A NEW ROOF FOR THE OLYMPIC MUSEUM AT LAUSANNE, SWITZERLAND

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Abstract

Within the works for upgrading and extending the Olympic museum at Lausanne (Switzerland) a new roof has been built to cover the existing building (finished in 1990). The new roof acts also as an unusual canopy, shading natural light in the south part of the building. It is composed of a grid of beams cast in ultra-high performance fibre reinforced concrete (UHPFRC). A comparison to other options (timber and aluminium members) has proven the UHPFRC solution to be the most competitive accounting for all requirements of the structure (economy, durability, easiness of construction, architectural expression, weight and construction details). Long lengths of the beams (up to 21 meters) have been obtained by assembling shorter members by using the match casting technique in combination with post-tensioning. In addition, the use of UHPFRC has allowed manufacturing durable elements, despite the limited thickness used and the high slenderness of the beams

Résumé

Dans le cadre de l'agrandissement du Musée Olympique à Lausanne (Suisse), une nouvelle toiture a été construite sur l'ancien bâtiment réalisé en 1990. La structure de cette toiture, fonctionnant aussi comme brise-soleil sur sa partie sud, est une grille de poutres en béton fibré à ultra-hautes performances. Une comparaison avec d'autres options (bois lamellé-collé, aluminium extrudé) a démontré que ce matériau peut être intéressant si tous les aspects sont considérés (économie, durabilité, facilité d'exécution, aspect architectural, poids et délais d'exécution). Des éléments de grandes dimensions (longueurs jusqu'à 21 m) ont pu être réalisés en assemblant des éléments plus courts par la technique des joints conjugués et de la précontrainte par post-tension. En outre, le BFUP permet de réaliser des éléments durables malgré leurs faibles dimensions transversales et leur élancement.

1. THE OLYMPIC MUSEUM AND HIS NEW ROOF

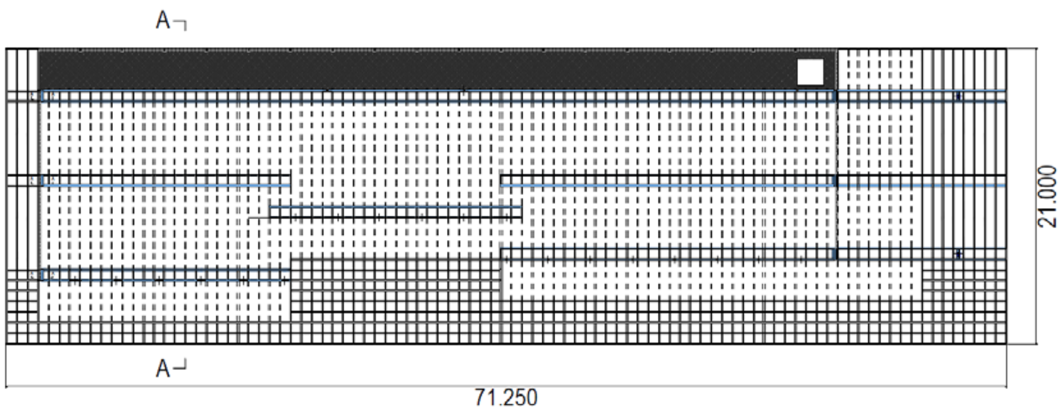
The Olympic Museum was built in 1990 at the shores of the Lake Geneva (Lausanne) and has become its most visited museum. It was decided to be upgraded and extended due to the high number of visits per year and accounting for a number of new requirements for museums. Within these works, it was planned to build a new roof over the existing terrace to host a new restaurant. On its south part, the new roof acts also as a canopy, shading natural light. The new structure covers the part of the building facing the lake with a total length of 71.25 m and a width of 21.00 m (figure 1). The works were started in January 2012 and finished in September 2013. During this period, a part of the museum exhibition was hosted in a boat moored at the shore of the Lake Geneva in front of the museum.

a)
b)
c)

Figure 1: a) South facade of the Olympic Museum and new roof during construction, b) view towards the lake, and c) view of the canopy

2. STRUCTURAL SYSTEM

The structure of the roof is composed of a regular grid of beams. In the transverse direction, the beams have a length varying between 18 and 21 meters. They are 1.00 meter height and are spaced at 0.75 m. These beams are suspended to steel girders covering the 71.25 m length of the roof. The steel girders are supported on concrete walls and steel columns. In the south part, facing the lake, the transverse beams have cantilevers ranging from 4.50 m to 9.00 m (figure 2). The north part over the restaurant and some regions at the south part are covered by a steel sheet with trapezoidal shape ensuring lateral stability. This steel sheet is replaced at the outermost south regions by longitudinal stiffeners spaced at 0.75 m and with a height of 0.535 m supported on the cantilevers and acting as diaphragms (opposing to lateral instability of the transverse beams). Accounting for the fact that the cantilevers are exposed to the environmental conditions at the south part, a joint has been provided close to the south façade for thermic insulation purposes. This joint transfers shear and bending moments of the transverse beams, which are maximum at this region. Some of the transverse beams have a length of 21 meters without joints. The others are not continuous (presence of the thermic joint), have inner spans ranging from 9.00 to 13.50 meters (figure 2) and are followed by the cantilever region.



a)
b)

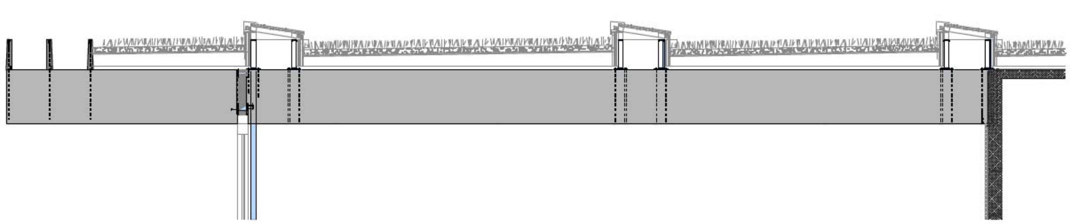


Figure 2: a) plan view and b) view of a transverse beam with a span of 13.50 m and a cantilever of 4.50 m (cross section A-A in plan view)

3. SELECTION OF MATERIALS

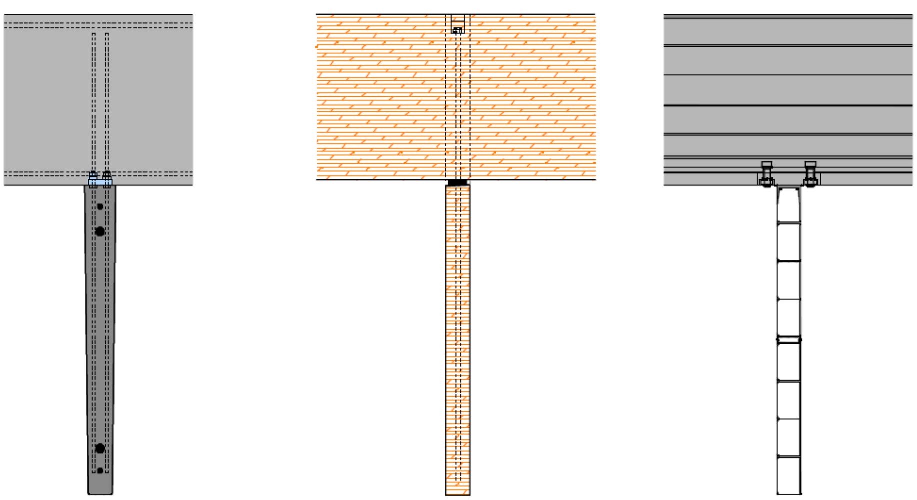
During the design of the structure, several options with respect to the material to be used for the roof were investigated (Figure 3).

3.1 Beams cast with ultra-high performance fibre reinforced concrete (UHPFRC)

In this option, finally selected to be built, the transverse beams and longitudinal stiffeners were cast in UHPFRC. The beams were precast by a specialized manufacturer, then moved to the construction site, erected and assembled with post-tensioning tendons. The transverse beams were 1000 mm high and the longitudinal stiffeners were 535 mm high. All sections were trapezoidal-shaped with web thicknesses varying between 80 and 100 mm. The advantages of this option were the excellent durability and the use of simple and efficient construction details. In addition, the appearance of the beams was in good accordance with the white marble facades. The most significant drawback of this solution was the need of arranging thermic joints in the most stressed regions (clamping of the cantilever between outer and inner parts of the building).

