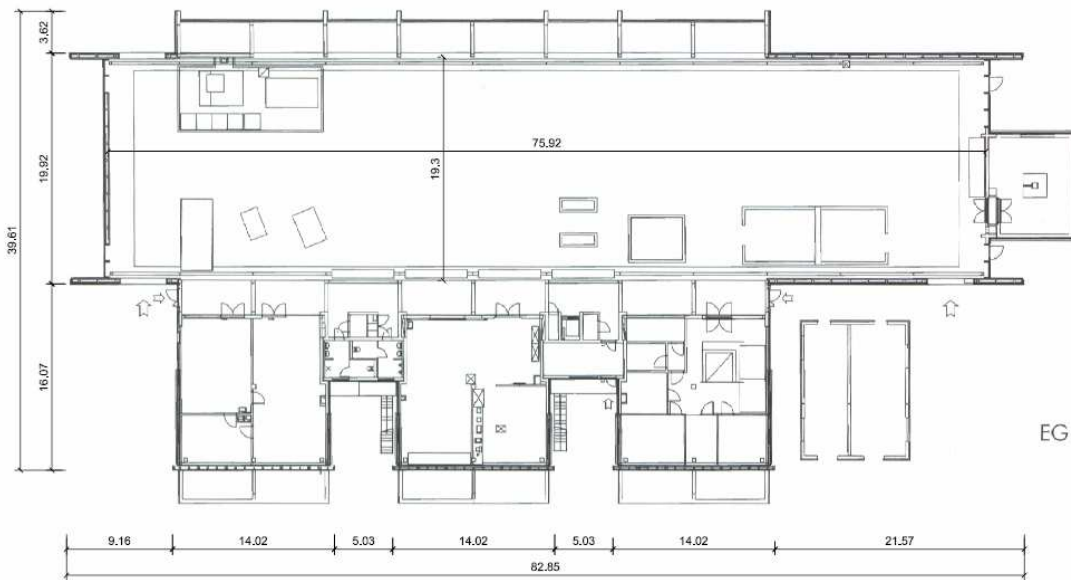


Fig. 2 Plan of the CBT (first erection step)

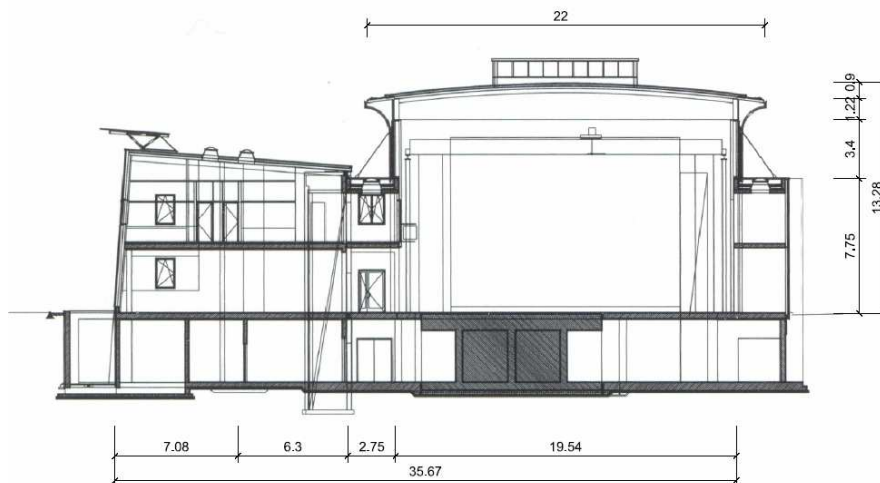


Fig. 3 Cross section of the CBT (first erection step)

4. Structural system and cross-sections of the main members

4.1. General aspects

Since the centre is dedicated – beside the education of students – to research and development purposes for innovative building components it has been erected with the newest wood products to illustrate the power of today's timber engineering. The wall and roof structures have been manufactured with the – then newly developed – massive timber construction method utilising Cross Laminated Timber (CLT) elements. Because the production methods for this elements at this time were in an early stage no gluing of boards at their narrow faces was possible. Since the gaps between the layers would have been aesthetically not satisfying all visible CLT-surfaces has been covered by non load-carrying OSB-panels.

4.2. Walls

The structural system of the walls for the office “towers” has been modelled as simple supported upstanding, slightly inclined beam with a cantilever. This beam is supported at the floor of the tower's cellar and the first floor respectively. The roof of this part of the building is resting at one side on the top of the walls and on the other side on the reinforced concrete wall of the office building.

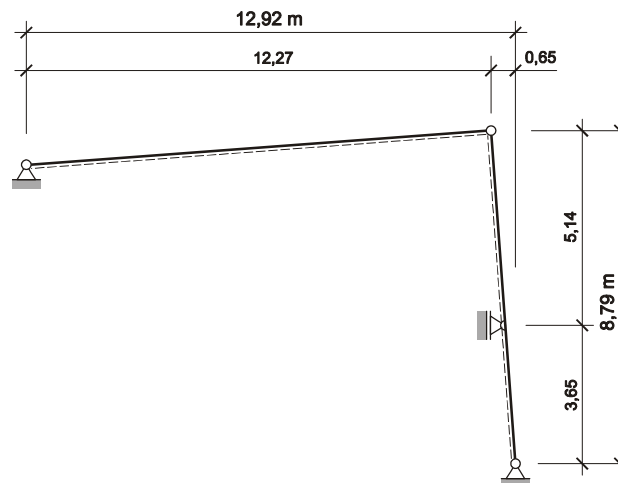


Fig. 4 Structural system of the wall and roof for the office “towers”

The wall elements for the office “towers” and the laboratory hall have been designed as sections with a width per element of 3,18 m and a height of 8,79 m and 12,37 m respectively. They are built-up as boxed cross-sections with a 5-layered 120 mm thick CLT-panel inside, a 3-layered (42 mm thick) CLT-element outside as flanges and sheathing respectively (between these are two glulam ribs (GL24h; 140 / 180 mm) and structural timber members (C24; 60/280 mm)) as a web. The ribs are rigidly glued to the panels so that the cross-section acts as a T-beam.

Since the wall is built-up with massive timber elements which are friction-locked connected no bracing system for the office towers was necessary.

The walls of the laboratory hall are designed with the same elements but have a maximum height of 12,37 m.

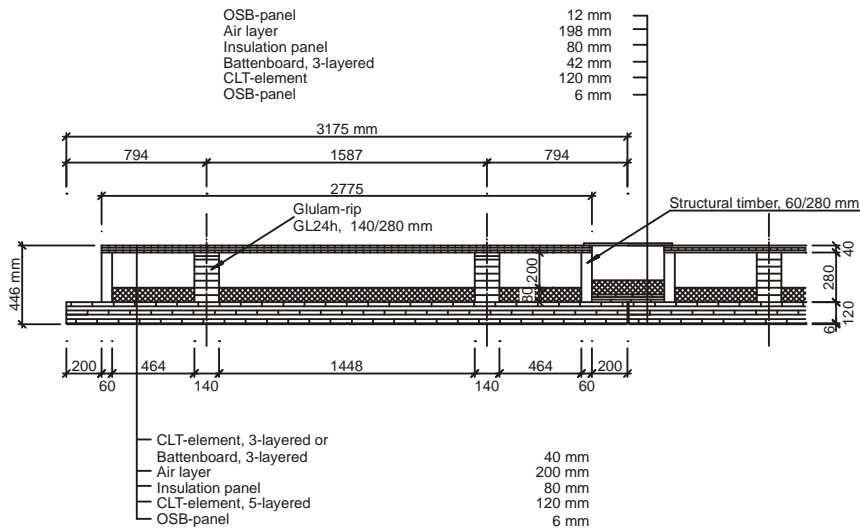


Fig. 5 Cross-section of the wall-elements

All wall elements with the façade system consisting of 3-layered larch laminboards included have been prefabricated in the production hall of the producer, transported to the building site and lifted there to their end position by means of a mobile-crane.



Fig. 6 First erected wall element of the office “towers”

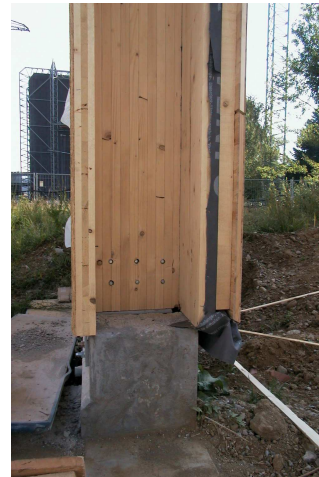


Fig. 7 Support of the wall elements with façade system (laminboards (larch)) at the north of the laboratory hall

4.3. Roof above the office “towers”

The roof above the office “towers” has been built-up utilising a 5-layered, 120 mm thick CLT-plate with glulam ribs (GL24h; 140/280 mm) with a span of 12,27 m. Ribs are friction-locked jointed with the CLT-elements so that the composite could be designed as a ribbed plate (T-beam). Due to aesthetical reasons between the ribs a non load-carrying OSB-panel (12 mm) has been applied.

