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Exploitation of repeatability of structures in great Timber Constructions

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Case: multifunctional Hall of Joensuu, Finnland

General:

The city of Joensuu arranged competitive bidding of a turn-key contract for multifunction hall of Joensuu Mehtimäki's sports park on December 2001. Offers for a contract, which were asked from five building contractors, had to be returned on February 2002. The total square area of the hall is about 15 000 m^2 and the gross volume is over 262 000 m^3. In the program of competition was, among other things, supposed that the building has to be timber-framed. According to the principles of a "French contract model", the contract price was regulated in 10.7 millions Euros; technically and functionally best solution would be the winner. In addition to the representatives of the city of Joensuu belonged to the valuation group also specialist members from fields of architecture and building arts, structural engineering and timber construction engineering as well as building techniques.

YIT Corporation was one of the building firms, which got the bid for a contract. Finnmap Consulting Oy was asked for YIT:s specialist in structural engineering. The other members of the design group were the architects' office PRO-ARK Oy, Helsinki, and the engineering office Instakon Oy, Vantaa, which took the responsibility for the HVAC-design.

Oval form was the core of competitive phase's design. In the very beginning of the competition a decision was made to examine some static structural models, functioning perhaps in totally different ways. The objective was, by making a reasonable amount of preliminary static calculations, to choose one of them deliberately, one that is clearly better than the other ones. The aim was also to get better and divergent construction solution than the other competing groups. Already in this early phase an oval dome structure was chosen; that seemed to be at the same time economic and tenable both from structural and esthetic point of views.