3.2 Timber construction

The members were designed and resulted in similar dimensions as the UHPFRC solution (the only difference being a constant web thickness of 80 mm). The advantages of this solution were the low production cost, a very limited weight and the possibility of avoiding thermic joints. The assembly details of the inner parts of the structure were also quite simple. However, the exterior region (exposed to environmental conditions) would have required top protection with metallic sheeting and relative complex assemblies. In addition, durability was notably lower than for the other options and maintenance costs could difficultly be avoided. The timber could have been protected with chemical treatments, which was problematic from an ecological point of view, and other protection means revealed as insufficiently reliable.



a) b) c)

Figure 3: Cross-section of the transverse beams and view of the longitudinal stiffeners for the three investigated options: (a) ultra-high performance fibre reinforced concrete, (b) timber beams and (c) extruded aluminium profiles

3.3 Structure in extruded aluminium

Profiles of about 600 mm high and 21 meters long could have been easily extruded in aluminium. Due to this reason, the transverse beams should have been connected by longitudinal welding of the two extruded profiles (Figure 3c). The sections were optimized working in cooperation with a specialized manufacturer, leading to an interesting economy of materials and to simple assembly details. Aluminium was very unfavourable from a thermic point of view and thermic joints were required by this solution. This problem could have been solved by combining aluminium profiles in the outer regions and timber beams in the inner regions. Finally, this solution was abandoned due to excessive cost and lack of experience of the construction companies in assembling and finishing this type of structures.

3.4 Selected option

Other options were rejected during the conceptual design for various reasons, accounting for economic aspects (both production and maintenance), technical reasons (complexity of construction details), construction technique (easiness of construction and limited construction time), durability issues and/or architectural needs. Thus, the UHPFRC was finally selected. The longitudinal beams (where the transversal UHPFRC beams were suspended) were manufactured in steel. This was justified by the very large efforts in some regions and the possibility of incorporating air-conditioning piping within the hollow profiles (Figure 2).

4. PRECASTING, ERECTION AND DETAILING

The UHPFRC members were precast in a specialized factory located at 80 km from the construction site. In order to enhance the easiness of demolding (figure 4a), the cross-sections of the beams were trapezoidal with varying thicknesses between 80 and 100 mm. Due to the slenderness of the members, and to improve transportation and erection of the beams, the beams with a total length of 21 meters were fabricated as two pieces of 10.50 m each (figure 4b). These pieces were later assembled at the construction site by means of the match-casted joints and post-tensioning (monostrand) tendons (figure 4c). For the other beams, the thermic joint was used as match-casted joint (figure 5c). This joint was composed of two tubes in stainless steel where the two monostrand tendons were located (in the tension side of the member). These tubes, together with the ducts, were injected with mortar after post-tensioning of the strands. In the bottom side, the compression forces are transferred by means of welded stainless steel plates.

Assembling the transversal beams and longitudinal stiffeners was made by means of stainless steel plates fixed to the longitudinal members prior to concreting (figures 5a and 5b). During erection, the plates were bolted to the transverse stiffeners (by means of nuts screwed at bolts partly cast outside the concrete of the transverse beams, figure 4d). The same detail was used to suspend the transverse beams to the longitudinal steel girders (figure 5c).

The flexural strength of the transverse beams is ensured by the post-tensioning strands. Transverse and longitudinal bars were also placed to ensure correct placing of the duct. In addition to this reinforcement, vertical bars were also arranged to fix or to suspend the beams (figures 5a and b).

a) b) c) d)

