THE MILES STAIR IN SOMERSET HOUSE

Raphaël Fabbri (1), Eva Jiricna (2), Cinzia Palazetti (3), Matthew Wells (4)

(1) Masse « Détail Structure Façade », Paris, France
ENSAPB (Ecole Nationale Supérieure d'Architecture de Paris-Belleville), Paris, France
(Formerly) C&E Ingénierie, Paris, France
(2) Eva Jiricna Architects Ltd, London, United Kingdom
(3) Il Cantiere, Pordenone, Italy
(4) Techniker, London, United Kingdom

Abstract

The Miles Stair is a UHPFRC helical staircase designed by the architect Eva Jiricna for the Somerset House Trust in London. Wrapping around a steel-mesh newel, the staircase goes through the five-story of the West Wing of the museum from mid basement to 4th floor reaching 19,7m in height. Staircases are functional elements, but they cannot be reduced only to their functional uses, and often they become architectural masterpieces. Especially the helical stairs which fascinated designers and builders like Leonardo da Vinci or Oscar Niemeyer. The entire Miles Stairs is the assembly of precast elements in reinforced Ductal® with organic fibres. The design is a compromise between the technical requirements, the functional conditions and the building's context. This paper starts with a presentation of the project of Eva Jiricna. Then the static behaviour of the structure and the design of the connections are presented. After that, the paper describes the technical details and explains why the UHPFRC was chosen and why it fitted perfectly for this project. In conclusion, a reflection is made on the feedbacks of this project.

Résumé

Le Miles Stair est escalier hélicoïdal en BFUP, conçu par l'architecte Eva Jiricna pour la Somerset House à Londres. Enroulé autour d'une « Newel » centrale, l'escalier franchit les 5 niveaux de l'aile ouest du musée. Les escaliers sont des éléments architecturaux éminemment fonctionnels, mais ils ne peuvent être réduits uniquement à leur aspect utilitaire. Bien souvent ils deviennent des œuvres à part entière. Les escaliers hélicoïdaux ont spécialement fasciné les constructeurs comme Leonardo da Vinci ou Oscar Niemeyer. L'ensemble du Miles Stair est un assemblage d'éléments préfabriqués en Ductal® armé avec Fibres organiques. La conception est toujours le résultat d'un compromis entre les exigences fonctionnelles, techniques et le bâtiment existant. Cet article commence par une présentation du projet d'Eva Jiricna. Le comportement statique et la conception des connexions sont ensuite présentés. L'article décrit les détails techniques et explique pourquoi le BFUP convient à ce projet. Une réflexion sur les nouvelles typologies d'escalier en éléments préfabriqués conclut l'article.

1. PROJECT DESCRIPTION

1.1 A new stair in an existing building

The Miles stair is a new staircase (2013), built in the West Wing of the Somerset House arts complex in London. This stair replaces an outdated one from the 1960's, and recalls another famous one in the building, the Nelson Stair (Fig. 1). Various studies were undertaken to establish the ideal location for the staircase with the introduction of a lift. It was concluded the most efficient method causing the least disruption to the building was to extend the existing shaft into the smallest of the unusable restricted spaces, dictating the necessity for a compact circular stair. The lift is located in the position of the original staircase, with the stair adjacent to the external facade, thus the arrangement creates open and naturally lit lobbies at each level. The final 5 story design by architect Eva Jiricna consisted of a helical stair, wrapped around a steel-mesh Newel. The shape of the stair is both continuous and organic in appearance, and also mineral and slender. This design makes it one of a kind, located between the legacy of the stone helical stairs and the slenderness of the new material.

Figure 1: Nelson Stair in Somerset House (left) Staircase void after demolition of the 60's stair (middle), first design of the Miles Stair in West wing of Somerset House (right) (Pictures by Eva Jiricna)

1.2 The choice of the UHPFRC

The Miles Stair is composed of three distinct and well identified materials: the helicoidal staircase, a flowing mass white and matt; the transparent glass balustrade, which follows the movement of the helical staircase; and the Newel, the tendons, the handrails and the brackets in stainless steel.