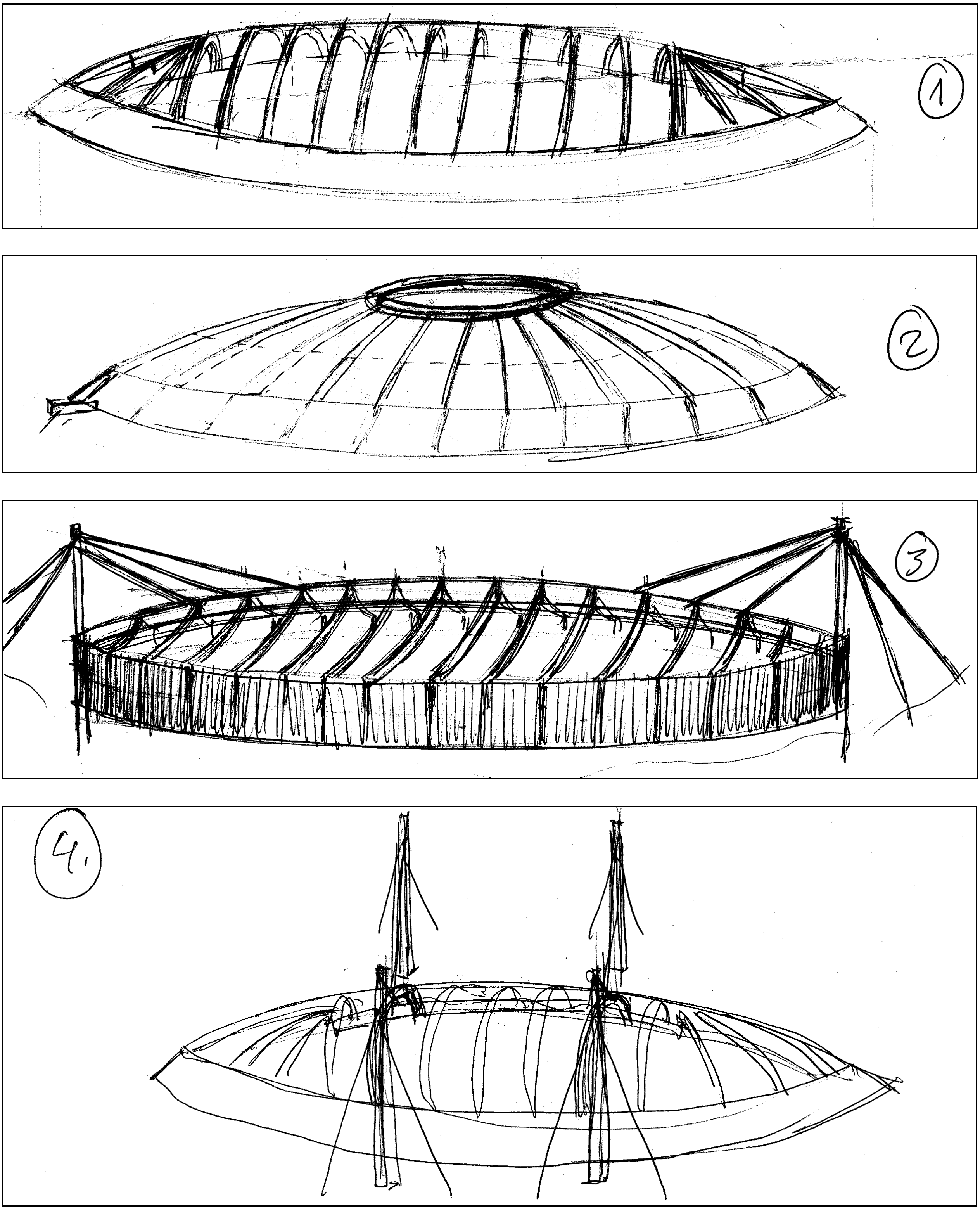

Figure 1: 4 First phase structural model sketches of the competition (Finnmap Consulting Oy)

Figure 2: Observing picture from inside of the hall (PRO-ARK Oy)

Due to the very tight cost limit and competitive phase's limitation of time available was it assumed, that probably part of the competing alternations would be based at least partly on cylindrical arc systems. Because this cross section seemed to be very cost-effective, a new target was set to find for the chosen oval dome consept as a convenient solution as possible. Cost savings were accomplished by means of erection techniques, optimization of structural dimensioning and, in particular, repeatability of structural elements.

The result of the competition:

The city of Joensuu chose above presented oval dome as a base concept to further design. Building contract between Joensuu City authorities and YIT Corporation was signed on 04.th June 2002. Implementation planning of the hall and also preparation of construction were started immediately, and construction work on site started 12.th August 2002.

The structural idea:

The main structure of the hall is formed of a cross supporting cupola laying on an oval formed basis. Main spans of the dome are 145x100 meters. As the structure bears in the both main axis directions, the forces effecting on the individual arcs has been minimized. The height of the top of the cupola is 31 m and the supporting primary structures are glued laminated timber and/or Kerto-LVL-structured (1) trussed arcs. In the final position these 28 separate arcs function as 2-linked arcs.

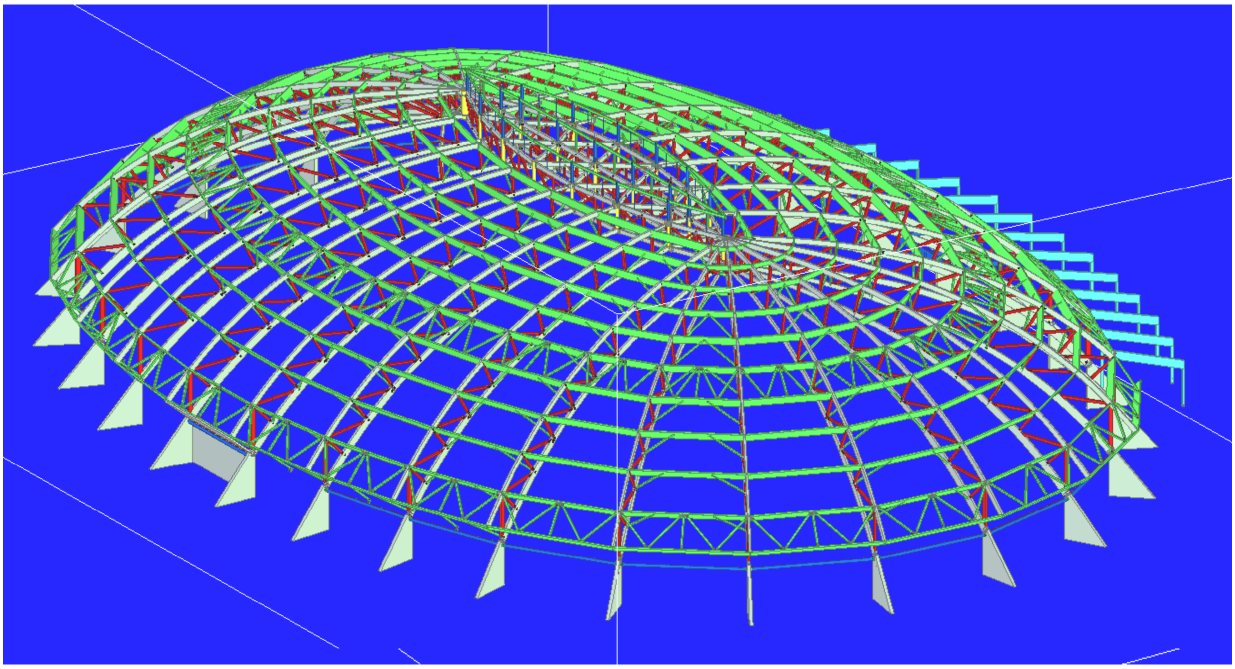

Figure 3: Observing picture of the frame structure (Finnmap Consulting Oy)

In the middle of the hall the arc-halfs sectorially join in a boat-reminding, timber structured space truss construction. That creates a dominating visual and structural reference point to the hall as well from outside as from inside. Geometry of the central part is alike edge of the external wall, the form of oval, hence all the main arcs are geometrically similar. Boundary dimensions of this central block are about 55x11 meters, total height of the block exceeds 6 meters. In the skylight structure the load transferring members are located diagonally compared with the direction of the flanges of the main arcs.

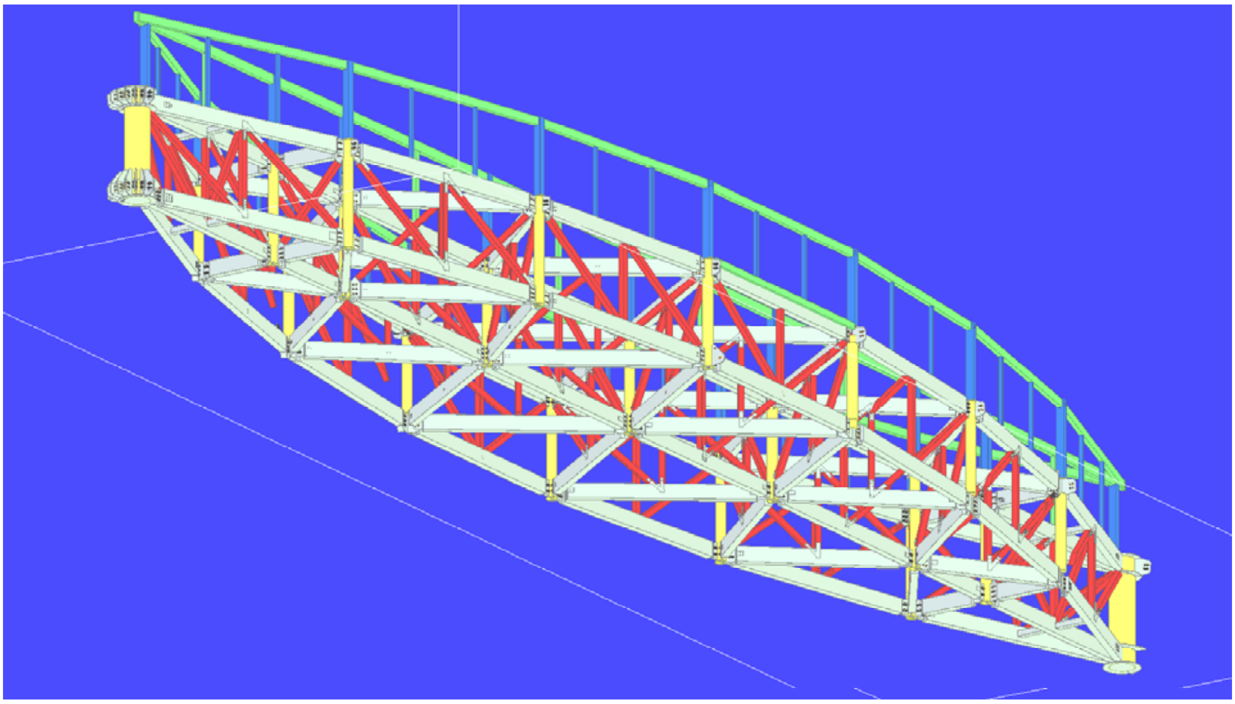

Figure 4: Observing picture of the Skylight Truss Block (Finnmap Consulting Oy)

Secondary structures of the ceiling are glued laminated timber and/or Kerto-LVL-structured [(1)] purlin beams, those who are buckling supports with tie struts to the main bend. Fire-resistance of the primary structures of the frame is 30 minutes, secondary structures 15 minutes. In addition to this there will be a sprinkler system and mechanical smoke abatement equipment because of the client's demands.

Hinged support points of the main trussed arcs are located about 4.5 meters above ground, and will be connected to at site concreted walls that are based on piled footings. Vertical- and horizontal components of the resultant arc support loads are approximately 2,5 MN, the obliqueness of the resultant being ca. 45°. Oblique forces of the main arcs will be carried by steel tube piles, that are vibrated to 45° angle. Pile lengths vary between 3-12 m. Joints of trussed arcs will be made by steel plates and -dowels, joints between arc blocks will be done by traditional steel joint techniques.

Design methods:

Force variables of structures have been calculated by using 3D FEM-program (Algor) in a complete calculation model including not only the superstructure, but the footings and piles as well. Calculations are done according to the Eurocode design rules. Force variables corresponding to different load combinations have been transferred to special calculation applications for wood-, steel- and foundation structures, developed by Finnmap Consulting Oy. Despite of the very requiring geometry and numerous load combinations have all structural parts been able to be dimensioned without any manual data transfer from one program to another. Optimization of structural members and minimizing human mistakes have been achieved by means of automatization and speed of numerous repeated counting routines. Dimensioning application of wood structures contains also design routines for doweled joints, so the connecting plates and dowel amount have effectively been optimized.

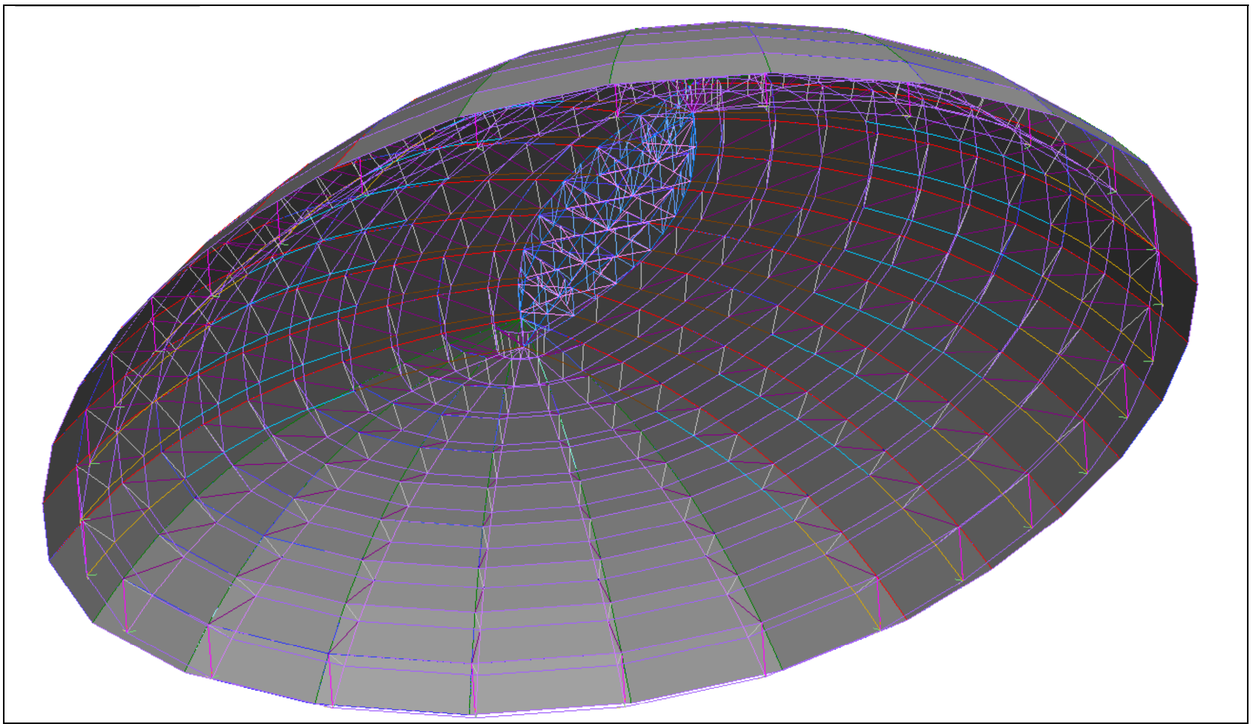

Figure 5: Algor-calculation model

Timber constructions including the connectors have been designed with the 3D modelling application X-Steel. Originally this program has been developed for producing engineering workshop drawings of steel structures, but as material independent it fits fine also for modelling of great timber consructions, especially, when these often contain a great number of steel structured connectors. Finnmap Consulting Oy has at this moment 17 program licences and experience also from earlier modelling tasks of timber constructions, so the choice was with this in mind quite easy. Benefit of 3D modelling systems is ability of producing observing-, line-, plan-, detail-, preform-, subassembly- and all the other drawings necessary in manufacturing and erection from the very same model. Small amount of macros of timber joints is a defect, improvements to this lack are welcome in the coming software packages.

Manufacturing- and erecting principle of the frame structure:

As well the main arcs as the central skylight structure will be assembled from factory-made plane frameworks to erecting blocks on site. Skylight space truss integrates the first erecting block, which will be lifted with two supporting towers up to approximately 6 meters height. After that assembling of trussed arcs will be continued, one end of the arc-halfs supporting on the wall, the other (upper end) resting on the ground. Two parallel arc-half couples always form one erecting block into which secondary parts, roofing base, roofing and also HVAC-installations will be assebled on the ground. When arc blocks have been pre-assembled, the Skylight truss structure will be lifted to its final erecting position, and lifting of arc blocks will be started by lifting upper ends of the blocks by turns from the opposite sides of the central longitudinal axis of the building. When all the blocks have been erected, adjusting parts of engineering workshop joints will be grouted and structures as well as HVAC-installations of intermediate spaces will be assembled.

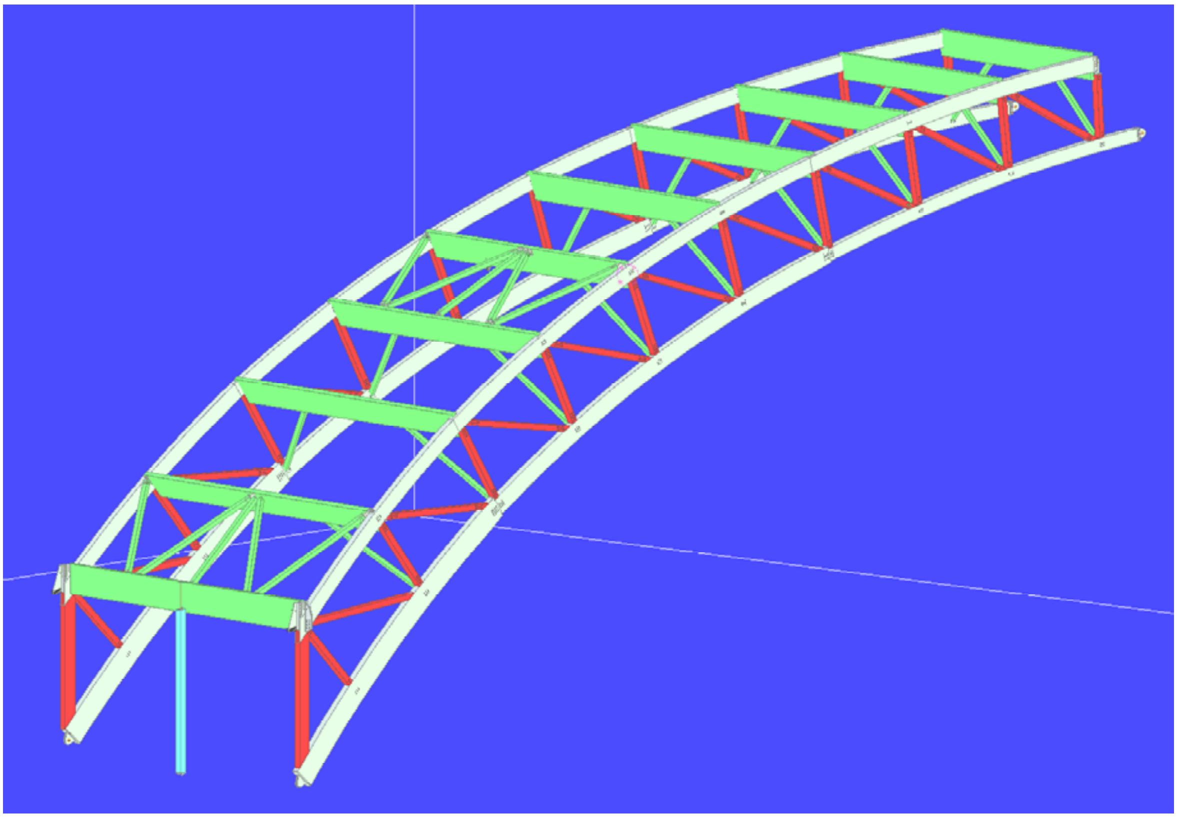

Figure 6: Pre-assembled erecting block (Finnmap Consulting Oy)

Exploitation of repeatability in frame constructions:

Above described structure contains over 2000 wood struts, approximately 6500 steel connectors, 39 000 steel dowels and almost 4000 bolts. The building will include more than 1400 m^3 wood structures and about 150 tons of steel structures. Boundary dimensions of the main arcs are similar in every 28 arcs, but as the forces of the gable end arcs are smaller, are also the dimensios of wood struts and connectors some reduced, corresponding the actual stresses. There are 756 wood struts in the main arcs, 81 of them are different on size. The average length of the series is therefore about 9.3, that is an absolute benefit considering process of manufacture and costs assembly and other productions.

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

Benefits of repeatability:

In this project repeatability has facilitated significantly manufacturing of wood and steel parts from subcontracting in wood engineering workshops and erection on site. Assembling of similar parts is faster when erection phase becomes familiar with repetitions. Repeatability is able to give strait savings in delivery of finished parts, because then the series of products is longer. For the same reason possible errors of erection phase are able to be avoided.

Benefits of a structural solution that is based on repeatability also recur in the substructures of the main arc; also those are identical with each other: 28 abutment walls with foundations make a massiv concrete placing contract where working routines are able to be repeated in production of 27 following supporting structures once practising. In addition to cost savings the quality of the product will improve and the time of construction will get shorter.

(1) supplier of the timber products have not yet been selected during the writing process of this text