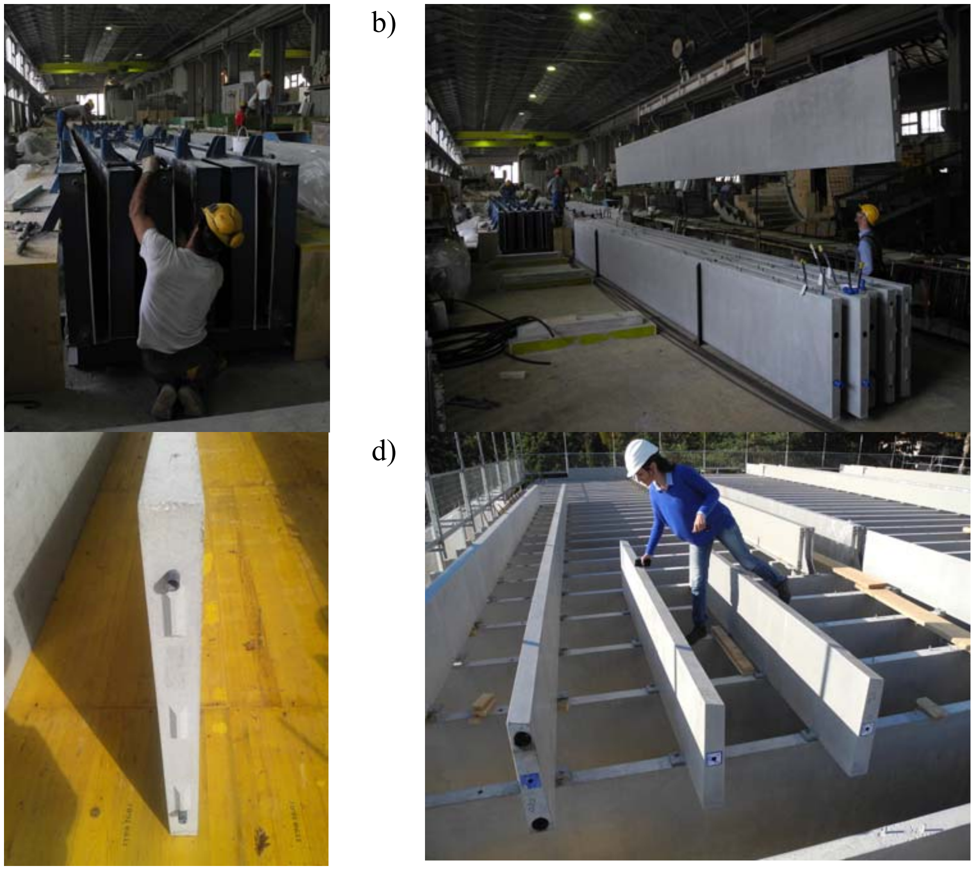
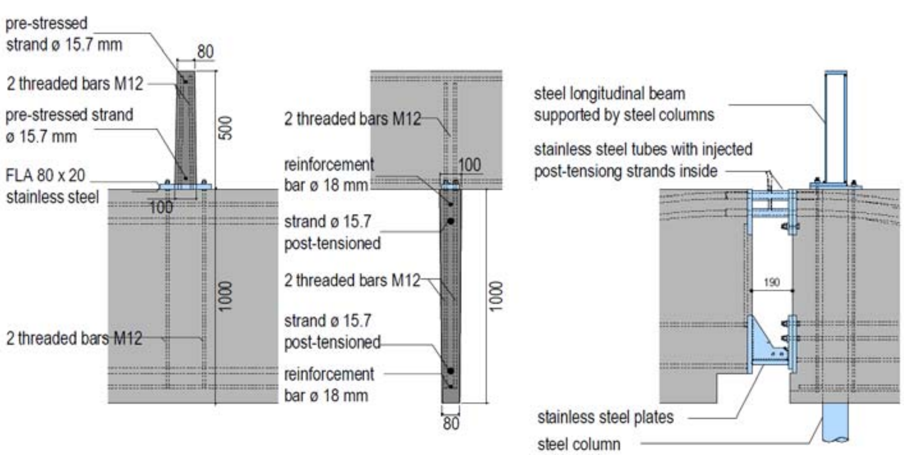


Figure 4: a) arrangement of steel formwork, b) handling of the 10.50 m elements, c) match-casted joint for the 21 meter beams and d) erection of longitudinal stiffeners over the transversal beams



a) b) c)

Figure 5: a) and b) detail of joint between longitudinal and lower transversal beams and c) detail of thermic joint and of the suspension of transverse beams to the steel beams

The longitudinal stiffeners have the same thickness (80-100 mm) but have a lower height (535 mm) and their length varies between 3.00 and 12.00 m. They were cast in the same manner and the bending strength of the longest members was ensured by means of two strands prestressed in factory before pouring.

5. UHPFRC PROPERTIES AND DESIGN CRITERIA

The « béton spécial industriel » (BSI® with 200 kg/m^3 metallic fibres, l_f = 20 mm, ϕ_f= 0.3 mm [1]) was used for all members with UHPFRC. No thermal treatment was applied after concreting. The quality of concrete was controlled by compression tests on 100x100x100 mm cubic specimens concreted and tested at different ages (figure 6) and by tension tests on 12 specimens (drilled cores from one specimen ϕ = 50 mm, ℓ = 200 mm), 8 prisms (90x90x400 mm) sawn from the same element (4 in the vertical and 4 in the horizontal direction) and 4 cast in place. The prisms were tested under 4-point bending and the results were interpreted according to [2].