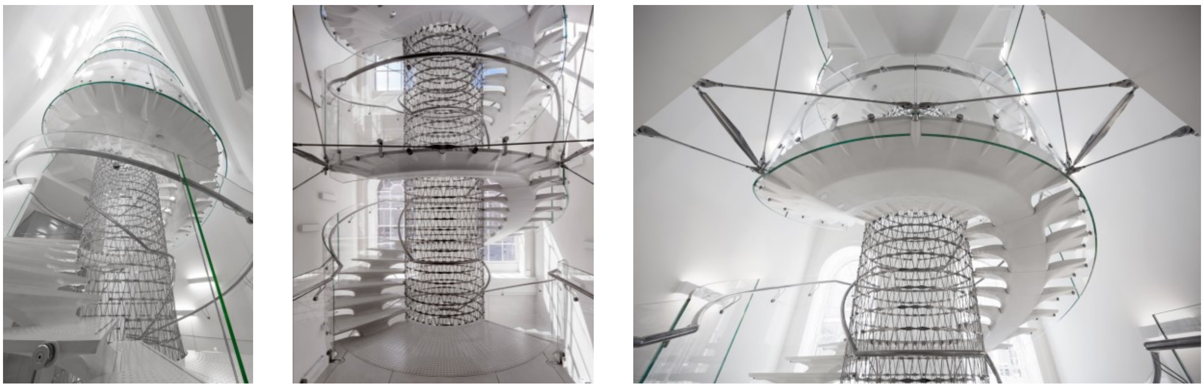

Figure 2: Miles Stair (Pictures by Richard Davies)

The UHPFRC is Ductal® B3 with Organic Fibres. This material has both the structural performances and the mineral aspect. Cast in suitable moulds, it is possible to give it an organic appearance with small thicknesses. The low height between levels does limit the structural height of the stair flights, so the normal reinforced concrete didn't fit.

The staircase is composed of 104 T-shaped treads, 7 main landings (4 cantilevered and 3 suspended) and 7 secondary landings. All the elements are assembled one after the other, continuously as a chain.

2. A STAIR MADE OF UHPFRC

2.1 General design

In the usual structures, the static scheme defines how to assembly the elements. In the case of Miles Stair, the requirements of the static, casting process and implementation are so intricated, that they must be thought of simultaneously. At the beginning, we have the choice between three typologies available per flight of stairs:

- First typology: a single helical girder with steps fixed upon it.
- Second typology (Fig. 4): separated T-shaped treads, assembled together by prestressing.
- Third typology (the chosen one): separated T-shaped treads assembled one over the other

The first typology (Fig. 3) is the best for the strength, but it is hard to cast the helical girder. Moreover, it is not easy to adapt the girder to the different gap between the storeys (the height of the flight of stairs is different for each level).