Standard roof element: Roof above offices

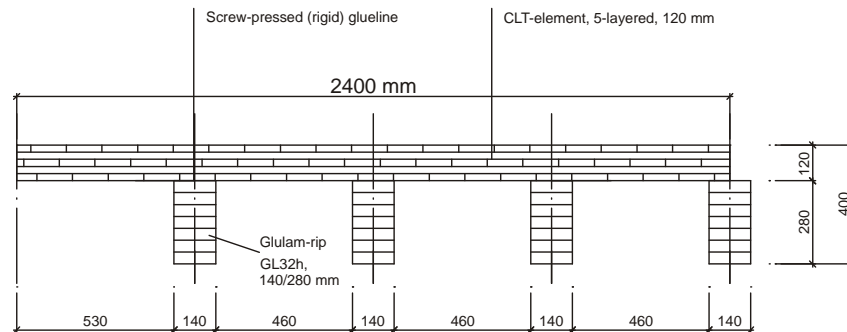


Fig. 8 Standard roof element: Roof above offices

Fig. 9 Roof above the offices
(with parts of the interior walls)Fig. 10 Assembling of the roof elements
above the office

4.4. Roof above the laboratory hall

The roof structure with a span of 19,82 m (total length 22,8 m) is an innovative hybrid composite consisting of slightly curved 5-layered CLT-elements (each 3,2 m in width) with a thickness of 120 mm and a suspending steel construction built-up by a spatial trestle formed with steel tubes \varnothing 76 mm and steel rods (\varnothing 32 mm and 24 mm respectively) as tension members. In the first and last third of the span the steel rods are doubled and connected with the CLT-elements by means of a special load-transfer steel part (see Fig. 23 and 24). The roof elements are point-bearied on the glulam columns transferring the load to the walls below. Since the production length of the CLT-element was limited at the producer, they were jointed in approximately thirds of the length (see Fig. 25). For the achievement of a sufficient exposure to the light in the laboratory hall every second element contains a roof light which is fixed on an attached glulam frame.

The structural system for the roof above the laboratory hall has been computed as a spatial suspended CLT-plate (see Fig. 13) which has been considered as a grillage structure with a rigid connection of each layer. The roof elements are bearing on single columns at the upper end of the walls which are connected at the northern part on the foundation and on the southern part on the reinforced concrete structure of the office area. To achieve a sufficient bracing structure for the laboratory hall the roof elements have been jointed in a way that they act as a shear-panel. Horizontal

forces are transferred by friction-locked elements of the (shear-) walls in the longitudinal direction and bracings within the end walls.

To achieve a better weather protection for the wooden façade of the laboratory hall an appropriate roof overhang of 1,65 m has been designed.

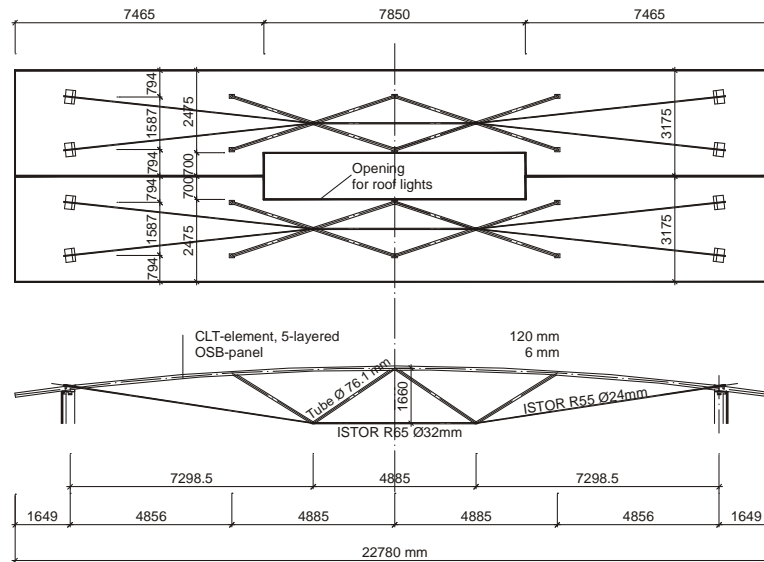


Fig. 11 Plan and cross-section of the roof above the laboratory hall



Fig. 12 First roof element at the final position and assembling of the second element at the ground

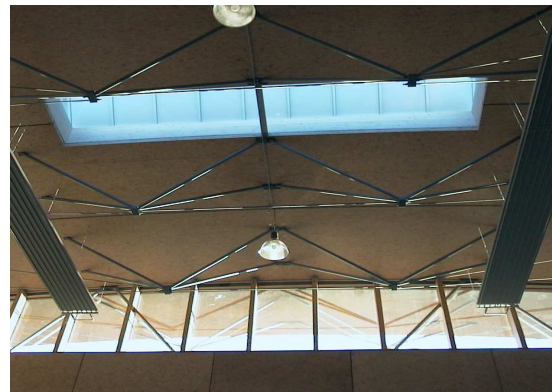


Fig. 13 Roof above the laboratory hall with steel trestles and suspension steel rods; in front: a roof light; in the end walls: bracings

5. Actions on structures

The CBT-building has been designed applying the Austrian Standards for actions: ÖNORM B 4010, B 4011, B 4012, B 4013 and B 4014. All these codes deal with loads for the deterministic safety concept. The snow load $s_0 = 0,95 \text{ kN/m}^2$ and the wind load $w = 0,40 \text{ kN/m}^2$ could be computed from the regulations of the mentioned standards.



The structural analysis has been done using the program package “RStab” from Dlubal / Germany. The design of the timber elements has been done in accordance to ÖNORM B 4100 – Part 2 which is a standard based on the deterministic safety concept.

6. Erection

Due to economical reasons all wooden components have been assembled to a high degree of prefabrication at the production hall of the manufacturer.

All walls have been totally prefabricated including the façade system and the inner surface (OSB). These elements have been transported to the building-site with trucks and have been lifted by means of a mobile-crane to their end-position. At the building-site only the connection with the reinforced concrete structure by means of steel angles and a special connection system at the edges of the wall elements has been necessary (Fig. 14).

Roof elements above the office building have been prefabricated as T-beams by means of screw-pressing the CLT-elements and the glulam-ribs. At the building site these elements have been lifted with a mobile-crane to their final position. At the support with the reinforced concrete wall they were fixed by means of a slotted-in T-shaped steel part and bolts. At the wooden wall end the assembling has been done with contact-pressing of the CLT-elements of the roof and the walls and fixing the joint with self-tapping wood screws. To achieve a connection of the glulam ribs with the wall elements a steel part connected at the wall with screws and to the ribs with dowels has been applied. With the mounting of insulation material and the attachment of a weather protection layer (polyurethane sheet) on the top of the roof finalised the construction. To achieve a better weather protection for the inclined wooden façade of the office “towers” a steel structure has been assembled linking the three office “towers”.

The roof above the laboratory hall has been assembled at the building-site using a wooden sub-construction. There the steel trestles were jointed with the CLT-element by means of wood-screws. Finally the suspending steel rods were put into the appropriate drilled holes and slightly prestressed with conventional steel nuts. Then these elements have been lifted on the top of the roof by means of a mobile-crane. The edges of the several roof elements have been jointed by means of an attached laminboard strip which has been fixed with selftapping wood screws. Again the mounting of an insulation material and the attachment of a weather protection layer (polyurethane sheet) on the top of the roof completed work at the roof above the laboratory hall.



Fig. 14 Lifting of a wall element by means of a mobile-crane

7. Interesting construction details

In the following the most interesting details of the CBT regarding the timber construction will be shown and shortly explained.

7.1. Details of the wall construction

Walls are connected with the foundation and the massive walls of the reinforced structure by means of simple steel angles. When lifted with the mobile-crane to their position only some special concrete dowels had to be mounted (Fig. 15).

The joining on the edges of the wall elements to achieve a continuous shear-wall but also to wind proof the void between them, has been done by a especially developed connection system. Approximately every 2 m glued-in rods (\varnothing 16 mm) have been glued into the 5-layered CLT-element at both edges of the wall. When they were lifted to their final position a steel ring (\varnothing 114 mm, $t = 6$ mm) with two cuts appropriate to the diameter of the steel rods have been inserted into the hole containing the ends of the rods. Finally the walls have been pressed together by nuts on the inner side of the connector (Fig. 16) and have been covered by a cap. Between the void at the edges of the wall elements a wind- and moisture proof sealing tapes has been embedded.



Fig. 15 Connection of the wall element with the foundation by means of steel angles



Fig. 16 Connection of the wall elements with special cylindrical steel fasteners with glued-in rods

7.2. Details of the roof construction above the office “towers”

The CLT-panels of the wall- and the roof-elements have been joined by means of selftapping wood screws (\varnothing 10 mm; length: 300 mm) every 30 cm. In the void two wind- and moisture proof sealing tapes have been applied.

The ribs of the roof elements have been connected with the walls utilising a T-formed steel part which was slotted into the glulam rib. To achieve a load-carrying connection dowels (\varnothing 10 mm) have been applied there. The other side of the steel part was connected with the wall by means of wood screws (Fig. 17).

At the other support of the roof element again a T-shaped steel part was connected on the reinforced concrete wall. Since only for some loading situations uplifting forces of small amplitude are applied, the ribs of the elements could be beared on elastomeric layers. For the uplifting forced only one bolt (\varnothing 12 mm) connecting the slotted-in plate of the steel part with the glulam rib was necessary (Fig. 18).

For the connection at the edges of the roof elements bolts (\varnothing 12 mm) in distances of one meter have been used.



Fig. 17 Support of the roof element at the end of the walls



Fig. 18 Support of the roof elements at the end of the reinforced concrete wall

7.3. Details of the roof construction above the laboratory hall

The steel trestles of the suspending system have been manufactured by a steel-worker with special plates at the end of the arms and a steel block with appropriate holes for the suspension steel-rods. At the building site they were fixed to the CLT-plates with four wood-screws (\varnothing 5 mm, length: 100 mm) (Fig. 19 and 20). In the middle span of the plate one steel rod (\varnothing 32 mm) has been applied while at the outer fields two rods (\varnothing 32 mm) have been fixed. The rods have threads at the end so that they could be slightly prestressed against the steel block of the trestles.



