COLUMNS AND ORNAMENTAL VERTICAL ELEMENTS MADE WITH UHPFRC FOR THE SAINT-NAZAIRE AQUATIC CENTER

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Abstract

As part of the implementation of its aquatic centre, the city of Saint Nazaire chose the lightness, transparency and brightness of the design of COSTE Architectures agency. BSI®, the UHPFRC developed by Eiffage Group, was selected for its mechanical properties and its high durability, to meet the technical and architectural requirements of such a project in an aquatic environment. The architect will of purifying the space led him to a solution with 40 slender columns. The three basin roofs are supported by a mesh of 40 structural columns, with a height from 3 to 10 m, made with the steel fibres BSI® UHPFRC mix. Non-structural but ornamental vertical elements, with an advanced design and extreme fineness, punctuate the large bay window along the hall basins. They are made with synthetic fibres BSI® formula.

Résumé

Dans le cadre de la réalisation de son centre aquatique, la ville de Saint Nazaire a retenu la légèreté, la transparence et la luminosité du projet de l'agence COSTE Architectures. Le BSI, le BFUP développé par le groupe Eiffage, a été retenu pour ses propriétés mécaniques et de durabilité afin de répondre aux exigences techniques et architecturales dictées par ce projet en milieu aquatique. La volonté de l'architecte d'épurer l'espace l'a conduit à une solution de poteaux élancés, en nombre réduit pour supporter la charpente de couverture. Les 3 toitures des bassins sont portées par un maillage de 40 poteaux structurels, hauts de 3 à 10 m, réalisés en BSI® à fibres métalliques. Des poteaux non structurels dits laminaires, au design avancé et d'une finesse extrême, rythment la grande baie vitrée le long de la halle des bassins. Hauts de 3 à 10 m, ils sont réalisés en BSI® à fibres synthétiques.

1. INTRODUCTION

For the construction of its Aquatic Centre, the city of Saint-Nazaire opted for the graceful, transparent and luminous project developed by COSTE Architectures (Fig. 1). BSI®, the UHPFRC developed by EIFFAGE, was selected for its mechanical properties and durability to meet the technical and architectural requirements of the project in an aquatic context. EIFFAGE's comprehensive expertise with the design and manufacturing process meant it was able to provide programme management at the expected level of quality.

Figure 1: Overview of the project – Coste Architecture

2. THE COLUMNS

The architect's desire to streamline the space led him to adopt a solution employing a limited number of slender columns to support the roof steel structure. The three roofs of the pools are supported by 40 columns in BSI® with steel fibres. The structure columns meet seismic requirements following stress modelling.

2.1 Structural validation

The columns stress analysis is carried out by a global finite elements models produced by Graitec's Advance Structure software (Fig. 2). The columns are modelled by their structural core, with a 35-cm diameter beam element. Both ends of the columns are assumed articulated. Thus the buckling height in the instability calculations is equal to the post height. The columns were verified under axial load to the serviceability and ultimate limit states. The SLS verification principle is based on not exceeding the deformation limits causing the BSI® to crack. We considered the effects of a first-order moment induced by the geometric imperfections, which were calculated in accordance with EC2 §5.2 (5) [1]. Furthermore, we then defined the maximum slenderness criteria to determine whether or not to include second-order effects induced by the deformation of the supports structure.

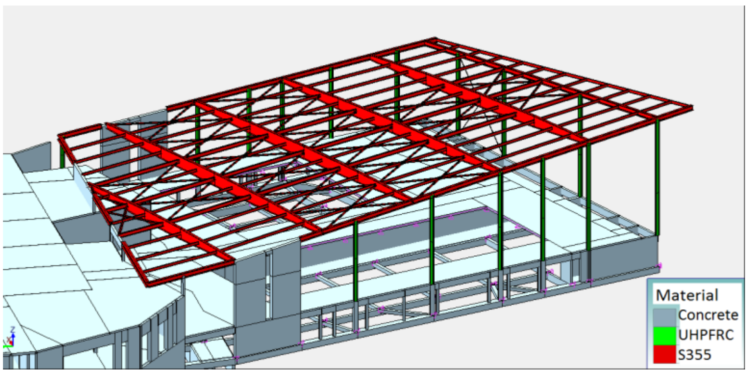


Figure 2: View of the structural model.