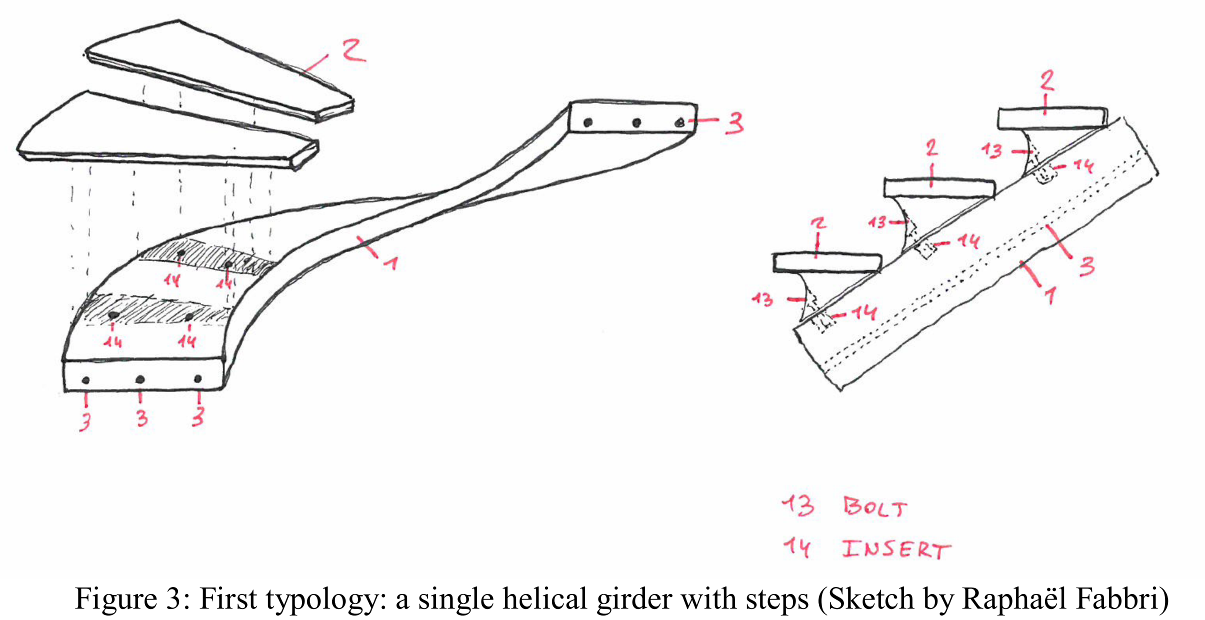

Figure 3: First typology: a single helical girder with steps (Sketch by Raphaël Fabbri)

The second typology (Fig. 4) is easier to cast and to resize each flight of stairs. But the implementation needs to support all the treads before the pre-stressing. Moreover, the pre-stressing anchors require thickening the slabs of the landings. The tight space available and the complexity of the shoring system forced this option to be abandoned.

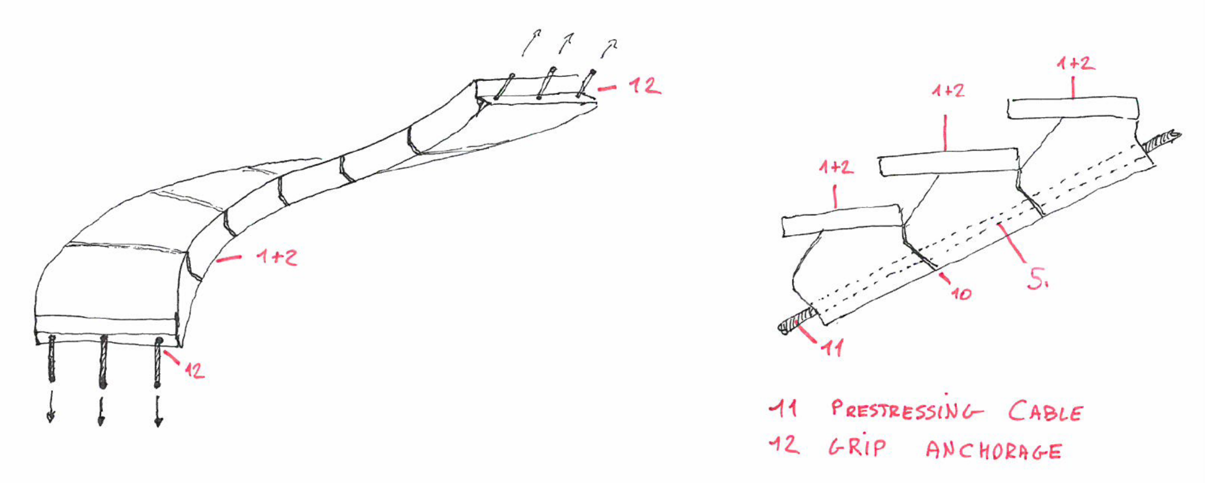

Figure 4: Second typology: separated treads with prestressing (Sketch by Raphaël Fabbri)

The chosen typology (Fig. 5) is not the best static option, but it solves all the other issues. The T-shaped tread is connected to the newel at the extremity of the step, and it connected to the tread below with prestressed bolts, placed in a "V". During the implementation, only the landings are supported with shoring, and the tread just assembled can be immediately used for climbing upwards.