Fig. 19 Steel trestles at the producer site

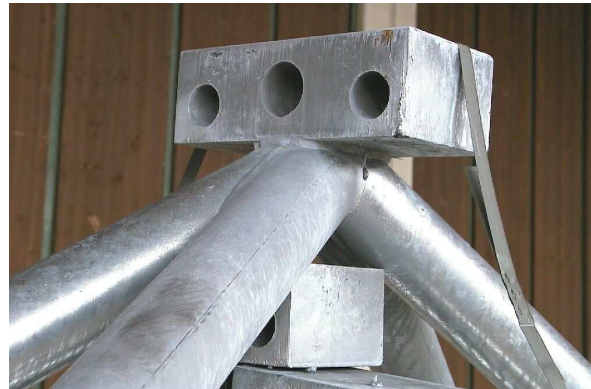


Fig. 20 Detail of the steel trestles with drilled holes for the steel rods

The connection of the two steel rods at the supports of the roof elements have been done by a special formed steel element with a rib at one end. This rib is toothed with the CLT-plate and introduces loads locally in compression parallel to grain so that only four wood screws have been necessary for this joint (Fig. 21 and 22).

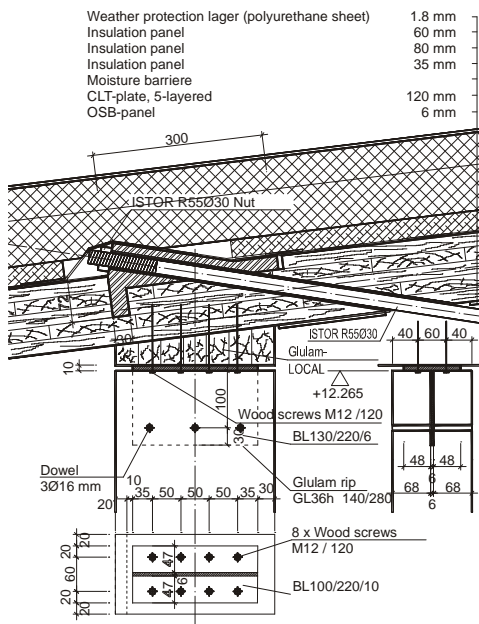


Fig. 21 Detail of the load introduction of the rods into the CLT-plate

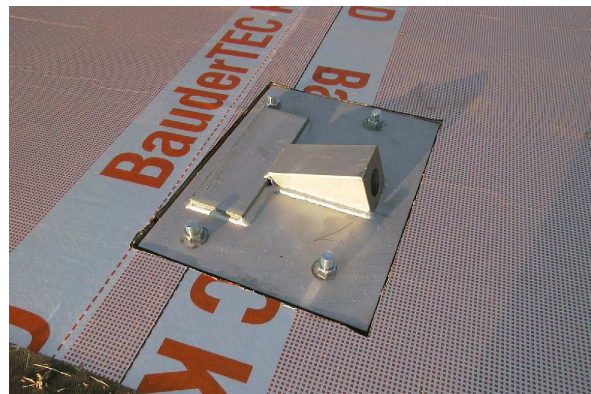


Fig. 22 Detail of the steel part for the load introduction of the rods into the CLT-plate

Since the CLT-plates couldn't be produced at the manufacturer in their total length, joints had to be designed in approximately a third of the span. This joint has been solved by a simple overlap of an attached 5-layered CLT-plate which is connected with wood screws with the CLT-element of the roof below (Fig. 23).



Fig. 23 Joint of the roof's CLT-plates by means of an overlap with a 5-layered CLT-strip

8. Wood preservation activities

Wood preservation activities have been done in two ways: Within the conceptual design the walls at the laboratory hall have a roof overhang of 1.65 m which should be sufficient for a good weather protection of the wooden façade out of larch wood. Above the inclined walls of the office “towers” a construction with a steel sheet roof protects the wooden construction.

Apart from that all wooden parts have been coated with a chemical wood treatment system (DANSKE TwinProof / Synthesa). This transparent glaze offers a double protection to the wood: on one hand the transparent UV-light blocker conserves it against degradation of the lignin and thereby graying. On the other hand it is particularly water-repellent. Because of the strong hydrophobic properties of this treatment system the water rolls-off the timber and doesn't wet the surface.

It has to be mentioned that critical items of this façade systems are the fixing points of the wooden laminboards with the underlying construction and the gaps between the boards because of their limited dimensions. This has been considered within the design process by scheduling the façade to a limited duration of service (approximately 15 years). Because of that all façade parts can easily be unmounted and exchanged by new boards. This argues why the laminboards have been fixed by a very simple fixing system (self-tapping screws) without further protection activities and suits to the basic principle of wood preservation to protect “wood with (easy to change) wood”.

9. Ecological aspects

Concerning ecological aspects it has to be mentioned that about 2/3 of the Styrian province's area is covered with forests. In addition about 50.000 employees are working in timber processing- and producing industry. As already mentioned in the chapter about investment design it has been a notable sign of the responsible persons to find a way for the erection of this public and academic building with timber and wood engineered products as a main material.

Instructions and case study no 10 has been prepared by P3 (M. Augustin, R. A. Jöbstl and T. Moosbrugger, Institute for Timber Engineering and Wood Technology at Graz University of Technology).



Case study no. 11

FLISA ROAD BRIDGE

1. General information

Date: June 2003

Price: 3 500 000 EUR

Owner: Statens Vegvegen

Design studio: Norconsult AS, Sandvika

Wood construction company: Moelven Limtre AS

Location: the bridge crosses the river Glomma in Hedmark County - Norway

Materials: glulam, steel

2. Introduction

When the old Flisa Bridge was opened in 1912, it was considered to be an excellent, futuristic construction. The three-span steel superstructure with spans of 55.5, 56.0 and 70.5 m was a truss bridge with hinges in the two end spans. The old bridge was supported by abutments and piers made of high-quality dressed stones on pile foundations. The existing steel superstructure was in a poor condition and was not suitable for today's traffic load and road width. The old bridge is shown in Fig.1.



Fig. 1 The old Flisa bridge

In spring 2000, a project team was formed to plan and carry out the project for a new Flisa Bridge, consisting of a structural engineer, an architect, the glulam manufacturer and experts from the Public Roads Administration. Previous investigations showed that the existing substructure was in a good



condition. It was therefore logical to develop a concept with a new superstructure on the old substructure. A premise was that the road level should not be elevated due to adjacent road links. This made a concrete girder or a built-up girder of steel unsuitable because the superstructure could not be lowered due to flooding. This led to the decision that the new superstructure should be of the same type as the old one, and be developed further to satisfy today's demands with respect to road width, free height and load capacity. With this considered, a new superstructure of timber was selected. One reason that timber was chosen instead of steel is that timber can compete with steel in price for truss bridges. In addition, the Public Roads Administration's development and experience in the field of timber bridges also contributed to the decision. In this phase a three-dimensional (3D) conceptual model of the bridge was developed by the architect to illustrate the new bridge (shown in Fig. 2).

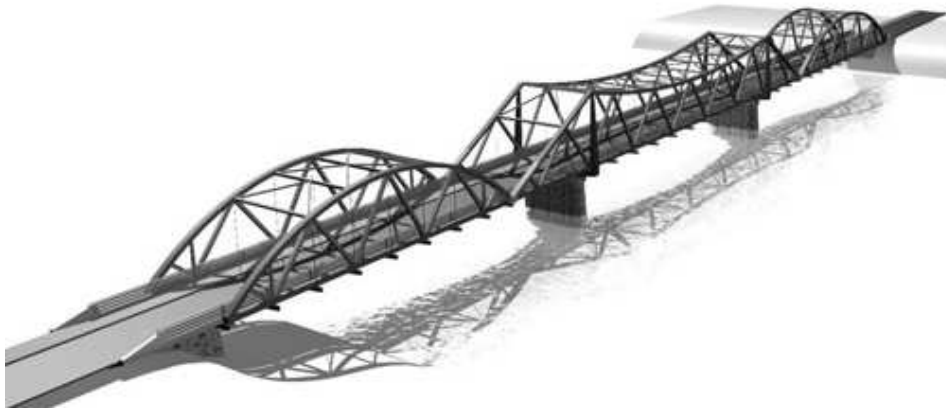


Fig. 2 3D model of the new bridge

3. Superstructure

The bridge is part of the national road network and is designed in accordance with the Norwegian national traffic load regulation, which specifies a uniformly distributed load of 9 kN/m and a 60 t lorry (represented by three equivalent axle loadings of 210 kN) per lane.

The superstructure was analysed by a 3D element program. A model of the whole superstructure with more than 1100 elements was made. Typical element length of the curved chords in the truss was about 1.4 m. The results from the analysis were used in the design of the truss, while steel cross-beams, deck plate and parapets were designed based on local models.

A truss system similar to the one on the old bridge was used. The middle section was cantilevered from the piers to support the two end spans, which are simply supported as shown in Fig. 2.

The glued-laminated truss girders in the middle section are cantilevered out about 17 m from the piers, which gives a section length of almost 90 m. The truss has a curved upper chord with the tallest height over the pillars being 9.5m. A 5.6 m spacing between the steel cross-beams gave a favourable span configuration for the bridge deck. The glued-laminated elements were:

- a) upper chord = 0.71/0.60 m
- b) lower chord = 0.61/0.53 m
- c) diagonals = 0.48/0.43 m.

Vertical steel rods of diameter 60 mm suspended the steel crossbeams between the truss joints. Lateral stability and transfer of wind forces are taken care of by a wind truss between the upper chords. The wind truss gives a free height of 5.9 m above the carriageway, which is higher than required by the client. The wind truss ends on the piers where the upper chords are laterally supported by a vertical steel column placed on the outside of each truss wall. These columns are rigidly fixed to the cross-beam, which makes the columns and cross-beam form a U-frame as shown in Fig. 3.

