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Realization of the Joensuu Hall – from the theory to the practice

Introduction

This presentation deals with the structural solutions of the Joensuu Hall, the special features of the implementation and the experiences gained from them.

When completed in January 2004, the Joensuu Hall will be the largest wood building in Finland, measuring 150 m in length and 110 m in width. It will have a total surface area of 14,654 m² and a cubical capacity of 262,510 m³.

In addition to ball sports such as soccer, basketball and Finnish baseball, the hall is suitable for track and field events, that is, sports involving running, throwing and jumping. The hall will also be used to organize various mass events such as fairs, concerts and exhibitions. In addition to the multipurpose premises, the hall will feature locker rooms and showers for athletes, a café, office and meeting premises and an auditorium seating 2,000, part of which is movable. The load-bearing structures and much of the interior decoration of the hall are made of wood.

The Joensuu Hall was commissioned by the City of Joensuu, which ordered the hall as a turnkey contract from YIT Construction Ltd (YIT). YIT in turn commissioned the architectural design from Proark Oy, the structural design from Finnmap Consulting Oy (FMC) and the building systems design from Instakon Oy. The contract price of the site is about EUR 10.7 million (VAT 0%).

LENTOKUVA VALLAS OY

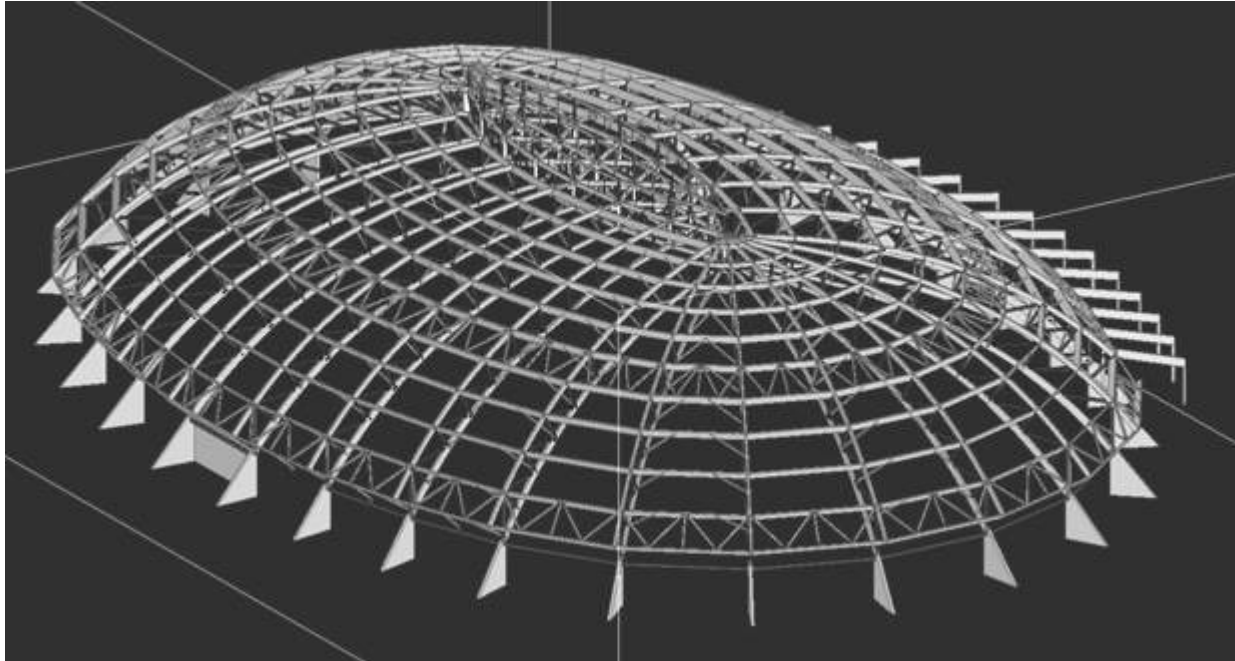


Picture 1: The Joensuu Hall under construction in the autumn of 2003

The structural concept¹

The main structure of the hall is formed of a cross-supporting cupola lying on an oval-shaped base. The main spans of the dome are 145 x 100 meters. As the structure is load-bearing in both of the main axis directions, the forces affecting the individual arcs have been minimized. The height of the top of the cupola is 31 m and the supporting primary structures are glued laminated timber (gluelam) and Kerto-LVL-structure trussed arcs. In their final configuration, these 28 separate arcs function as 2-linked arcs.

FINNMAP CONSULTING LTD



Picture 2: General view of the frame structure

In the middle of the hall the arc-halves sectorially join in a timber-structure space truss construction whose shape is reminiscent of a boat. It creates a dominating visual and structural reference point to the hall, both when viewed from the outside and the inside. The geometry of the central part is similar to that of the edge of the external wall – shaped like an oval – and thus all the main arcs are geometrically similar. In the skylight structure, the load transferring members are positioned diagonally compared with the direction of the flanges of the main arcs.