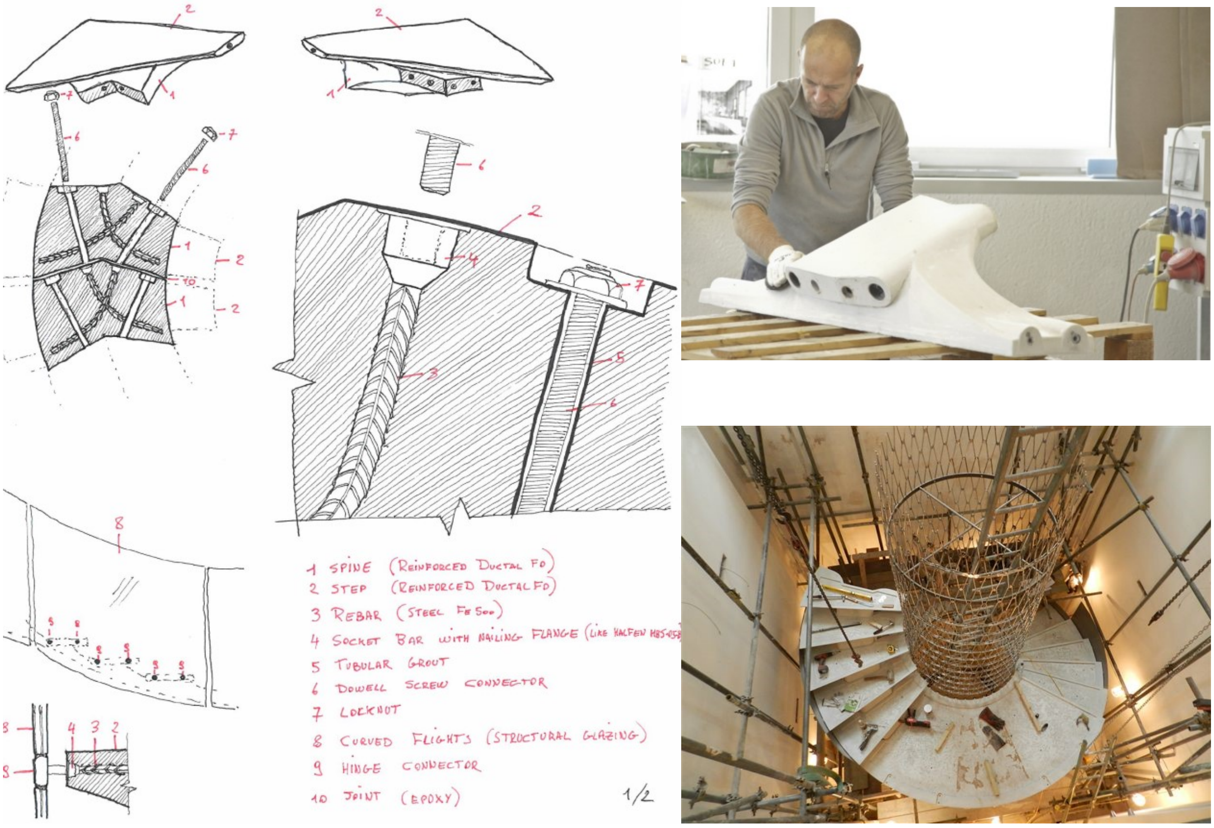

Figure 5: Third typology: treads assembled one over the other (Sketch by Raphaël Fabbri)
Implementation tread by tread (Pictures by Il Cantiere)

2.2 Structural assumptions for organic fibres

The material used for the stair is the Ductal® B3 (white) with organic fibres. The structural design is based on the recommendations for UHPFRC with steel fibres, with some adaptations for organic fibres. Main figures are summarized on Table 1. The new UHPFRC recommendations of 2013 [1] were not already published at the time of the project, so the design methods described below are based on the former recommendations of 2002 [2]. The following four constitutive curves were chosen for calculating the Ductal® FO :

- The constitutive curve at the Service Limit State (**SLS**) is defined with an instantaneous elastic modulus (Ei = 35,000 MPa). In order to prevent the opening of cracks at the SLS, the Lafarge Explanatory Note [6] recommends remaining within the elastic field for the substantiation of the unreinforced Ductal® FO. According to clause A.4.5,34 of BAEL91 [4], the opening of cracks in the sections of reinforced Ductal® FO is reduced by limiting the stress in the reinforcements.
- The constitutive curve at the Service Limit State according to Displacement (**SLS-D**) is defined with a delayed elastic modulus (Ev = 19,444MPa). The verification must take account of creep by an affine transformation of the constitutive curve according to a coefficient $(1+\alpha\varphi)$(article 6.2,1). In the present study, the normal stress in the structure is mainly due to almost permanent loads ; the coefficient $\alpha = M_{QP}/M_{Rare}$ is thus considered to be equal to 1. The value recommended by Lafarge [6] for the coefficient φ is 0,8 without heat treatment.
- At the ultimate limit state (**ULS**) the design curve is defined with an instantaneous elastic modulus (Ei = 35,000 MPa). The tensile plastic stage of the Ductal® FO is limited to elongation: $\varepsilon_{(0,3mm)} = 0,3mm/L_C \leq 10‰$ with $L_C = 2/3\,h$ (see [6]). The plastic compressive stage of the Ductal® FO is limited to extension: $\varepsilon_{bcu} = 3,00‰$.
- The constituive curve at the Ultimate Limit State for Stability of Form (**ULS-SF**) is defined with a delayed elastic modulus (Ev = 19,444MPa). In accordance with article 6.4 of the BPEL91 [3], the verification at the ultimate limit state for stability of form must take account of creep, via an affine transformation of the behaviour curve according to a coefficient $(1+\alpha\varphi)$(article 6.4,4). In the present study, the normal stress in the structure is mainly due to almost permanent dead loads; the coefficient $\alpha = M_{QP}/M_{Rare}$ is thus considered to be equal to 1. The value recommended by Lafarge [6] for the coefficient φ is 0,8 without heat treatment. The tensile plastic stage of the Ductal® FO is limited to elongation: $\varepsilon_{(0,3mm)} = 0,3mm/L_C \leq 10‰$ with $L_C = 2/3\,h$.

Table 1: Summary of design values for the UHPFRC considered

Designation	**Values for unreinforced Ductal FO**	**Values for reinforced Ductal FO**	**Values for Ductal FO in the spine connection**
Young's elastic modulus	Ei = 35 000MPa	Ei = 35 000MPa	Ei = 30 000MPa (see § 2.4)
Nominal Compress. Strength	f_{cj} = 150 MPa	f_{cj} = 150 MPa	f_{cj} = 150 MPa
Tensile strength	f_{tj} = 5,1 MPa	f_{tj} = 6,3 MPa	f_{tj} = 0 MPa
Partial factor	γ_m = 1,3	γ_m = 1,3	γ_m = 1,3