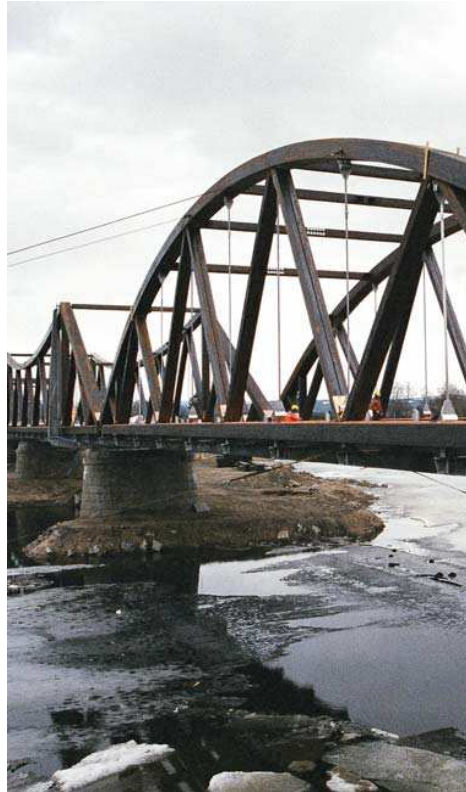


Fig. 3 New concrete top and steel cross-beam at pier top

The end spans are simply supported truss girders with arch upper chords supported at the cantilevered middle section and at the abutments. The two end sections/spans are 38.4 and 53.6 m long as shown in Fig. 4.

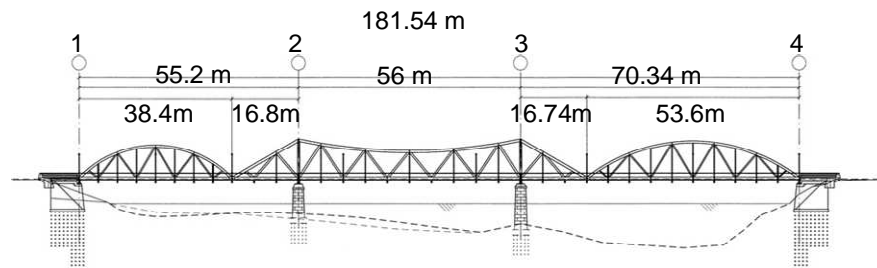


Fig. 4 Bridge elevation



The height of the arches is 8.0 and 9.0 m, respectively. The truss member dimensions are similar to those used in the middle section. Lateral stability and transfer of wind forces are taken care of by a wind truss between the upper chords. Near the ends the wind forces are transferred to the deck by vertical steel columns in the truss rigidly fixed to the crossbeams.

Two traffic lanes each 3.25 m and an elevated 2.5 m wide pavement gives the bridge a total width of 9.0 m. The new superstructure is more than twice as wide as the old one, therefore the piers and abutments were too small. This was solved by using large steel cross-beams to support the truss girders. Fig. 3 shows the cross-beam at the top of the pier after one truss has been installed.

The new bridge has a span of 70.34 m and a total length of 196 m including the bridge deck behind the abutments. This makes it the world's longest timber bridge with respect to clear span designed for today's traffic loads, and one of the longest with respect to total length. The two other long timber bridges in Hedmark County are Tynset Bridge, built in 2001 with a span of 70 m; and Evenstad Bridge, built in 1996 with a total length of 180 m.

4. Connections

The design and detailing of connections in timber bridge structures are critical to their load-bearing capacity and durability. Simple connections such as nails, bolts and timber connectors have too little capacity. In addition they give greater slip than desirable. The preferred connection has been embedded steel plates in sawn slots in the members to be connected.

By using dowels through holes in the plates, forces are transferred between the steel plates and the wood material. This makes it possible to have many parallel plates in a connection, which gives a high load-carrying capacity.

The main development that has taken place over the past decade, reducing the cost of glulam as a structural material, is the mechanisation of the connection process. Originally, drilling of holes for the dowels was carried out by hand, and because of the accuracy required, this was a slow and expensive procedure. This is now a mechanised process where the drilling of holes can be done quickly with pipes, using a template to secure accurate positions of the holes (see Fig. 5) and as such is much cheaper to carry out.



Fig. 5 Connections between timber members



The connections used in the Flisa Bridge are designed to transfer tensile forces up to 5600 kN in the ultimate limit state. Typically 8 mm thick steel plates and 12 mm dowels were used. The centre distance between the steel plates is about 80 mm which is near optimum distance. The most stressed connections have eight parallel plates and 46 dowels in each of the elements to be connected.

5. Construction period

Because the superstructure was mainly prefabricated and had to be lifted onto the piers and abutments from locations in the river, a temporary embankment area was made. This could only be done in the winter months when the water level in the Glomma River was low. The contractor filled the riverbed at the bridge site so that about 120 m of the shallowest part of the river was closed with only about 50 m of the eastern part being open.

Demolition of the old superstructure started when the old bridge was closed to traffic in November 2002. Simultaneously, prefabrication of the superstructure and work on the substructure started. The truss girders were manufactured and fully assembled in the workshop to make sure the elements fitted together and that the total length of the girders was correct. Then the truss girders were taken apart and impregnated with creosote before they were transported to the bridge site. Assembly of the first sections started in February 2003 and was completed by early spring.

After the main structure was assembled, the remaining components such as the bridge deck and the parapet were installed. Finally the copper cladding, asphalt and adjacent roads were completed allowing the new bridge to be opened on 5 June 2003, only seven months after the old bridge was closed. Fig. 6 shows the truss being lifted into place, while Fig. 7 shows the completed new bridge.



Fig. 6 Lifting of the truss



Fig. 7 View of the new Flisa bridge

6. Literature

P. K. Ekeberg and K. Søyland: Flisa Bridge, Norway – a record-breaking timber bridge, Bridge Engineering 158

Instructions and case study no. 11 were prepared by Petr Kuklík.



Case study no. 12

WOODEN CHURCH

1. General information

- date: 1648,
- price: not possible to evaluate,
- owner: Roman Catholic Church,
- location: Poland, Opole County, Olszowa village,
- surroundings: rural,
- materials used: hand-prepared wood, stone

2. Object description

The building is a church dated at year 1648. It is located at the border of Olszowa village. The church was rebuilt in 1748 and 1988. In 2007 there was made heavy repair, in which the foundation has been totally rebuilt.

3. Construction elements

3.1. Foundation

Originally the building was founded in the shallow level on sandy soil, at the depth of ca. 31-34cm (**Fig.1**). After the reconstruction of settlement it is now founded at 100cm below ground level, what is proper value for Opole region (ground freezing zone). The new foundation is designed as the high continuous footing (**Fig. 2**) under the brick ground beams.

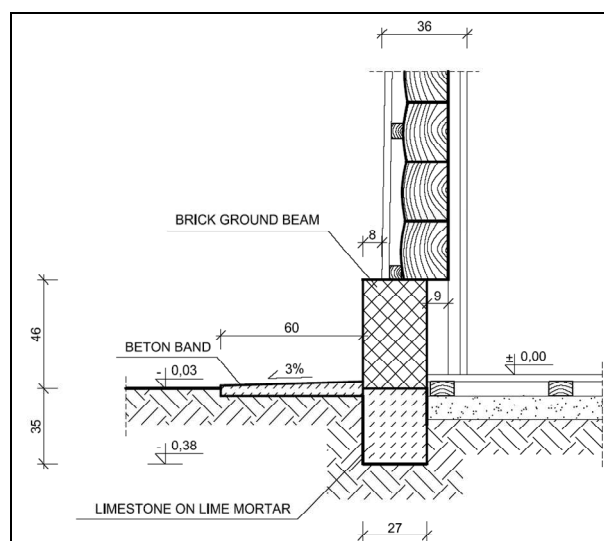


Fig. 1 Cross section of an old footing

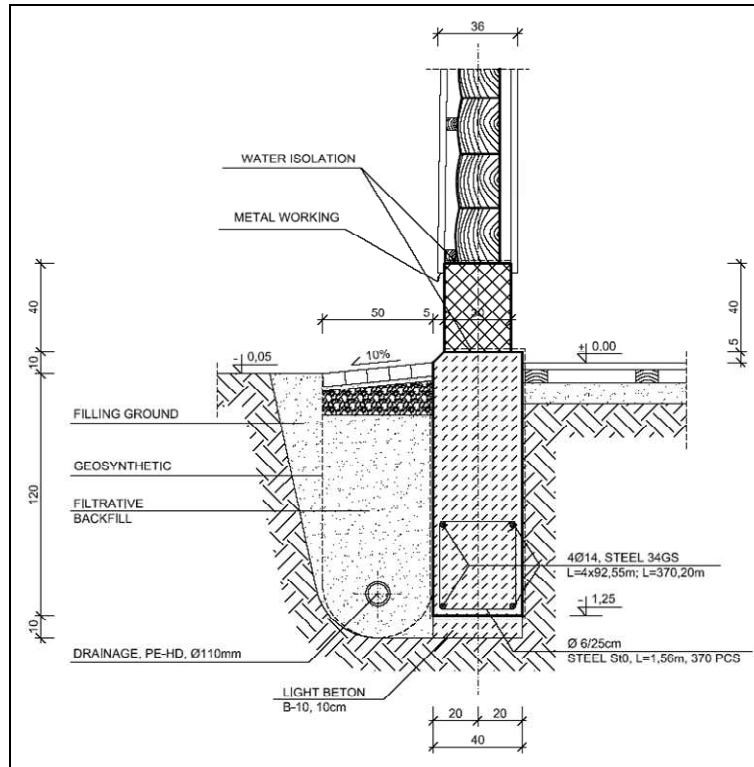


Fig. 2 New continuous footing detail

3.2. Wall elements

The walls are constructed from simple wooden trunks (Fig. 3), with dovetail joints in the corners.



Fig. 3 The walls of the church



3.3. Roof

The roof construction is shown at **Fig. 4** and **Fig. 5**. The roof trusses are placed with 132-161cm spacing. The roof slope is about 51°-53°.