The justification method for the columns is presented in the diagram of Figure 3 which is used to determine the need to include prestressing in the columns on the basis of two criteria:

- Slenderness ratio versus buckling;
- Intensity of the axial load, including wind lifting force inducing negative normal forces.

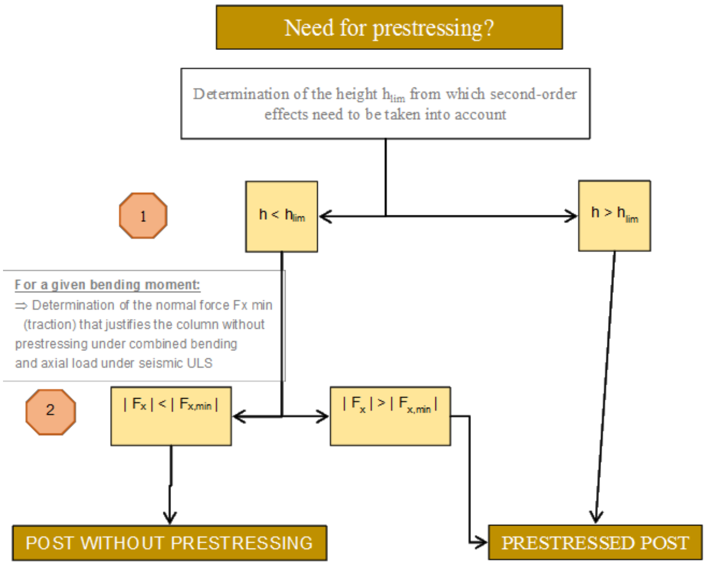
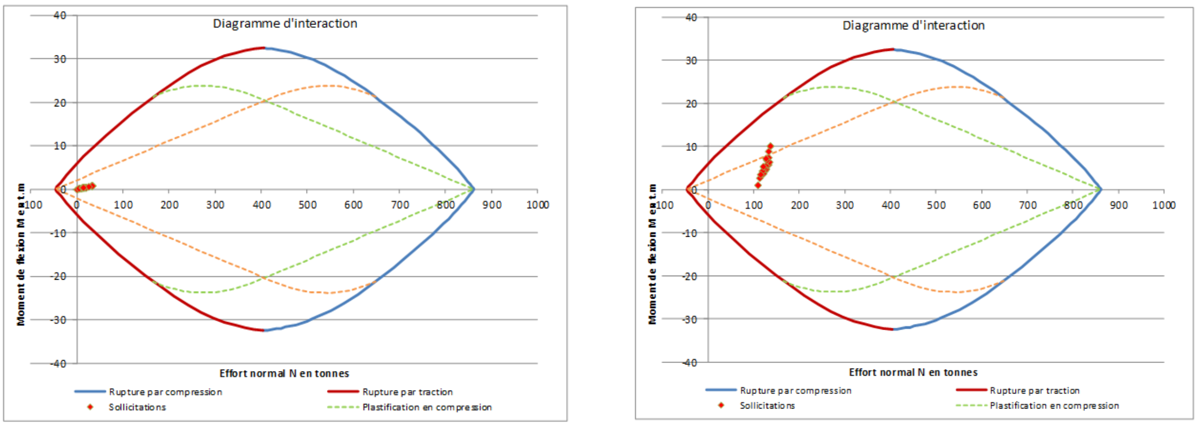


Figure 3: Diagram for determination of the acceptable columns height without prestressing



(a) Non-prestressed columns efforts (b) Prestressed columns efforts

Figure 4: Diagram of interaction N-M

Once the maximum slenderness ratio has been determined, taking into account the maximum ULS load observed for all the columns, the maximum elements height allowing second order effects to be neglected was determined. The maximum slenderness ratio $\lambda_{lim} = 20.A.B.C/\sqrt{n}$ was calculated from the maximum load. Thus, the second-order effects were supposed to be negligible where h < 6,50 m. The need for prestressing in columns was then demonstrated where $\lambda > \lambda_{lim}$, that is all the columns where the height $h \geq 6.5\ m$.