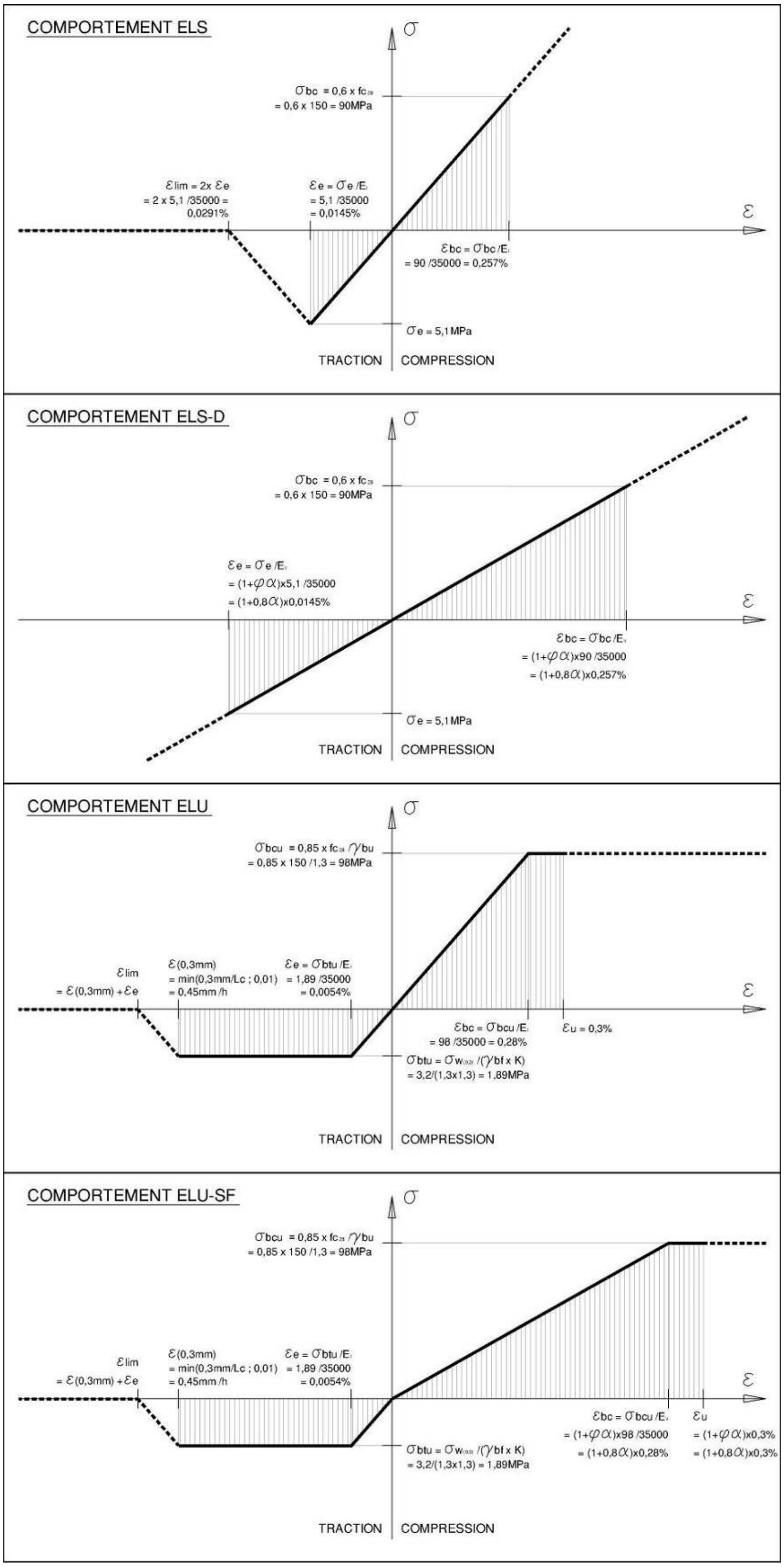

Figure 6: The four constitutive laws of the Ductal® FO

2.3 Static scheme

The structural elements are modelled as follows:

- The steel ties are modelled as trusses elements with constant circular cross-sections.
- The unreinforced Ductal elements are modelled as slabs with constant thickness.
- The reinforced Ductal elements are modelled as beams with variable cross-sections.

Figure 7: Landing (left) and T-shaped tread (right) (Pictures Il Cantiere)

All connections between elements are fixed, except the extremities of all the trusses elements are hinges (obviously), and the top of each staircase flight, which is an axial relaxation.

The support conditions are the following one:

- Hinge of the main landings supports: Constraints of displacements in X, Y and Z and no constraint of rotation
- Fixed supports of the steel ties: Constraints of all displacements and rotations
- Supports given by the Newel: Springs in the directions X, Y and Z. (For the stiffness definition see below)
- The stiffness of the supports given by the newel is evaluated with the calculation of the displacements under a nominal load.