Fig. 4 Roof construction



Fig. 5 Full roof truss

As the roof coating the wooden shingle is used (50x9x2cm), mounted on lath grid with 25cm axis spacing (**Fig. 6**)



Fig. 6 Wooden shingles

4. Computational models used

The computational models were created for the verification calculations. The reconstruction of the building required to make several computations with use of special software. The 3D model of selected roof truss was taken into consideration (**Fig.7, 8**).

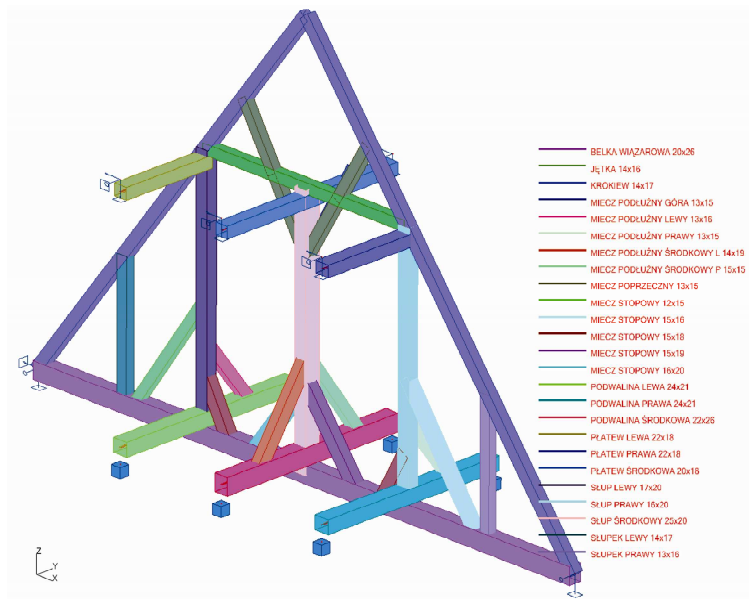


Fig. 7 3D model of the roof truss

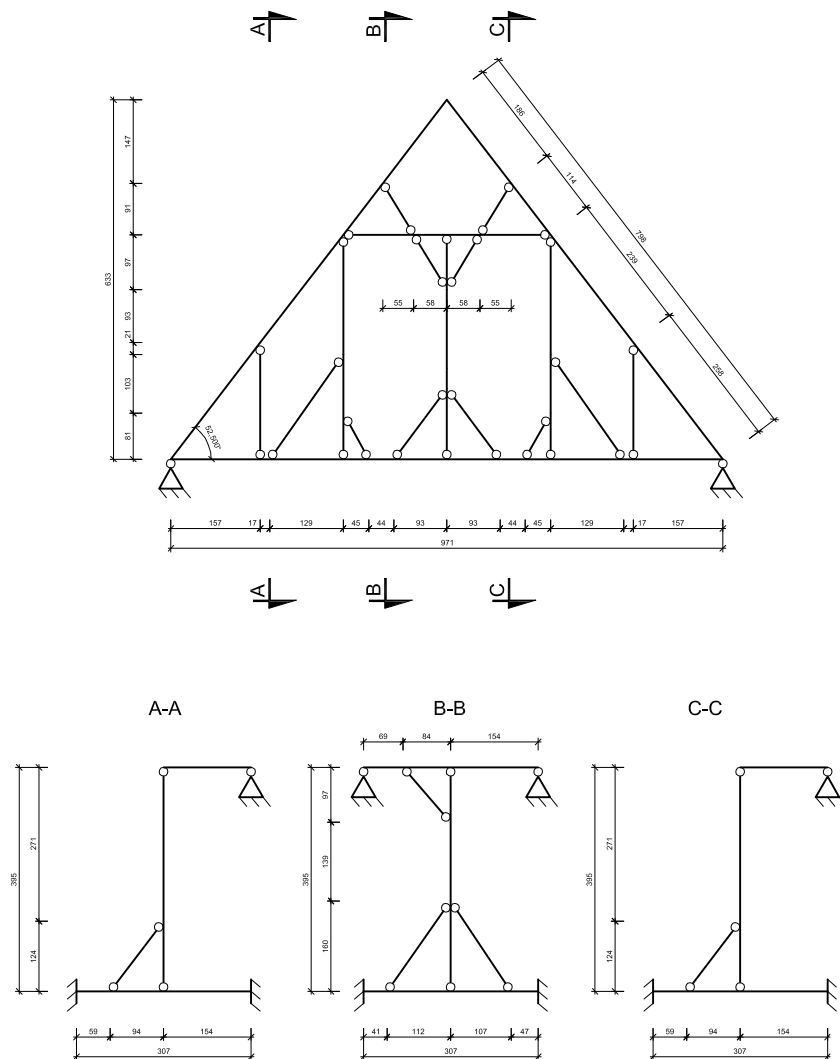


Fig. 8 The computational model of the roof truss

5. Actions on structure

The construction is loaded with typical set of forces, according to polish standards. It is grouped into few parts:

- snow: $S_k=0,27\text{kPa}$,
- wind at 1st area according to PN (polish standard): $p_k=0,25\text{kPa}$,
- dead loads of roof, floors and walls casing,
- operational loads of choir mezzanine: $q_k=2,0\text{kPa}$.

The calculations were focused on roof construction because of its direct loading by natural forces. Operational loads of higher levels of the church are very small due to seldom presence of people on this stage.

6. Project documentation, plans, and drawings

At the below pictures one can see respectively: plan view of the structure at choir level (**Fig.9**) and the cross-section (**Fig. 10**).

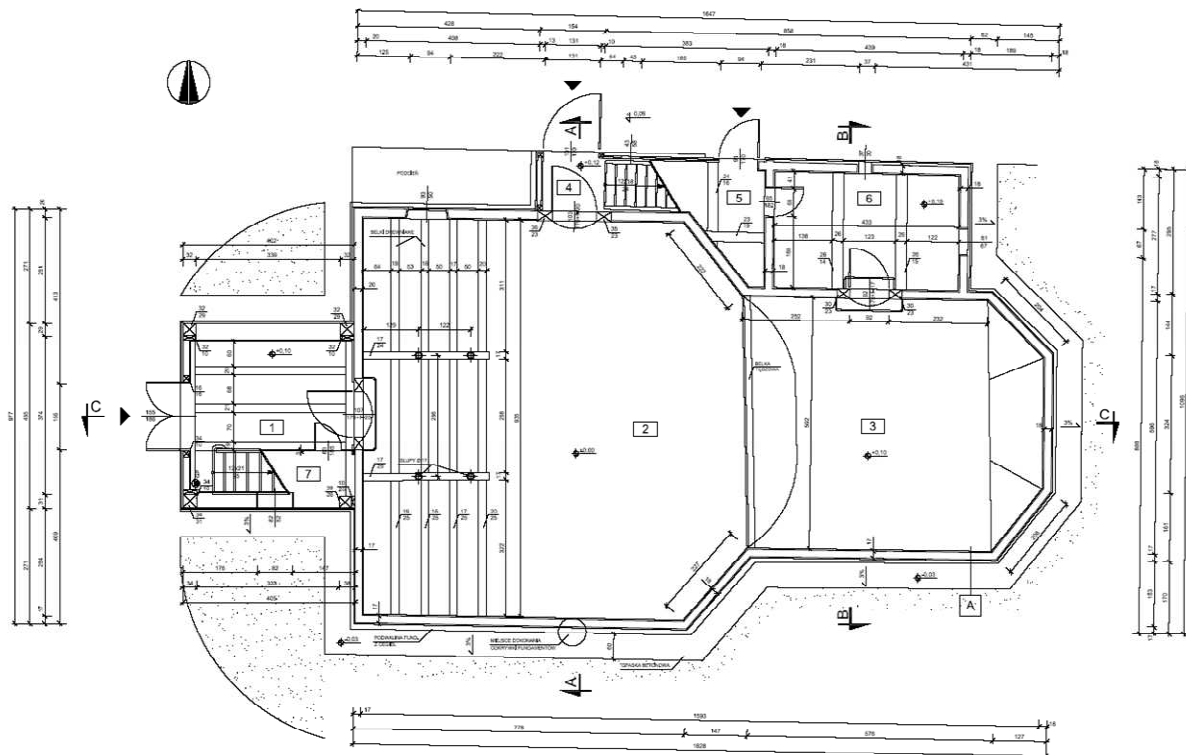


Fig. 9 Plan view of the choir level (+3,84m)

