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Design and Construction of Kupolen Exhibition Hall and Sports Arena

Conception et construction de la salle d'exposition et de sport de Kupolen

Entwurf und Bau der Ausstellungs- und Sporthalle von Kupolen

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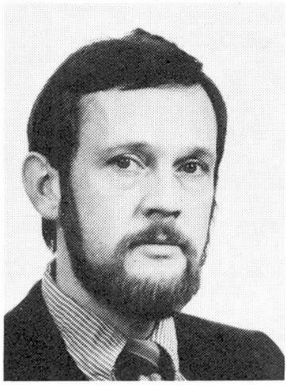

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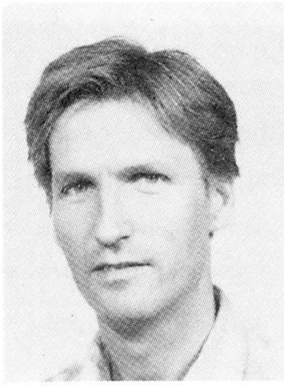

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SUMMARY

This article describes some of the interesting features of a multi-purpose project containing a huge dome structure with a free span of 123 m. The construction of the dome was done using an innovative construction process using no false work or other temporary framework. The dome has a rather great slenderness ratio. The article describes some of the special problems, such as the large amounts of snow avalanching from the sides of the dome.

RÉSUMÉ

L'article présente quelques aspects intéressants d'une installation à usage multiple, dont les particularités d'une structure géante en forme de coupole de 123 m de portée. La mise en oeuvre s'est déroulée selon une méthode novatrice, sans recours à un échafaudage ou autre support temporaire quelconque. Les auteurs soulignent le remarquable élancement de la coupole, et présentent des problèmes spéciaux tels que celui du glissement possible d'importantes masses neigeuses de la surface courbe.

ZUSAMMENFASSUNG

Es werden einige interessante Aspekte einer Mehrzweckanlage beschrieben, die als Kennzeichen ein riesiges Domtragwerk mit 123 m freier Spannweite enthält. Der Bau wurde in einem innovativen Vorgehen ohne jegliches Lehrgerüst oder anderer temporärer Unterstützung errichtet. Der Dom besitzt einen bemerkenswerten Schlankheitsgrad. Unter anderem werden spezielle Probleme angesprochen wie die grossen Schneemengen, die vom Dom abgleiten können.

1. Project

Kupolen in Borlänge, situated about 250 km north-west of Stockholm, Sweden is a result of an idea that came up during discussions between the town of Borlänge, an exhibition arranger and the real estate developer and contractor Siab. Their common interest was to combine the towns need for an indoor sports arena at a low cost, the arrangers need of a larger exhibition space an the developers interest for a real estate development. In exchange for the building rights for the Kupolen project and also some other building rights, the town got their sports arena large enough to contain a soccer plane with full international size and with 3000 seats. **Figure 1** shows two perpendicular sections through the project and **Figure 2** gives an impression of the finished structure.

The 7000 m^2 floor area of the main floor can also be used for large exhibitions, **Figure 3**, with a back up area 5000 m^2 for lounge, conference centre etc. To complete the project and to help financing the project, it also contains a 15000m^2 shopping mall under the main floor, a hotel and an office block with 4 stories. These 2 buildings are both situated under the cupola and along the long sides of the sports area but with no structural connection to the dome. The Kupolen sports and exhibition hall was constructed in 1989.