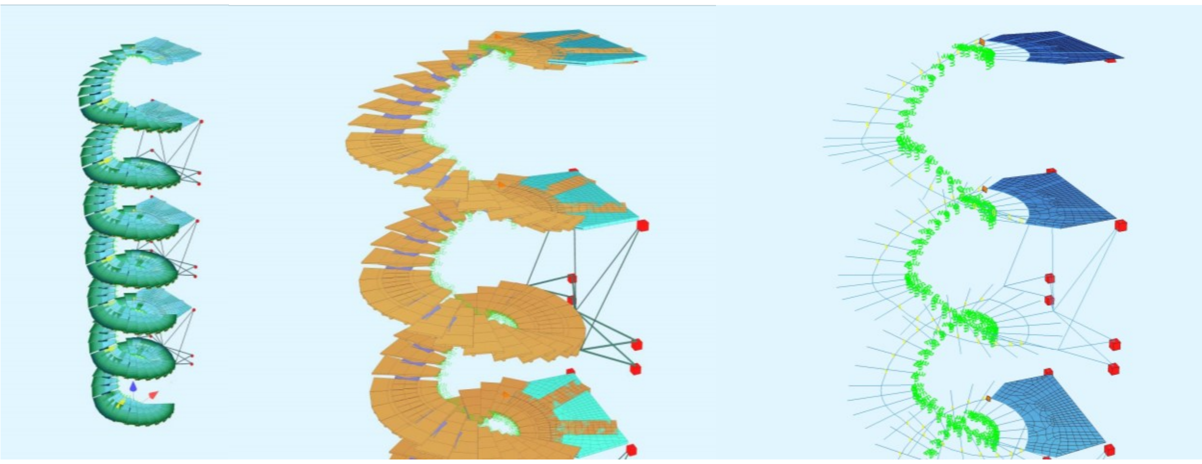

Figure 8: Calculation model with SOFISTIK (Pictures C&E Ingéniérie)

2.4 Design the connections

The "spine connection" is the most stressed, because it carries heavy loads with a small cross-section (the "spine" is roughly a rectangle of 450 mm x 80 mm). The compression is transmitted by contact of the V-shape surface. The prestressed bolts support the tension due to the bending moment. The shear due to the vertical loads and the torsional moment is transmitted by the conic-heads of the bolts.

Figure 9: The "Spine connection" (left) and Prestressed bolts (right) (Pictures Il Cantiere)

In order to take into account the joint between the treads, the tensile stress of Ductal® FO is cut off to 0 MPa in the spine of the stairs. Some prototypes of staircase elements have been tested, in the aim to verifying the behaviour of the joint between treads. The observed results have been compared with a theoretical model, computed with Sofistik. The displacements measured have been higher than what have been calculated. The characteristics of the Ductal® FO and of the screwed bars inside have been modified consequently to correct the behaviour.

Figure 10: The prototype testing (left) and theoretical model (right)
(Pictures Il Cantiere & C&E Ingéniérie)

The Connection between the UHPFRC and the stainless steel is made with couplers, put in the concrete during the cast. To reduce the thicknesses, the architect has suggested a design with "*frog eyes*": the minimum thickness on the edges is 30 mm, and around the couplers a cylinder (diameter 60 mm) thickens the material.

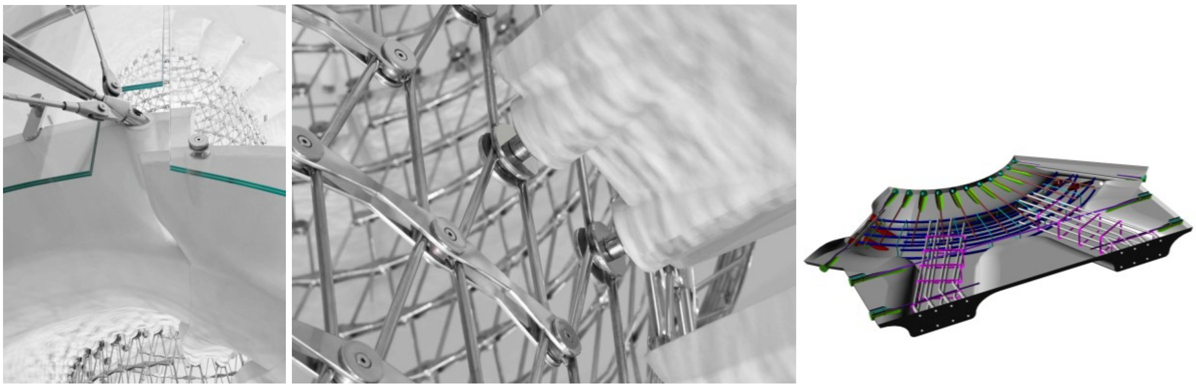

Figure 11: "Frog eyes" connection (left) and reinforcement inside the landing (right) (Pictures Il Cantiere)

The glass balustrade is fixed upon the landings alternatively with a "*frog eye*" and with T-shape plate. The plates are assembled with two inserts and two countersunk bolts.