The secondary structures of the ceiling are gluelam- and Kerto-LVL-structure purlin beams, which are buckling supports with tie struts at the main bend. The fire resistance of the primary structures of the frame is 30 minutes and that of the secondary structures is 15 minutes. In addition, there will be a sprinkler system and mechanical smoke abatement equipment because of the client's demands.

The hinged support points of the main trussed arcs are located about 4.5 meters above ground, and will be connected to in-situ cast concrete walls based on piled footings. The vertical and horizontal components of the resultant arc support loads of approximately 2.5 MN, the obliqueness of the resultant being ca. 45°. Oblique forces on the main arcs will be carried by steel tube piles that are vibrated to a 45° angle. Pile lengths vary between 3-12 m. The joints of the trussed arcs will be made with steel plates and dowels. The joints between the arc blocks will be made using traditional steel joint techniques.

¹ Ismo Tawast. Internationales Holzbau-Forum 4.-6. Dezember 2002

The structure described above contains over 2,000 wood struts, approximately 6,500 steel connectors, 39,000 steel dowels and almost 4,000 bolts. The building will include more than 1,400 m³ of wood structures and about 150 tonnes of steel structures. The boundary dimensions of the main arcs are similar in each of the 28 arcs, but as the forces on the gable end arcs are smaller, the dimensions of the wood struts and connectors have been slightly reduced to correspond to the actual stresses. There are 756 wood struts in the main arcs, 81 of them different in size. The average length of the series is therefore about 9.3; this is a real benefit considering the process of manufacture and costs of assembly and other production considerations.

In addition, the space truss of the middle section features much repetition: There are 230 wood struts, 53 of them are different, and the average length of the series is 4.34.

The force variables of the structures have been calculated using the 3D FEM program in a complete calculation model, including not only the superstructure, but the footings and piles as well. Calculations are done according to the Eurocode 1-3 design rules. Force variables corresponding to different load combinations have been transferred into special calculation applications for wood, steel and foundation structures which were developed by Finnmap Consulting Oy.

Implementation

The prefabrication of the frame began at the factories of the Finnish companies Late-Rakenteet Oy and Finnforest Corporation in December 2003. Once on-site installation works began, prefabrication proceeded in tandem with the works until July, when the last wood elements of the frame were delivered to the site. The delivery of the wood frame elements was divided such that Late-Rakenteet Oy delivered the gluelam sections of the wood frame, that is, the flanges and the purlin beams of the main arcs. Finnforest's delivery included the diagonals of the main arcs and the structures of the space truss.

On-site installation works were started up in March with the wood columns and beams of the service premises. The aim was to roof the service premises as soon as possible, so that the extensive indoor construction works required in these premises could be started up. The wood frame of the service premises was conventional and easy to install.

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Picture 3: Installation of the wood frame of the service premises

The installation of the frame of the hall section began with the assembly of the space truss on top of steel-structure lifting beams in the middle of the hall. Because the plane frameworks were connected with steel bolt joints, this stage resembled the installation of a steel frame. The dimensional accuracy of the elements meant that this geometrically demanding structure could be installed rapidly without encountering dimensional problems. The installation of the roof, outer walls, windows and building systems of the space truss and their painting were also performed on the ground to save on costs and time.

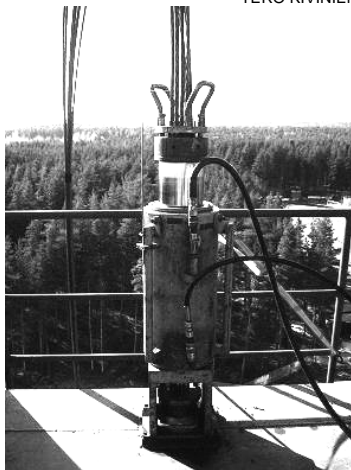
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Picture 4: Installation of the space truss

After the completion of the installation works, the space truss was hoisted onto two support towers using four hydraulic jacks having a hoisting capacity of 120 tonnes each. The load was 55 m long, 11 m wide and about 6 m high and had a mass of about 150 tonnes. Hoisting was halted at a height of about 14 metres to minimize the wind stresses the load was subjected to. However, the achieved height was enough to ensure that the space truss was not in the way of the other installation works. The hoisted space truss was guyed into place with eight steel cables dimensioned to withstand storm winds, that is, winds of over 21 m/s. The use of hydraulic jacks for hoisting proved to be the right choice, because the height of the four hoisting points could be controlled to an accuracy of a few millimetres, and thus the frame was not subjected to additional burdens. The motion of the mobile cranes could have been substantially rougher.

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Picture 5: Hydraulic jack

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Picture 6: Hoisting of the space truss with four hydraulic jacks

The main arcs had to be assembled on-site from three partial trusses with maximum dimensions of about 5 x 17 m². This solution was adopted due to logistical reasons, as the highway transport of larger trusses would have been unreasonably expensive and practically impossible.

The lower ends of the main arcs were supported on the foundations with joints that enabled the truss to rotate during hoisting. This solution was familiar from the design solutions of steel-structure halls. The main arcs were assembled in pairs on support towers and were connected by the purlin structures installed between them. As with the space truss, roofs and building systems were installed in the main arc sections while they were still at ground level.

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Picture 7: Installation of the main arc sections

Upon completion of the preliminary installation works, the space truss was hoisted to its final height of about 31 metres. The hoisting of the main arcs was carried out using a single mobile crane of about 170 tonnes to hoist each section. This made it possible to keep the loads on the wood frame considerably more even than if, for example, paired mobile cranes had been used to hoist each of the sections. Hoisting was performed two sections at a time so that the reaction of abutment on the space truss would be symmetrical after attachment. Before the mobile cranes were detached, the main arcs were “pre-stressed” with hydraulic jacks. This established stresses in the space truss corresponding to the final stress, rather than a tensile load that would have compromised the structures.

The last stage in frame installation was to install the purlin structures between the main arcs as well as the roof structures. The installation of the frame was seen to completion in August, at which point a total of about six months had been used for installation works.



Picture 8: Hoisting of the main arc sections with mobile cranes

Weather conditions – an additional challenge for installation works

The installation of the frame was carried out under very challenging circumstances. During the winter of 2002-2003, the 4.5 m high concrete foundations of the main arcs had to be sometimes cast in temperatures of $-30\text{ }^{\circ}\text{C}$. On the other hand, the summer of 2003 was very hot in Finland, with long periods when temperatures exceeded $30\text{ }^{\circ}\text{C}$.

In spite of the temperature fluctuations, the greatest problem was posed by abundant rain in the tail-end of the summer and in the autumn, during which it turned out to be difficult to protect the large wood trusses. Protecting the joints was especially problematic and in fact water did get into them from time to time. The wet joints made the wood expand and hindered the installation works. Frame drying during the autumn of 2003 had to be performed carefully so that overly rapid drying would not cause splitting in the wood structures. In addition to drying, sections of the wood elements had to be sanded and lacquered to remove dirt and slight dark discolorations.

The ideal conditions for installing a large wood frame would seem to be a dry winter with temperatures of a few degrees below zero.

Measurements play a greater role when building with wood

The measuring of large steel-structure halls culminates in measurements for the positioning of the basic bolts of the foundation. After this is performed, the bolt joints fit into place as a matter of course, and no further measurements are necessary in practice.

In the case of extensive wood frames, joints have to be made within the trusses as well on site. The drilling and doweling of dowel joints at the Joensuu Hall could result in changes in

truss shapes, and thus erroneous measurements were a possibility. Small measuring errors in the joints can recur such that the length of the arc may change by as much as 10-15 cm. Consequently, unlike with steel construction, demanding measurements had to be carried out the entire time while frame installation was ongoing.

The challenging geometry of the frame of the Joensuu Hall posed further challenges, because the hall features practically no straight lines.

Design and production quality

Design inspection process

FMC and YIT carried out an inspection of the structural plans of the Joensuu Hall. The Building Review Department also required an external inspection of the structural plans. YIT commissioned this work from the Technical Research Centre of Finland (VTT).

During the plan inspection process, YIT commissioned, on VTT's recommendation, tensile tests of the joints that were considered to be critical.

The tensile tests showed that the ultimate failure mode of multilayered dowel joints is cleavage fracturing. As a result, it was noted that the tensile capacity of the joints was 30-45% lower than the calculated value.

Once this came to light, YIT, VTT and FMC cooperated on a plan to strengthen the critical joints – in the Joensuu Hall, about 10% were critical. The tensile strength of the strengthened joints was also tested with tensile tests, because the computational method was considered to be too unreliable. Strengthening measures were carried out on site and at the production facilities of the prefab element suppliers in the spring of 2003.

The Finnish Ministry of the Environment was immediately informed of the results of the tensile tests. It drafted an amendment to the national application document ENV 1995-1-1. The Ministry of the Environment also informed the EU Commission of the matter.

Production quality assurance

YIT operates in line with an ISO 9001-certified quality system. Therefore, a quality plan, including a frame manufacturing and installation plan, was also required for the Joensuu Hall site.

The frame manufacture and installation plan was grouped into work plans to be carried out by stage of work as follows:

- quality plan for wood frame suppliers
- quality plan for steel element suppliers
- work plan for the service premises
- work plan for the space truss
- work plan for the main arcs
- hoisting plan for the space truss
- hoisting plan for the main arcs
- work plan for the purlin beam structures
- moisture management and drying plan

Each work plan included a detailed description of the work stage. The plans adopted positions on matters such as the resources to be used, the preconditions for starting up work, material receiving and transfers, work performance, occupational safety, risks, preparing for risks, possible deviations from plans and the quality assurance measurements and records to be made and kept.

Summary

Large wood buildings such as the Joensuu Hall pose a challenge to their builders. Engineering expertise during installation, weather conditions, measurements and quality assurance all play a greater role in the construction of such buildings.

When the aim is to find the cheapest alternative and merely create a functional venue, it is often difficult for wood to compete with steel, for example, as a frame material. Even in the case of the Joensuu Hall, the use of steel instead of wood would have reduced total costs by 5-10%. However, wood buildings have several benefits compared to other materials. For example it's ecological and has a significant aesthetic value that is difficult to measure in monetary terms.



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Picture 9: General view of Joensuu Hall