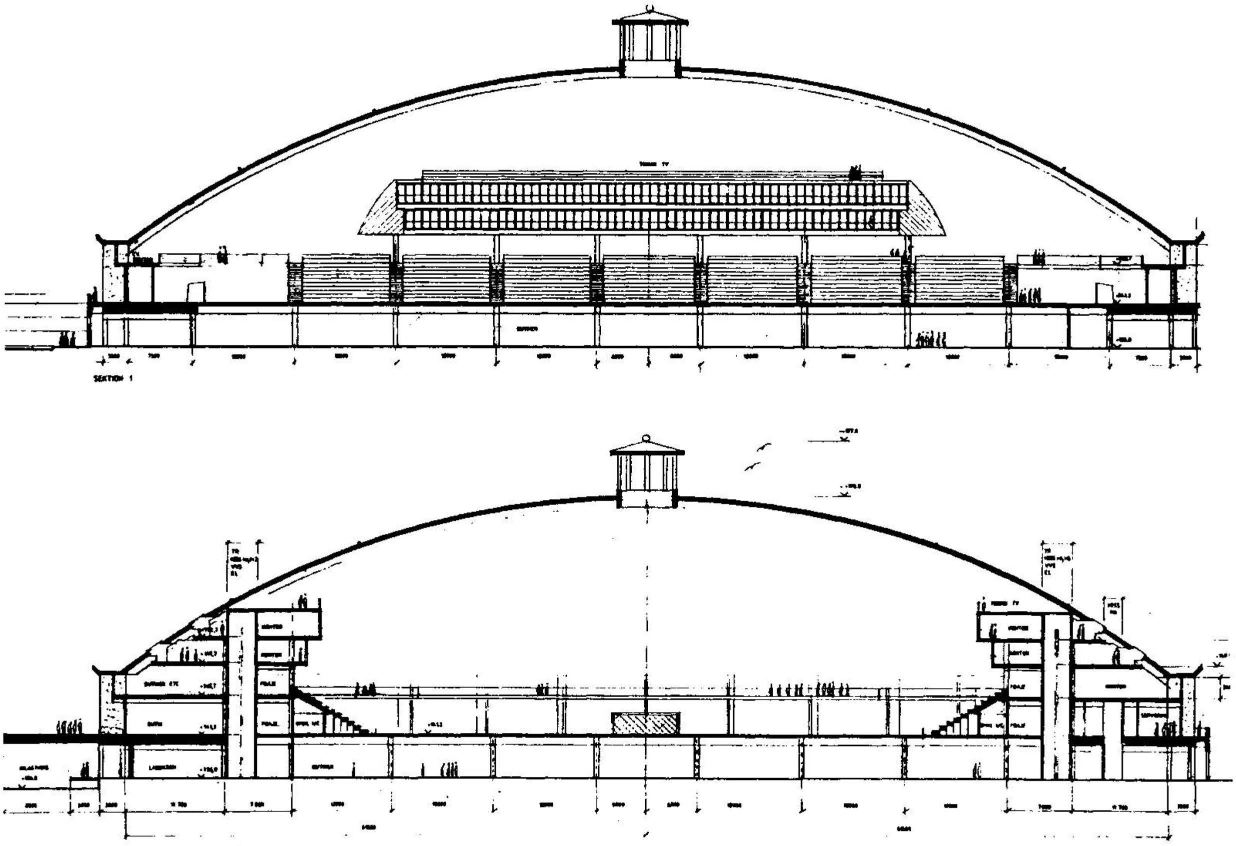


Figure 1 A longitudinal and a transversal section through the project.

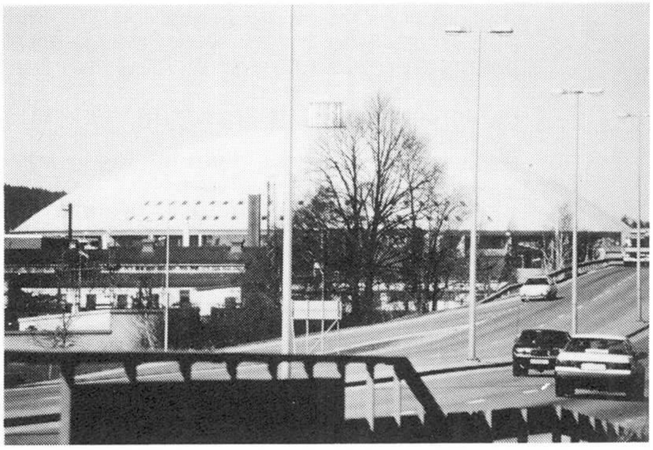


Figure 2 Outside view of the dome.

Figure 3 Inside view of the dome.

2. The dome

2.1 Structural design

The dome structure is supported by 40 generously proportioned columns. On top of the columns there is a post tensioned ring beam. The effective area of the ring beam is about $1 m^2$ and the effective tension force is approximately 10 MN. The length of the ring beam is about 400 m. The tension system used is 6 cables each with 12 0,6" strands and with lengths of about 90 m. They were set out two by two with displaced joints. The form work for the ring beam situated about 7 m above the main floor area was done using prefabricated curved shell concrete elements. These structures that form a part of the final ring beam were completed with reinforcement and cables before placing the concrete, see **Figure 4**.

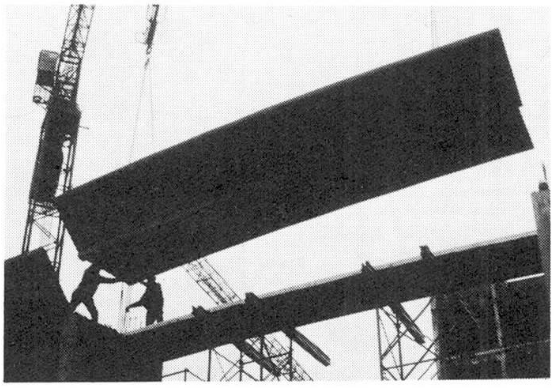


Figure 4 The ring buttress beam was constructed using prefab shell elements also forming the water drainage system.

The actual cupola structure is made up by steel beams forming a Schwedler dome. The total thickness of this structure is just 350 mm and all beams were made using welded H-beams. Since the circumference is approximately 400 m the distance between the main beams is 10 m the first turn. The ring structures are also made up using welded steel H-beams and were placed with a distance of about 6 to 7 m. Diagonals made up with hollow square welded steel pipes completed the net of the dome. The thickness of the plates forming the beams were varied from thick close to the buttress to thinner closer to the top to take account of the variation of moments and forces.

One reason for choosing such a thin structure is that there are many windows belong to the hotel and the office block in the cupola. The schwedler net of beams were covered by elements made up of thin steel box sheeting and plywood. The elements were complete containing insulation and had a bottom perforated corrugated steel sheeting for noise absorption. The element had prefabricated roof topping of white Sarnafil rubber coating.

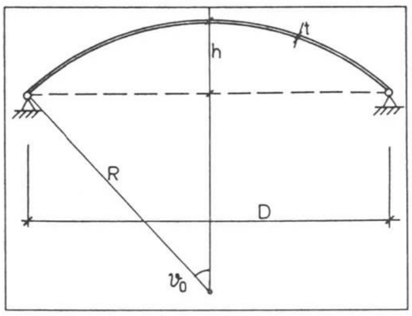


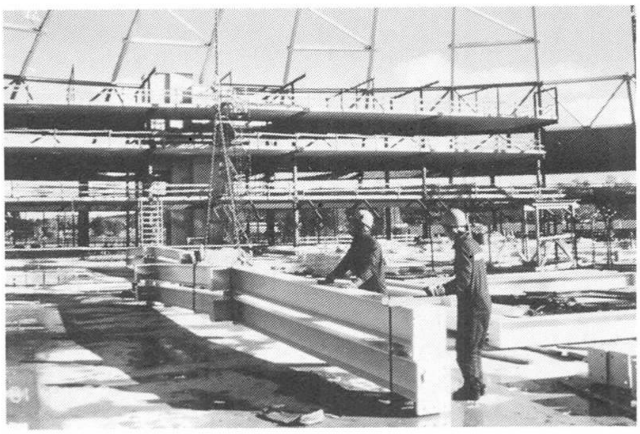
Figure 5 Measures for the structure. R = 100m, D= 123 m, h = 21m and t_{eff} = 80mm.

The radius of curvature of the structure is 100 m and the free span is 123 m. The stiffness of the finished structure could be calculated having a equivalent thickness of 80 mm leading to an slenderness ratio (R/t) of 1250 for the shell, (**Figure 5**). The structure were calculated for different symmetrical and non symmetrical snow and wind loading combinations both using standard simple hand calculations and second order FEM analysis using a system with more than 10000 degrees of freedom. The structure is also calculated to be able to carry point loads in different combinations from the exhibition in the joints. The structure is also controlled for the accidental situation were one main beam has been taken away.