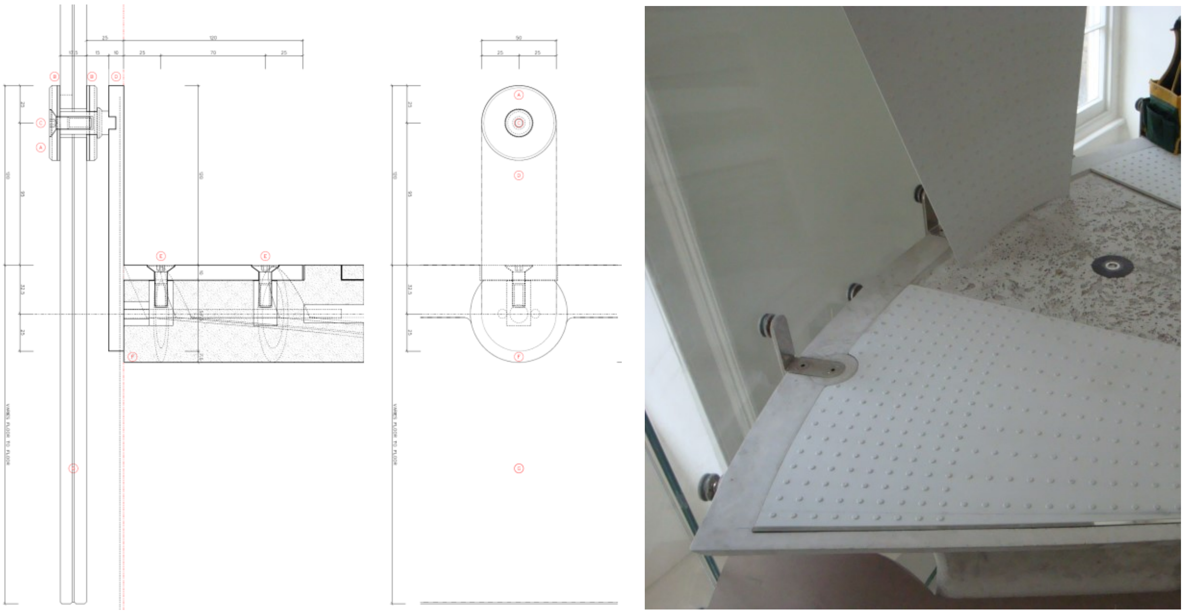

Figure 12: Balustrade connection (Pictures Il Cantiere & C&E Ingéniérie)

3. CONCLUSION

With a total cost of £1,6 million (including demolitions), the Miles Stair is not the first stair made with the UHPFRC (Louvre Museum staircase in Paris, Zaha Hadid office Stair in London …), but it is the most complex one. More than the technical challenge, the Miles Stair opens new fields of plastic expression. It is an "*hybrid object*" that explore fully the mechanical and plastic possibilities of the material. The quality of the result is due to "*savoir-faire*" of Il Cantiere but also to the capacity of the architect to "*understand the material*", to suggest and to improve the design.

ACKNOWLEDGEMENT

The authors would like to mention and thank everyone who contributed to this project and made it possible:
Somerset House Trust: Client
Eva Jiricna and Duncan Webster (Eva Jiricna Architect Limited): Architect
Matthew Wells (Techniker): Structural Engineer
Coniston: General Contractor
Clifford Chapman Staircases Limited (Cliff Chapman, Derek Hann & David Sanger UK & Site Coordinators: in charge of the newel, the balustrade and the steel connections
Cinzia Palazzetti, Gigi Rossi & Stefano Rossi (Il Cantiere srl): in charge of the UHPFRC elements and the implementation
Jean-Marc Weill (C&E Ingénierie) and Raphaël Fabbri (Formerly C&E Ingénierie): UHPFRC engineer

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