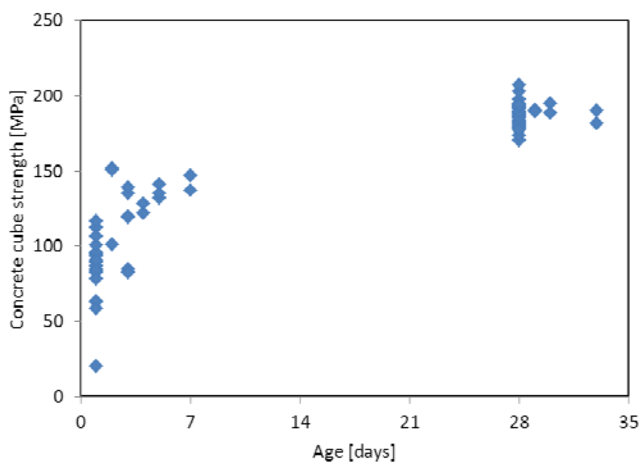


Figure 6 : Compressive strength measured on 100x100x100 mm cubes as a function of the concrete age

The tests have shown a relatively low scatter with respect to the concrete compressive strength at 28 days (average value equal to 188 MPa, standard deviation equal to 9.8 MPa for the 58 specimens tested at 28 days) and the tensile strength of the cement matrix (between 8 and 12 MPa). The behaviour after cracking was however more scattered. This is essentially due to the relatively inhomogeneous distribution of fibres and to the influence of the reinforcement (constructive bars, rods, post-tensioning ducts of the transverse beams and pre-tensioning strands of the longitudinal stiffeners) on their orientation.

Due to this reason, the ordinary and prestressed reinforcement have been designed according to classical design methods so that they ensure carrying all the tension forces at ultimate due to bending, shear and in-plane spreading of concentrated forces (anchorage forces of post-tensioning tendons and forces of the structural elements at the thermic joints). The contribution of the fibres enhances (and was considered) in the bond properties of concrete and to ensure the strength of the out-of-plane spreading of the concentrated forces.

The very high compressive strength was required in order to keep the dimensions very limited despite the significant concentrated forces (anchorage of tendons and thermic joints, see figure 5c).

In order to avoid lateral instability of the thin and slender beams, all supports were arranged on bottom of the longitudinal steel beams and the rods used to fix them to the longitudinal elements were designed accounting for the potential second order effects.

10. CONCLUSIONS

A detailed study of structural solutions for the new roof of the Olympic museum has allowed comparing a solution in ultra-high performance fibre reinforced concrete (UHPFRC) to others in timber and extruded aluminium. The timber and aluminium solutions were finally not selected due to a number of reasons. This study has demonstrated UHPFRC to be an interesting material for building roofs under demanding conditions. In addition, the UHPFRC allows producing durable elements despite thin dimensions and high slenderness. Nevertheless, it is still to be checked if the amount of fibres can be reduced accounting for the fact that for members with relatively significant dimensions, placing of ordinary or prestressed reinforcement is unavoidable to ensure the strength for the acting internal forces.

11. TEAM AND OTHER DATA

Client:	CIO, Comité International Olympique, (Lausanne, Switzerland)
Structural design and engineering:	Muttoni & Fernández ingénieurs conseils SA (Lausanne-Ecublens, Switzerland)
Architecture:	B+W architecture sarl, Ueli Brauen + Doris Wälchli (Lausanne, Switzerland)
Precast elements manufacturer:	MFP Préfabrication SA (Marin-Epagnier, Switzerland) and Dénériaz SA (Lausanne, Switzerland)
Material supply and technical assistance:	EIFFAGE TP - Département BSI® (Neuilly sur Marne, France)
Steel elements manufacturer and erection:	Stephan SA (Fribourg, Switzerland)
Prestressing:	Freyssinet SA (Moudon, Switzerland)

REFERENCES

[1] EIFFAGE TP - Département BSI®, « Carte d'identité du BSI »

[2] Baby, F., Contribution à l'identification et la prise en compte du comportement en traction des BFUP à l'échelle de la structure, PhD Thesis, Université Paris Est, (2012), 522 p.