2.2 Method of construction

The dome structure is made up of 1140 beam elements. Due to the geometry of the system chosen, it was possible to reduce the amount of different elements to only 32 different types. Between the joints all beams are straight, so all changes in angels are made at the joints. The elements are screwed together using high strength frictional bolting mainly with end plates at right angels to the direction of the beams.

The erection of the dome was done using no false work or other temporary strutting. First were elements containing two main beams with length approx. 12 m and the ring and diagonal beams between these two erected from the concrete ring beam, **(Figure 6)**. After all elements of the first turn and the ring beams connecting these had been erected the second turn was erected from the first, **(Figure 7)**. The method used, was like constructing a snow igloo. Directly after one turn was completed it was covered by the roof elements.



Figures 6 and 7 Method of construction.

3. Structural system for the lower floors and the foundation

3.1 Framework

The main floor of the building is cast in situ concrete using a new method for composite action between steel sheeting form work, steel beams and concrete. The system allowed the need for very little strutting of the form work despite that the columns had the spacing of $12*12\ m^2$. The floor is designed to carry 54 ton lorries.

On this floor were cast the 40 columns carrying the ring beam that founds the base for the dome structure.

The office and hotel blocks was constructed using steel framework and pretensioned hollow core slabs. These structures have there own framework and have no structural connection to the dome.

3.2 Foundation

The soil strata underlying the project consists of silt to great depth, more than 50 m. Piling was considered but should have been very costly due to the great depth to the rock. Although the soil investigation showed the risk for rather great both total and differential settlements, a continues concrete footing was chosen. The risk for differential settlements was great, due to the existing ground slope of about 5 m from one end to the diagonal end of the building. Vertical drainage in combination with surcharge loading was recommended in the soil investigation report for compacting the upper layers of the silt, but the time needed for this operation was to short due to the tight schedule of the project. An other problem was the risk for water upheaval during excavation because the ground water table was just a few meters below the excavation level. The final solution chosen was the installation of vertical sand drains with centre distances of 12 m to a depth of about 10 m the minimise the pore pressures and to use a very careful and well planned method for excavation. The excavation started in the low end allowing the water to drain out in ditches with a centre distance of 12 m. The ground was directly cowered with fibre texture and a rather thick layer of gravel carried out by crane. After compacting the gravel, the concreteing of the concrete slab started. The bottom slab with a minimum thickness of 250 mm and a thickness of 850 mm under the columns has no contraction joints and is accordingly constructed in one piece $135*150m^2$. The structural design of the foundation slab is by assuming the ground acting as an elastic media with point loads from the columns spread out by the elastic slab.

4. Special problems

4.1 Acoustics

The sports arena is for multi-purpose use so it could also be used for concerts and other musical events. Since the office and hotel blocks are situated inside the dome but structurally independent, it was a difficult task to design the sound insulation between the dome structure and the wall of the above mentioned buildings. Also the windows directed into the exhibition hall had to be insulated for high noise levels.

An other interesting problem has been detected when there are heavy pop concerts in the Kupolen. At a few times the whole building including soil strata below has come into slow vibrations. These vibrations have not caused any problems but have been noticed in buildings close to the project.

4.2 Fire protection

Only the part of the steel structure close to the inside buildings have been fire protected using fire protection painting. Thorough investigations have shown that the temperature of the main part of the dome could not reach dangerous temperature levels.

4.3 Snow problems

In the wintertime the Dalkecarlia area has lots of snow. The large area of the dome collects lots of snow and there is a risk that the snow is avalanching down with high speed from the dome and can be a problem for all the people visiting the sports arena and the shopping mall. The snow precautions are made up first by rings of steel wires allowing the snow to come down in small flakes and also reducing the speed. As a second and hopefully final stop the concrete buttress ring is formed with a 3m wide and 1 m deep snow and rain drainage canal, see **Figure 4** . The drainage canal is at the outer edge completed with a snow stopping fence. The canal is also fitted with heating. Despite all these precautions there still has been snow coming over the edge when the canal is filled over the fence and the weather is so cold that the heating could not melt the snow.