For the prestressed columns, the cable is straight and positioned at the centre of gravity of the concrete section. We used 7 T 15 S cables tensioned at one end. UHPFRC tensile law were taken from AFGC 2013 recommendations [2]. The interaction diagrams (N, M) for the two kinds of columns are given in Figure 4. Prestressing allows that elements can be placed in areas where the second-order effects, namely increased bending due to deformation, will be far less damaging for the structure.

2.2 Prestressing

The columns are prestressed using the BBR CONA CMI internal post-tensioning system with 7T15S cables applied by ETIC. The anchorage section without any reinforcement, required specific end block tests to be performed in accordance with recommendations for UHPFRCs as per the procedure in ETAG 013 [3].

The cables were also prefabricated in the workshop and fitted with adjustable centring devices for their insertion in the formwork with variable sections, and in accordance with a straight position and without any other steel reinforcement.

The top end of the columns consisted in an embedded anchor point so that it would have no visual impact on their top section. The reservation for the base anchorage had to be reduced to a minimum to apply tension to each of the strands individually, each strand having been combed during the prefabrication stage, to allow for the installation of the steel reinforcement for connection to the structure.

2.3 Mould

Measuring from 3 to 10 m in height, all the columns had the same structural diameter of 35 cm, the architectural outline inspired by algae was shaped around this structural core.

Using a 3D architectural design, a 10 m tall, 1:1 scale model was machined on a 5-axis machine, in a lab-type resin. The model lines could be adjusted by the architect when he was seeing the object at full scale.

Figure 5: Column's model

The model was carefully primed before being moulded. At the same time, the metal shell was prepared to stiffen the polyester moulding of the model.

2.4 Prefabrication

The columns were poured flat using white, grey or black BSI® with metal fibres, in accordance with the architect's instructions. The height of the columns depends on their position under the sloping roof. Only columns measuring more than 6.50 m high are posttension prestressed. A duct for 7T15S cable was installed precisely along the centre axis of the column's resistant cylinder, using a stirrup, prior to concreting.

For each formwork brace, partitions were precisely machined according to the column cross-section. They included the necessary box-outs for the path of the tensioning strands, injection tubes and vents, attachment inserts for the roof frame and steel reinforcement at the base plates for installation (See details of anchorages Figs. 6-7).

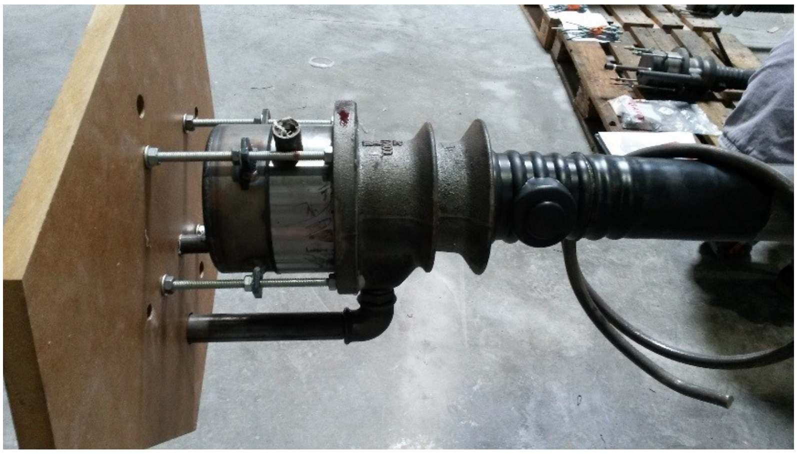


Figure 6: Passive anchorage

Figure 7: Active anchorage

The columns were removed from the mould daily after 20 hours curing and having reached about 70 to 80 MPa, without heat treatment. Young columns were transported to the storage area using slings every 3 m. The columns have been post-tensioned as soon as their strength exceeded 110 MPa, at around 7 to 10 days age.

The active anchorage will finally be hidden protected by a shrinkage-free grout.

3. THE NON-STRUCTURAL COLUMNS

Non-structural columns, with an advanced and extremely thin design (Fig. 8), are installed along the broad glazed window of the pool hall. They are made using BSI® with synthetic fibres.

3.1 Structural validation of the architectural sketch of the non-structural columns

These components only play an architectural role as far as their justification is concerned. The non-structural columns were designed like individually isostatic columns subject to wind pressure only (Fig. 9). They were discretised to take into account the considerable variation in the characteristics of the various cross sections.