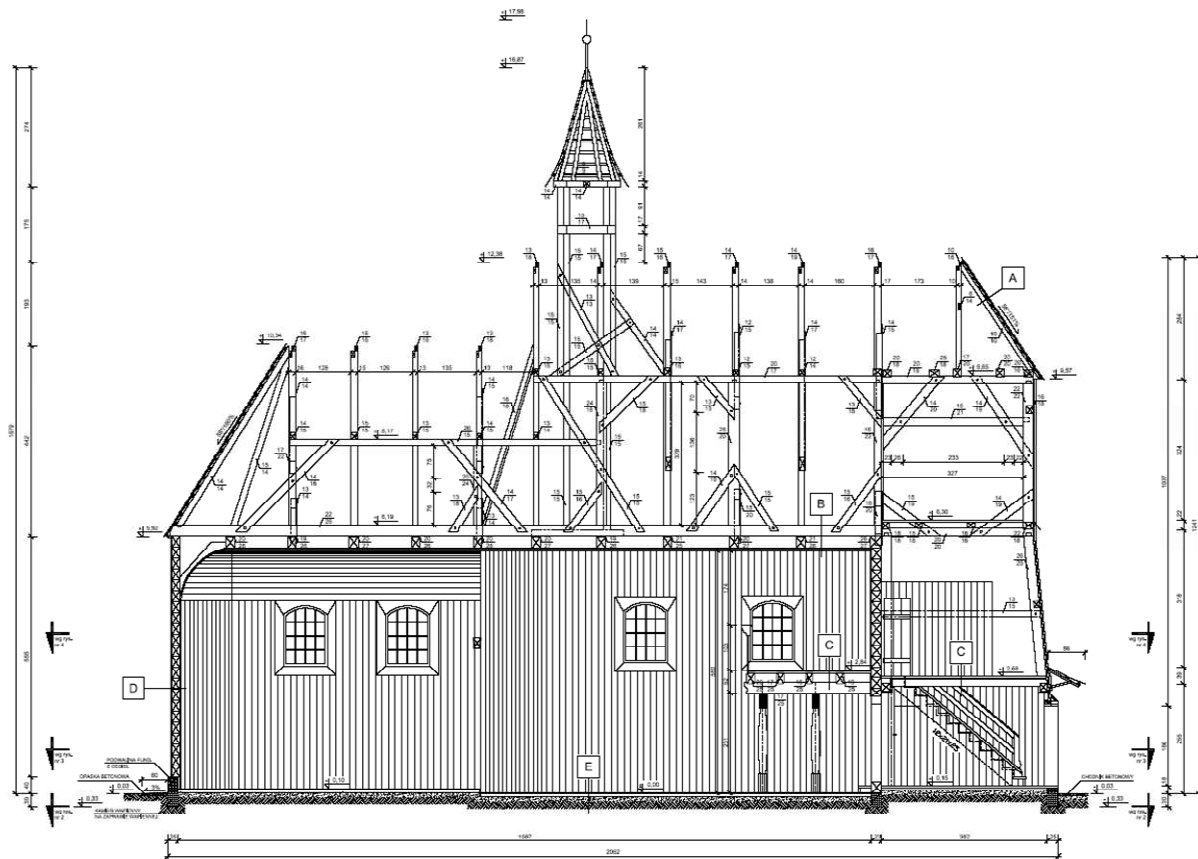


Fig. 10 C-C cross-section

7. Erection

The erection of structure was led between in the year 1648. A sequence of works was typical for this type of constructions:

- ground work – foundation digging
- continuous footings and ground beams
- walls
- roof construction
- roof coating
- finishing works

8. Interesting construction details

The main interesting points of described structure are those connected with roof construction. All the details had to be precisely described during the measurements of building, which was caused by the lack of any building documentation. Other interesting points were damages caused by local weakening of a few elements of the roof. This was also the subject of reconstruction design.

9. Some technical and historical aspects

Wooden churches are the special kind of buildings. They have often very complicated geometry due to many years of rebuilding and repairs. But they have also high historical value, concerned with history of the people living in the regions they are placed, so their documentation is very important for future renovations and repairs.

Instructions and case study no 12 were prepared by Andrzej Marynowicz.



Case study no. 13

SPORT HALL ROGLA

1. General information

Date:	1987
Price:	
Investor:	Unior,d.d., Kovaška c. 21, Zreče, Slovenia
Design studio:	Razvojni center Celje, TOZD Projektiva, Ul. XIV. Divizije 14, Celje, Slovenia
Construction company:	
Location:	Rogla, Pohorje muintain, Slovenia
Materials used:	glue-laminated timber, reinforced concrete

2. Investment design

Sport hall Rogla is situated on Pohorje mountain area in the north part of Slovenia. The hall is a part of a huge sport complex, today it is one of the most famous sports centres in the middle of Europe. The whole sport complex is placed on the top of Pohorje Mountain on the altitude of approx. 1500 m., therefore it is very convenient for acclimatisation training of sportsmen. The hall is purposed for indoor sports with a playground for basketball, volleyball and tennis.

Since the hall is situated on mountain area on a relative high altitude (1520 metres), wind and especially snow actions can be very heavy. In April 2006 a snow of total height of 2.5 metres, and consequently, some cracks appeared around the support and the middle hinge. Consequently, a special project for a reconstruction of the both supports and the middle hinge was proposed.

3. Bearing system

3.1. General description

The main structure bearing system consists of 10 glue-laminated arch beams which are placed on a constant distance of 5 meters. The beams of the overall span of 35.2 meters are supported with rigid reinforced concrete foundations (*Fig. 1*). The overall ground-plan dimensions of the hall are 40.40 x 45.35 m², total floor area A = 1832.14 m².



Fig. 1: Inside photo of the hall.

3.2. Description of the glue-laminated beams

Main bearing capacity beam elements are glue-laminated arch beams with a various height $h(x)$ which varies between 130 cm and 120 cm according to the shear stress distribution along the beam element. The width is 20 cm and it is constant along the span. The beam inclination (α) according to the horizontal axis is not constant and varies between 58° at the support and 15.8° at the first third of the span (Fig. 2).

Geometrical properties of the beam cross-section according to their position on the longitudinal x-axis (Fig. 2) are listed in Table 1.

	Cross-section 1 20/130 cm	Cross-section 2 20/130 cm	Cross-section 3 20/130 cm	Cross-section 4 20/129 cm	Cross-section 5 20/124 cm	Cross-section 6 20/120 cm	Cross-section 7 20/120 cm
α	58°	30°	15.8°	15.8°	15.8°	15.8°	15.8°
$A_x [m^2]$	0.260	0.260	0.260	0.258	0.248	0.240	0.240
$I_y [m^4]$	0.0366	0.0366	0.0366	0.0358	0.0318	0.0288	0.0288
$W_y [m^3]$	0.0563	0.0563	0.0563	0.0554	0.0512	0.0480	0.0480

Tabel 1: Geometrical properties of the cross-section location according to Fig. 2.

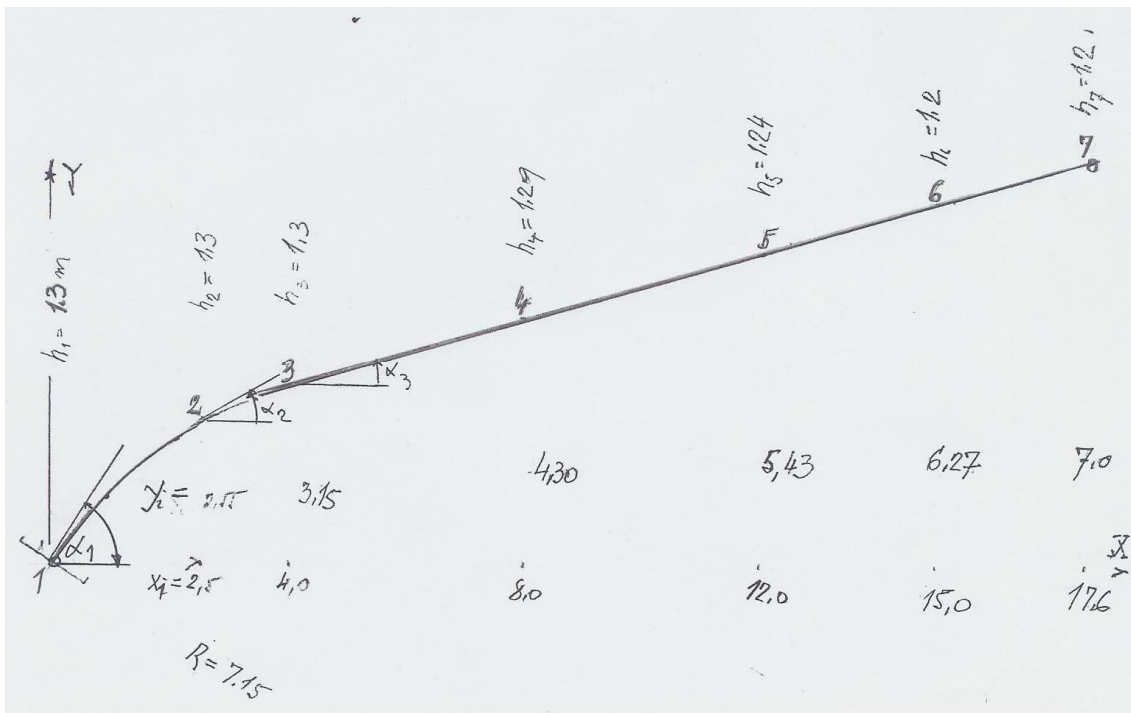


Fig. 2: Scheme of cross-section position of the main beam element.

Timber lamels were produced from middle class of slovenian pine (conifers II. class according to at that time valid slovenian standards JUS.U.C9.300). Therefore, according to Eurocode 5 classification (EN 1194) the used timber material can be classified as class GI 28c.

Foundation was made of reinforced concrete C25/30. Properties of the used materials are listed in Table 2. Beam connection to the reinforced concrete foundation is made using classical stell elements (steel quality S220). A detail description of the connection is given in Section 8.

	$E_{0,m}$ [GPa]	G_m [GPa]	$f_{m,k}$ [N/mm ²]	$f_{t,0,k}$ [N/mm ²]	$f_{c,0,k}$ [N/mm ²]	$f_{v,k}$ [N/mm ²]	ρ_k [kg/m ³]
Timber GI 28c	11.60	0.59	28	16.5	24	2.7	410
Reinforced concrete C25/30	29.0	12.1	2.6	2.6	25	0.30	2500
Steel S220	200	76.9	220	220	220	127	7850

Table 2. Properties of the used materials.

4. Computational models used

For the beam element a static design with a simple supported beam with a middle hinge is used (Fig. 3). Supports A and B simulate the rigid concrete foundations.

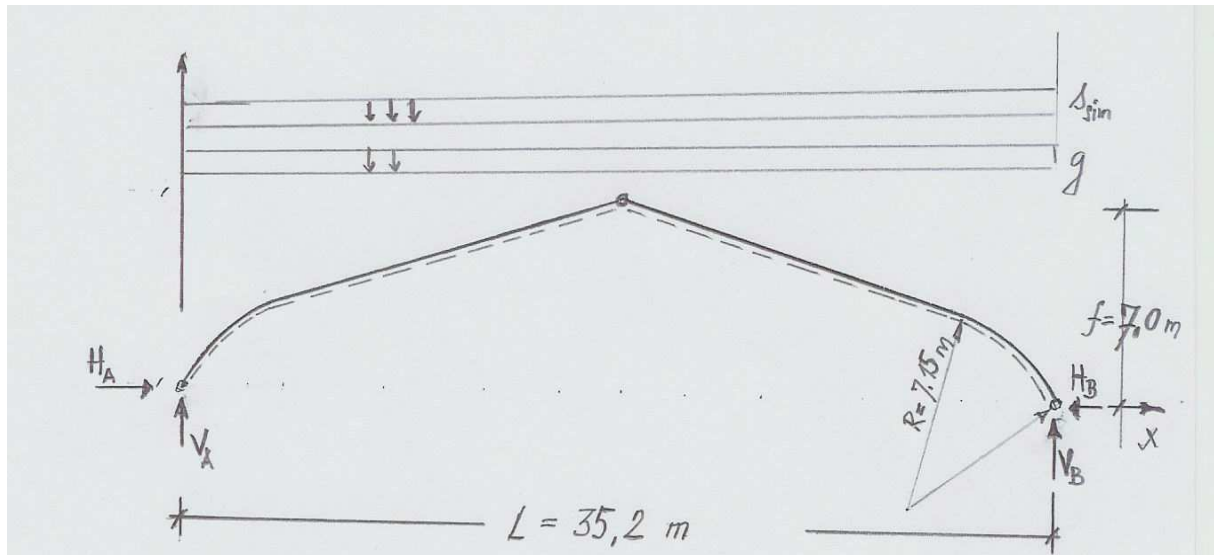


Fig. 3: Static design with two supports and the middle hinge.

Statically analysis was made using known analytical expressions. The results were controlled using a simple computer programme for planar frames (programme FRAME).

5. Actions on structure

Loads were determinate according to in year 1987 valid Slovenian standards.

1. Dead load: $g = 0.4 \text{ kN/m}^2$ (roof load) + beam dead load
2. Live load: /
3. Snow: $s = 1.25 + \frac{H - 500}{400} = 1.25 + \frac{1500 - 500}{400} = 3.75 \text{ kN/m}^2$
- 3a. Full snow ($s_{\text{sim}} = 3.75 \text{ kN/m}^2$) symmetrically (Fig. 3).
- 3b. Full snow ($s = 3.75 \text{ kN/m}^2$) and a half of snow load ($s/2$) asymmetrically.
4. Wind: $w_0 = 1.1 \text{ kN/m}^2$, (Fig. 4)

Considering aerodynamically coefficients ($c_{pe} = \pm 0.4$) for a different roof inclination the calculated wind load was:

$$w = \pm 0.4 \cdot 1.1 = \pm 0.44 \text{ kN/m}^2$$

5. Seismic action: VI. MCS – not considered.

Actions of loads are presented on Fig. 3 (dead load, snow) and Fig. 4 (wind).

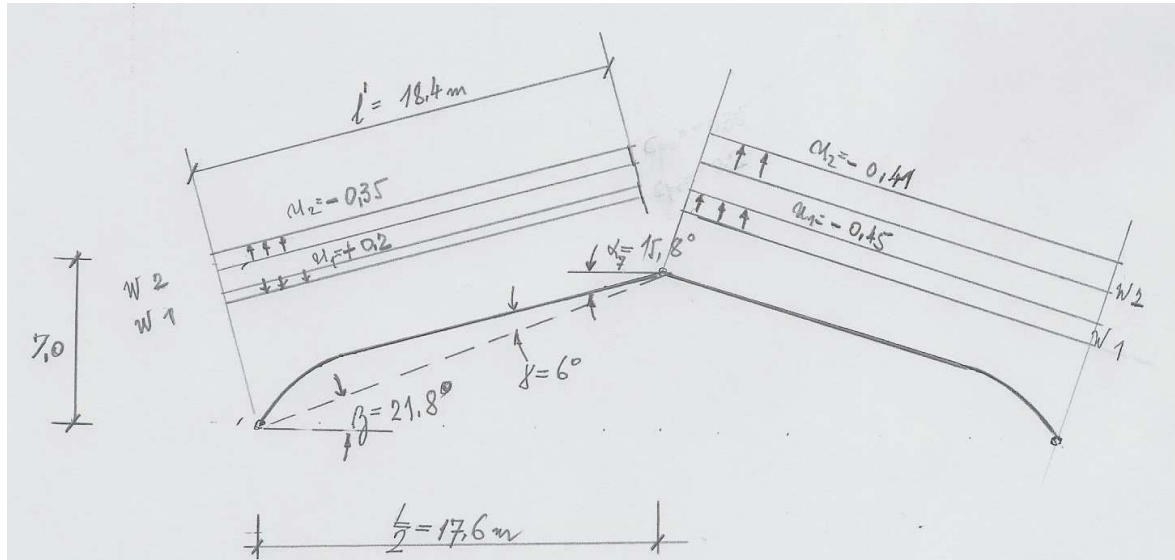


Fig. 4: Wind load actions on the main bearing element.

The dimensions of the timber beam were determined according to the maximal force actions. Actions (bending moments, shear and axial forces) on the main beam element due to symmetrically vertical load ($g + s_{sim}$) are schematically presented in Fig. 5.

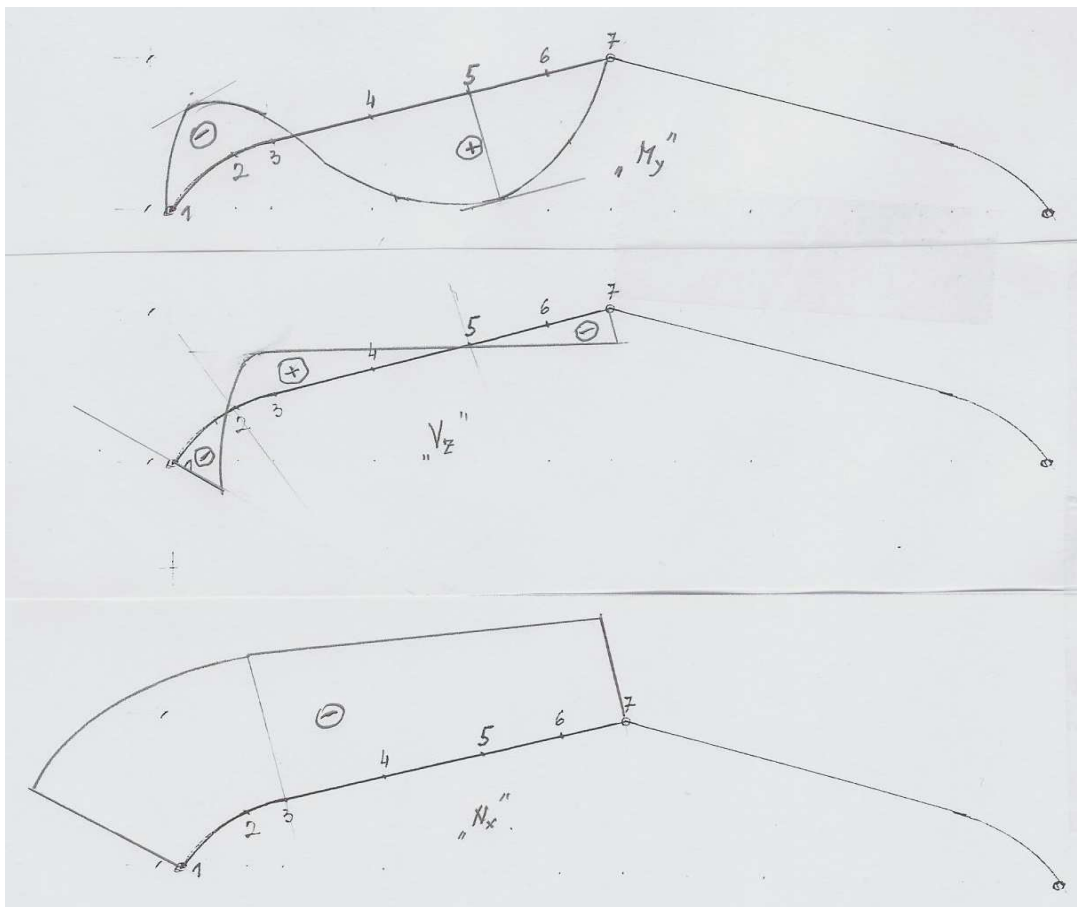


Fig. 5: Schematically presentation of bending moments, shear and axial forces due to symmetrically vertical loads ($g + s_{sim}$).

6. Project documentation, plans, and drawings

6.1. Project documentation



Leonardo da Vinci

WP6 – Case studies



Investitor: UNIOR ZREČE

Objekt: ŠPORTNA DVORANA NA RCGLI

Št.proj.: 030/87

Faza: PGD

PREDMET: S T A T I Č N I R A Č U N

Odg.vodja proj.: Jože Kocitar, dipl.ing.arh.

Odg.projektant: Mitja Pangeršič, dipl.ing.gradb.

Projektant: Vinko Kuzman, dipl.ing.gradb.

Odg. projektant za leseno strešno konstrukcijo:
Janez Štupnik, dipl.ing.gradb.

Izdelano: RAZVOJNI CENTER CELJE,
TOZD PROJEKTIVA

Celje, april 1987

Fig. 6: General project documentation.



Firma oziroma ime in sedež predlagatelja Razvojni center Celje, n.s.o. TOZD Projektiva, n.sub.o. Celje, Ul.XIV.divizije 14			Registrski list številka 2*
Številka registrskega vločka registrskega sodišča in njegov sedež 1-460-02 Celje		Številka registrskega vločka sodišča vpisa in njegov sedež	
Datum vpisa 3. 12. 1979	Datum predhodnega vpisa 15. 10. 1976	Številka predhodnega vpisa 2	Številka vpisa 3
Ornamba in številka sklepa Srg 680/79	Temeljno sodišče kot registrsko sodišče v Celju		Enota v Celju
Na podlagi sklepa registrskega sodišča je bil opravljen vpis v sodni register prilagoditev ZZD, sprememba sedeža in pooblastil			
s temile podatki:			
1 Dejavnosti oziroma posli subjekta vpisa, katerega firma oziroma ime sta vpisana v registrski list št. 1			
<p>Glavna dejavnost TOZD je:</p> <ul style="list-style-type: none"> - izdelava investicijske dokumentacije (pripravljalna dela za investicije), - izdelava kompletne tehnične dokumentacije za vse vrste nizkih in visokih gradenj ter komunalnih objektov, - izdelava zazidalnih načrtov, - izdelava tehnične dokumentacije za tehnološko opremo, - izdelava tehnične dokumentacije za dvigala, žičnice in vlečnice, - izdelava tehnične dokumentacije za alarmne in varnostne naprave ter avtomatske postroje v industriji, - industrijsko in grafično oblikovanje, - izdelava tehnične dokumentacije za oblikovanje enteriera (notranje opreme). 			
		<p>R IV 96/80</p> <p>Ta fotokopija se ujema z izvirkom. Taksa po tar. št. 32 ZOST</p> <p>je nalepljena in uničena na fotokopiji.</p> <p>TEMELJNO SODIŠČE V CELJU</p> <p>Enota v Celju</p> <p>dne 20/10 1979</p> <p>Sodnik</p> <p>DR. J. J. J.</p>	
Vsebuje številka:		2. Registrski list	

*) Vsebuje seznam z registrskim listom št. 1
 **) Vpisni predmet vpisa (prvi odstavek 4. Člena uredbe)
 Obrazec RL, št. 2b — Registrski list št. 2: dejavnosti oziroma posli subjekta vpisa.
 Založnik: Inštitut IIR-SFRJ, Beograd — Založba Obzorja, Maribor

Fig. 7: Special project documentation.

7. Erection

The foundations were built completely classical with a reinforced concrete of a strength class C30/37 and steel class S400. The glue-laminated beams of a half of total span (17.60 m) were produced in company Hoja and then transported to the building-site. The both parts were connected together as a hinge connection, as presented in *Fig.8* (for details see Section 8).

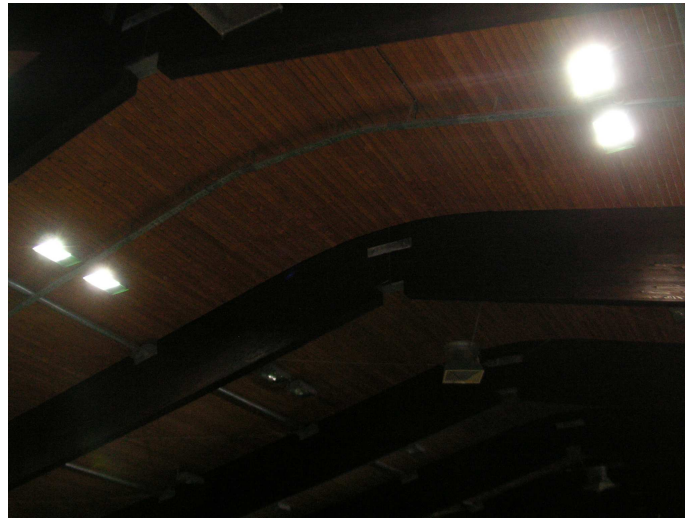


Fig. 8: A hinge connection between two curved beam elements.

8. Interesting construction details

Connection of the main timber beam element to the concrete foundation was made as a hinge using a special steel box (s.c. “shoe” connection). The box was with two steel stirrups and a special tube connected two another two steel stirrups which were fixed to the base. A simple scheme is presented in *Fig. 9*, whereas photos from two different sides are presented in *Fig. 10*.

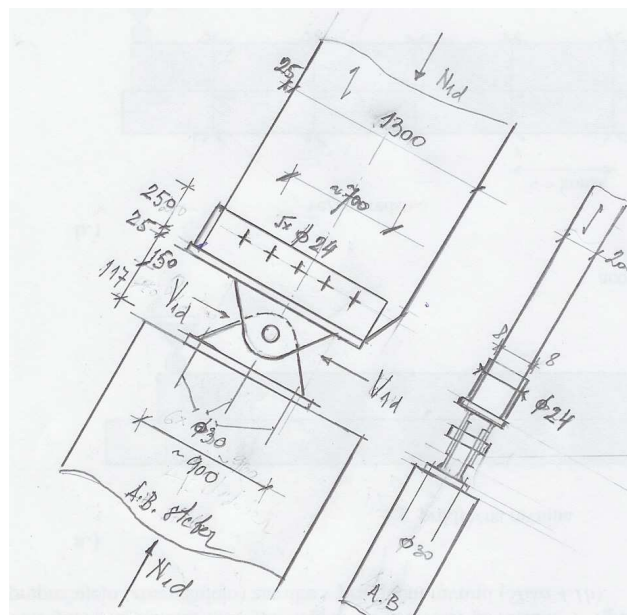




Fig. 9. Schematically presentation of the hinge connection of the timber beam to the foundation.



Fig. 10: Connection of the main timber element to the concrete foundation.

9. Protection from weather effects

To assure a horizontal protection of the building a classical bracing system using steel diagonals were built in the upper horizontal plane of the curved beam element (Fig. 11).



Fig. 11: A steel bracing system in the upper horizontal beam plane.



In April 2006 a heavy snow of a total height of 2.50 meter fall (*Fig. 12*). Therefore, the snow load was bigger as it was predicted in the statically analysis (3.75 kN/m^2) using at that time valid Slovenian codes.



Fig. 12: A heavy snow in April 2006.

Because the snow load was not symmetrically distributed on the roof, some cracks appeared in the timber beams close to a base connection (*Fig. 13a*) and around the middle hinge (*Fig. 13 b*).

a.)



b.)



Fig. 13: Cracks by the connection to the base (a) and in the middle hinge (b).

Because of that a special project for reconstruction of the main timber beam element was done (Dobrila, Premrov) inserting a special plywood board in the middle of the beam span (*Fig. 14*). Additionally, a special analysis was made to calculate the maximal permitted snow load for the actual dimensions of the main timber bearing capacity beam element.

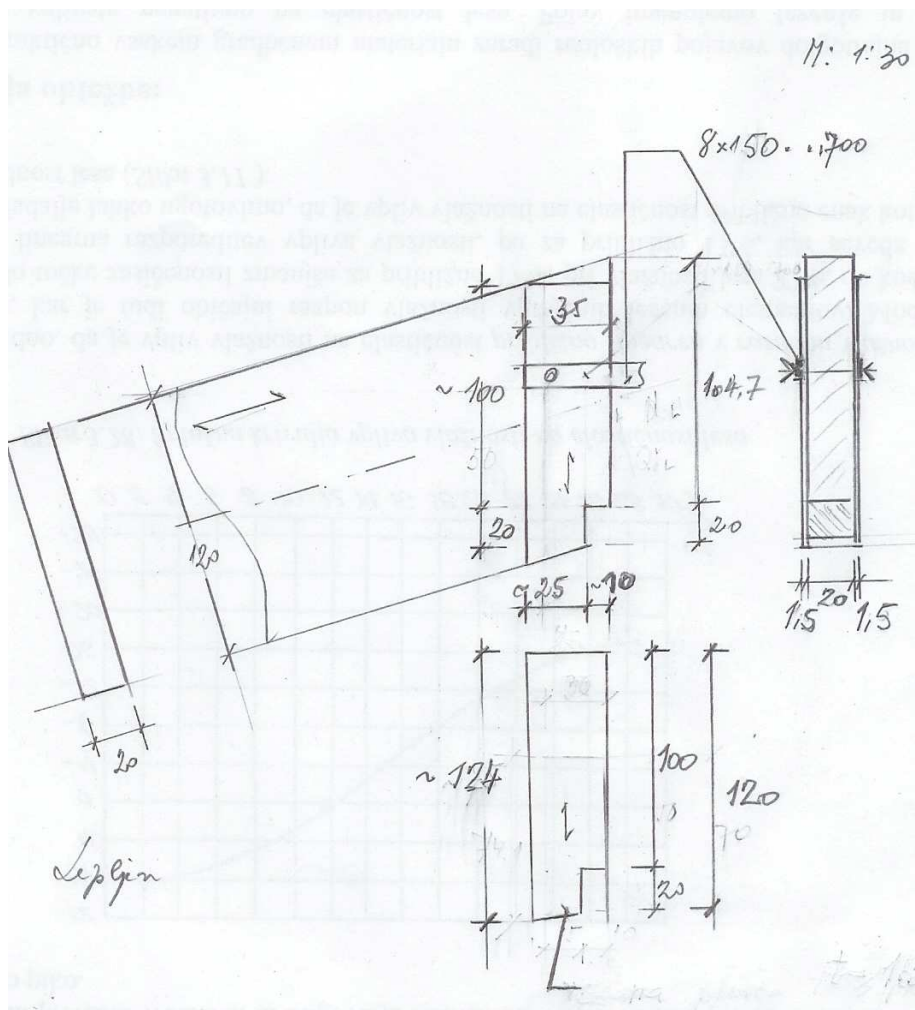


Fig.14: Reconstruction in the middle hinge using a special plywood board.

10. Economical and ecological aspects

As presented in *Fig. 1* the building is very undisturbing incorporated in a beautiful green Pohorje mountain landscape. Additionally, timber is a healthy natural material and is consequently particularly desired for sports activities.

Instructions and case study no 13 were prepared by Assoc.Prof.Dr. Miroslav Premrov.