As these components are made of BSI® with synthetic fibres, the checks are not subject to any regulation. However, we applied the UHPFRC – 2013 recommendations [2]. The results were checked by prototype testing.

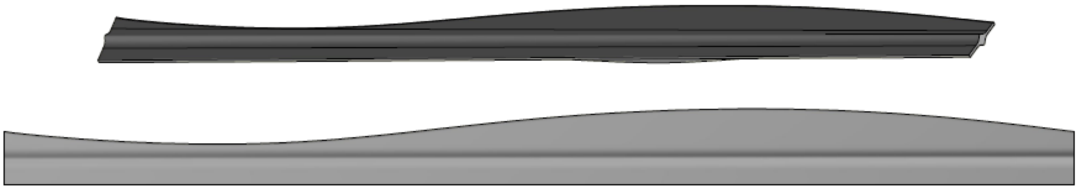


Figure 8: Ornamental elements

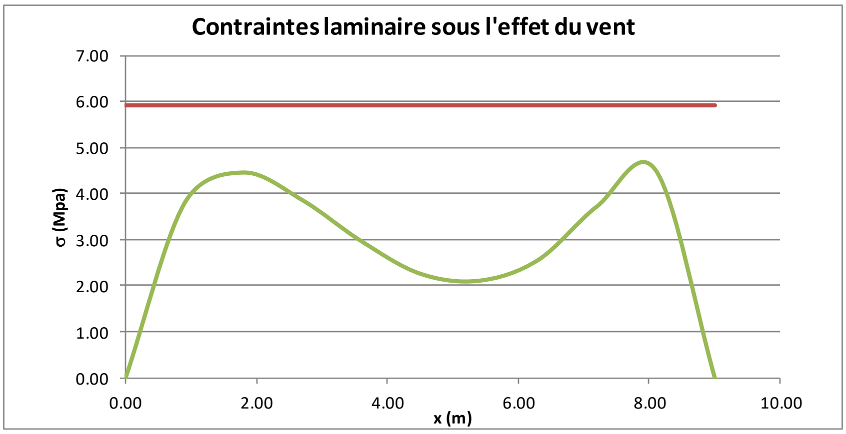


Figure 9: Stresses under wind loads

Figure 10: Ornamental column's model

The non-structural columns were tested for bending when placed horizontally. It was calculated that the tensile strength of a 6 m non-structural column simply supported under its own weight was the same as a 9 m element under wind loads.

3.2 Mould

Measuring from 3 to 10 m high, the columns are formed of two parts: a round core measuring a few centimetre in diameter and wings that rotate around this core. Using a 3D architectural design, a 10 m tall, 1:1 scale model was machined on a 5-axis machine, in a lab-type resin (Fig. 10). The model was carefully primed before being moulded.

At the same time, the metal shell was prepared to stiffen the polyester moulding of the model.

3.3 Prefabrication

Partitions were machined to create the concreting braces; they included box-outs for the attachment inserts at the top and a base steel attachment plate. The concrete was injected into the mould through a small 3 cm opening. Mould removal occurred the same day (Fig. 11). The study of the provisional phases revealed the need to lift these components with a spreader to balance the lifting points every 2 m.

Load tests simulating wind loads were conducted to confirm the model results obtained for the non-structural columns in BSI® with synthetic fibres that are not covered by any design regulations.

Figure 11: Storage of precast elements

4. CONCLUSION

After a design finalisation stage that included provisional phases that often determined the dimensions, the creation of the moulds is a major phase in the production line, which must also comply with the architect's design while incorporating all the construction provisions leading to a perfect finish.

Management of the prefabrication at the rate of one part per mould per day resulted in prefabricated components worthy of being ready to install.

ACKNOWLEDGMENT

With the BSI®, EIFFAGE has developed a process involved in every step of the project, to achieve a very uncommon, innovative and architecturally strong production.

REFERENCES

[1] AFNOR (2005) NF EN 1992-1-1, Eurocode 2. Design of concrete structures. Part 1-1: General rules and rules for buildings.

[2] AFGC, Ultra High Performance Fibre-Reinforced Concretes, Recommendations, 2013.

[3] AFNOR (2016) NF P 18-710, National addition to Eurocode 2 - Design of concrete structures: specific rules for Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC).