

THE "NOTRE-DAME-DE-LORETTE" FIRST WORLD WAR MEMORIAL

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The Fiber Concrete Prestressed Ring of the Memorial

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Jean-Marc Weill, born 1964, is an engineer, architect and professor of various architectural schools. He is the founder and Director of C&E Engineering office based in Paris. Over the past 10 years he has developed an expertise on the design and calculation of UHPC Structures (fiber high resisting concrete). His office was in charge of the structural design of the Notre-Dame-De-Lorette Memorial.



Fig.1: The elliptic ring memorial (Source Eiffage+Jerome Pouille Photographer)

Summary

- 1-Introduction
- 2-Fitting into the site, geometry and geology aspects.
- 3-The Ultra High Performance Fiber -Reinforced Concrete Material
- 4-Structural Analysis
- 5-Building the ring-ellipse

Keywords

Ultra high performance fibre-reinforced concrete, post-tension, torsion, BSI,

1. Introduction

The international memorial built at Notre-Dame de Lorette, near the town of Ablain-Saint-Nazaire in Northern France, designed by the Philippe Prost architectural workshop (France) and built by the contractor Eiffage (France), forms an elliptical ring of 129.00 meters by 75.00 meters, located near to the existing military cemetery. The work covers a 328 metre perimeter within 600,000 names engraved on metallic panels. The ring comprises 122 segments, 49 of which form a curving 125 metre long footbridge on four supports. This paper seeks to set out and summarise the ring's design and construction process based on contributions from all of the parties involved in the project.

2. Fitting into the site, geometry and geology aspects

2.1 Historical and political context

The Notre-Dame-de-Lorette International Memorial is a Nord-Pas-de-Calais Region initiative, creating a magnificent monument by the elegance of its architecture. Whereas the memorials built immediately after the Great War were intended to commemorate the death of soldiers who fought for the nation states, this one, for the first time, celebrates people for humanity alone, bringing together some 600,000 people from around the world in alphabetic order without any distinction by nationality, race, religion or rank, united in posthumous brotherhood. Their names are engraved in steel, the very material the bullets and shells were made of. [1]

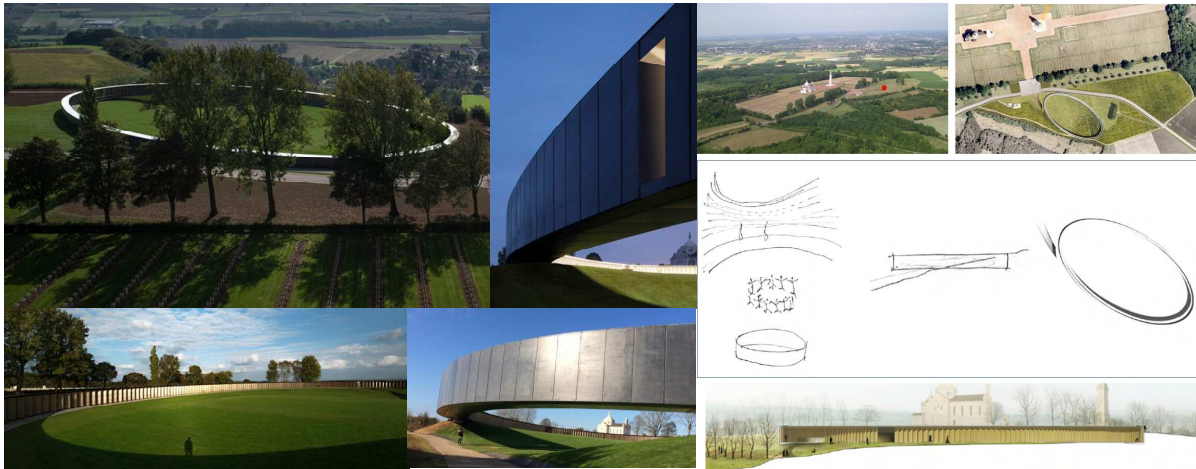


Fig.2: Graphics and Photos (Source AAPP):
Site view including the ring, conceptual sketches by Philippe Prost Architect, Section showing the ring on site

2.2 Site and geometry

The choice was made to blend the memorial into the site. Anchored in the land to the North, it can hardly be seen from the existing national necropolis. On the contrary, from the South, thanks to the slope of the land, the ring is suspended between heaven and earth, as if the mark the fragility of peace... [2] The work covers a 328 metre perimeter. The ring is made up of 122 L-shaped segments, 49 reinforced of which form a curved footbridge 125 metres long on four supports including a 56 meters span opposite the battlefield where the terrain falls away under the memorial... Access is from the North-West side, through a U-shaped trench (visible on the left of the plan). All of the segments have ultra-high performance fibre-reinforced concrete ground slabs and are topped with a canopy overhanging from the vertical face of the footbridge.

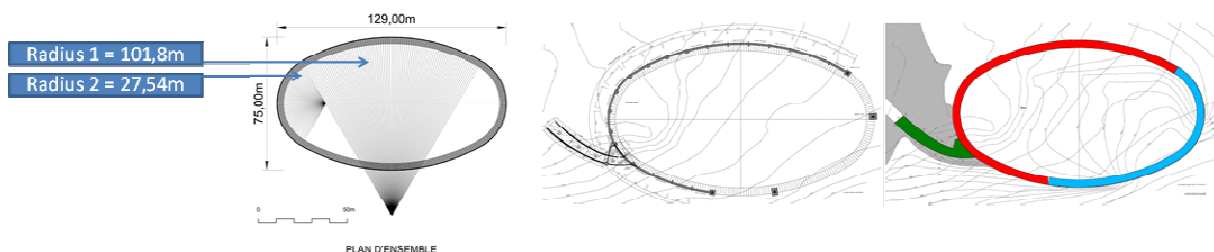


Fig.3: Visualisation of the two supported conditions of the ring.
On the left side the ring is continuously supported (red)
On the right side the ring is simply supported on punctual supports (blue)

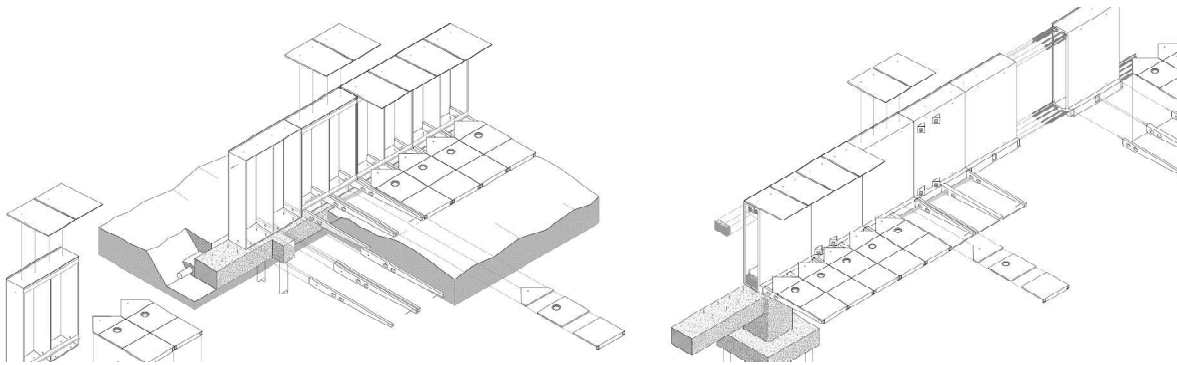
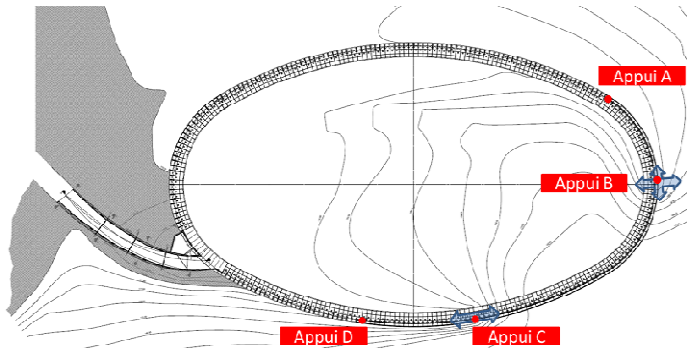


Fig.4:
Structural axonometric view when the ring is continuously supported (left) and acting as a curved beam (right)
(source C&E)

The positions of the supports under the curved beam are as follows:



The ways the forces are transmitted back to the supports are as follows:
→ The torsion forces are blocked by supports A, C and D.
→ The vertical bending moment (continuous beam) applies at B and C.
→ The transfer of the shear force applies at supports A, B, C and D.

Fig.5: Localisation of the punctual supports A/B/C/D

Restatement of the spans:

- Span L1 (pre-stressed box beam) between supports A and B: 28 metres
- Span L2 (pre-stressed box beam) between supports B and C: 56 metres
- Span L3 (pre-stressed box beam) between supports C and D: 37 metres

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Support design was guided by the principle of restricting the curved beam as little as possible at support B and C levels to leave it some "breathing space".

2.3 Geology of the site and its foundations

The natural soil is made up of Pleistocene era silt covering the chalky Senonian and Turonian era ground. These formations have been reformed over a depth of many metres in places due to the trenches, tunnelling and shell holes or other events caused by the fighting during the Great War. The water table is at a depth of more than 15 metres. As a result:

- The piles are anchored in chalk and the altered marl chalk.

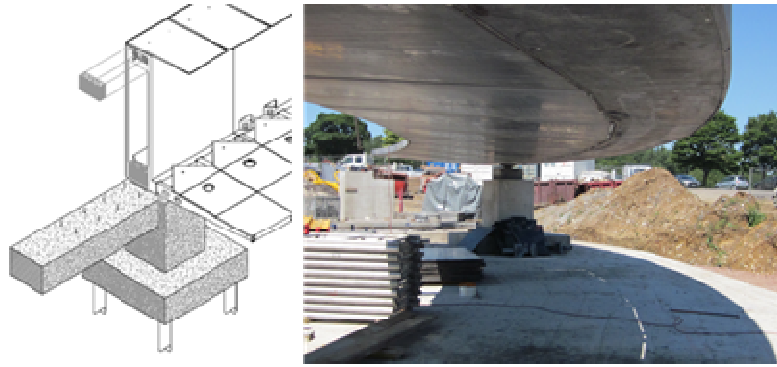


Fig.6: Visualization of the punctual supports A

3. The Ultra High Performance Fibre-Reinforced Concrete material

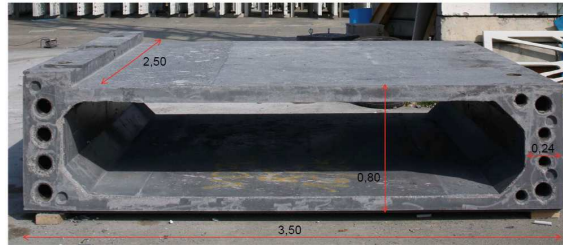


Fig.7: B.S.I. Typical cross section (source Eiffage)

3.1 Foreword

The Memorial ring is made from Ultra High Performance Metallic Fibers-Reinforced Concrete. The one retained for the project is BSI-CERACEM® made and put to use by Eiffage Constructions (France), the contractor chosen by the client. The composition and the manufacture of Ultra High Performance Fibre-Reinforced concrete is factory managed. The aggregates are formed from fine grain granulates ($0.2\mu\text{m} < \varnothing < 7\text{mm}$) and pouring is facilitated by the use of superplasticizers as follow :

→ PREMIX:	70 %
→ Water :	20 %
→ Superplasticizers :	4,5 %
→ Metallic fibers	2,5 %
→ Air	3,0 %

Characteristics		
Density	ρ	2,75 t/m ³
Characteristic compression	f _{ck}	160 Mpa
Traction/Bending	σ_{bt}	6.3 Mpa
Average value of Elasticity modulus	E _{cm}	58 Gpa
Poisson's ratio	ν	0.20
Thermal dilatation coefficient	α	13 $\mu\text{m}/\text{m}^{\circ}\text{C}$
autogenous shrinkage	.	600 $\mu\text{m}/\text{m}$
drying shrinkage	.	240 $\mu\text{m}/\text{m}$
Water porosity	.	9%

Table 2: Mechanical characteristics of the BSI- CERACEM®

4. Structural analysis

4.1 General calculation assumptions

The summary of the general calculation assumptions is as follows:

- Reinforced concrete works (foundation soles, piles) : Concrete class: C30/37
- Reinforcing steel for reinforced concrete works: Elasticity limit: 500 Mpa
- Prestressing is achieved with cables in T15S reels, 1860 Mpa class (Dywidag)

The stressing steel is partially replaced with the metal fibres present in the Special Industrial Concrete (BSI) used. Stress limiting in the Ultra High Performance Fibre-Reinforced concrete at the

Service Limit States (SLS). The seals between prefabricated segments cannot accept any traction. The characteristic shearing limit is limited by the following factors:

4.2 Segments forming the curved footbridge

4.2.1 Foreword

The segments forming the curved footbridge extend along a span of 125 metres. They are made from a box section beam that is 3.5 meters high by 0.8 metres wide and they are assembled by prestressing and post-tensioning so as to form a continuous beam that rests on four supports.

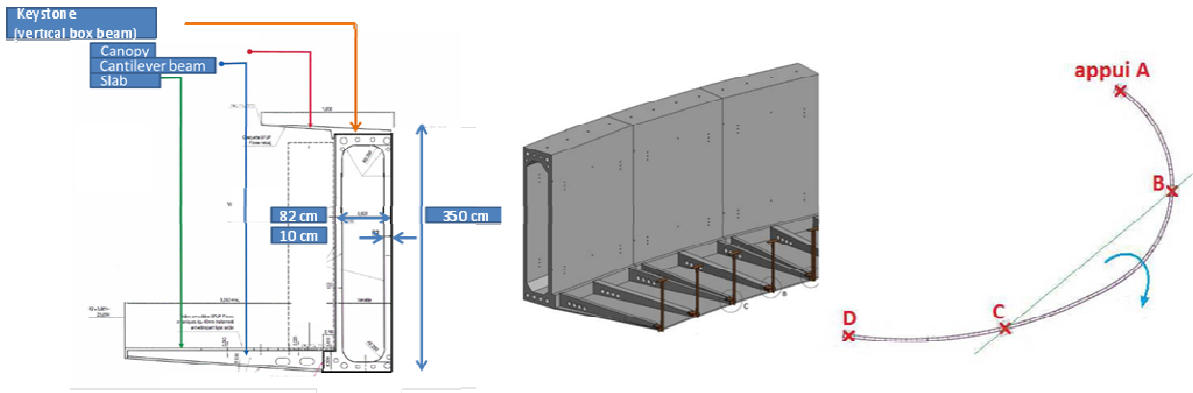


Fig.8: Typical cross section and visualisation of the torsional effect due to the curve (source Eiffage)

4.2.2 Model geometry

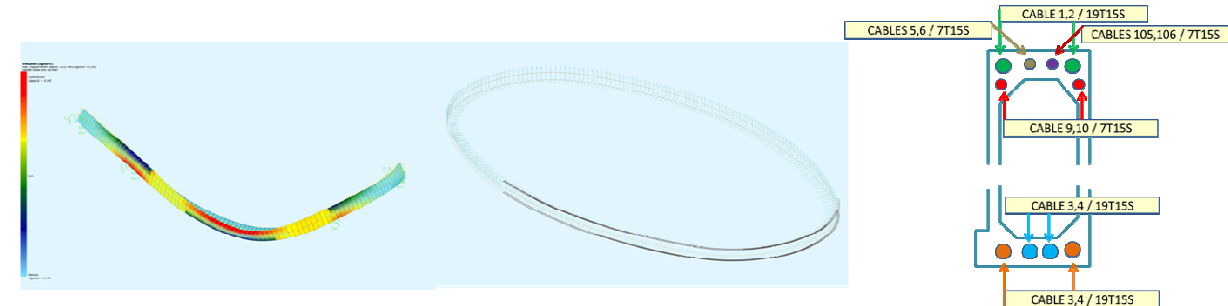


Fig.9: Model done with SOFISTIK Software during the construction stage (Source C&E) showing the curved beam and the prestressing cables position.

4.2.3 Implementing prestressing

The anchoring short cables are located inside the box to eliminate torsion peaks. This assumption raises the issue of operating the cylinders within the reinforced box.

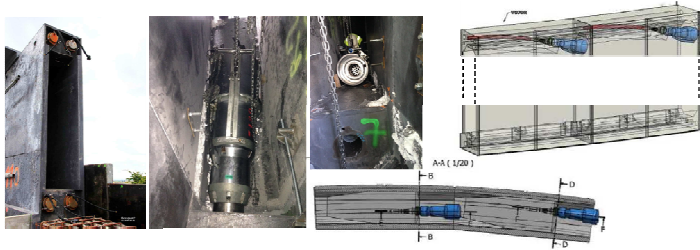


Fig.10: Visualization of anchoring inside the box to eliminate torsion peaks (source Eiffage)

4.2.4 Shear and bending stress analysis

Checking the shear stress at the Service Limit State at the section cores

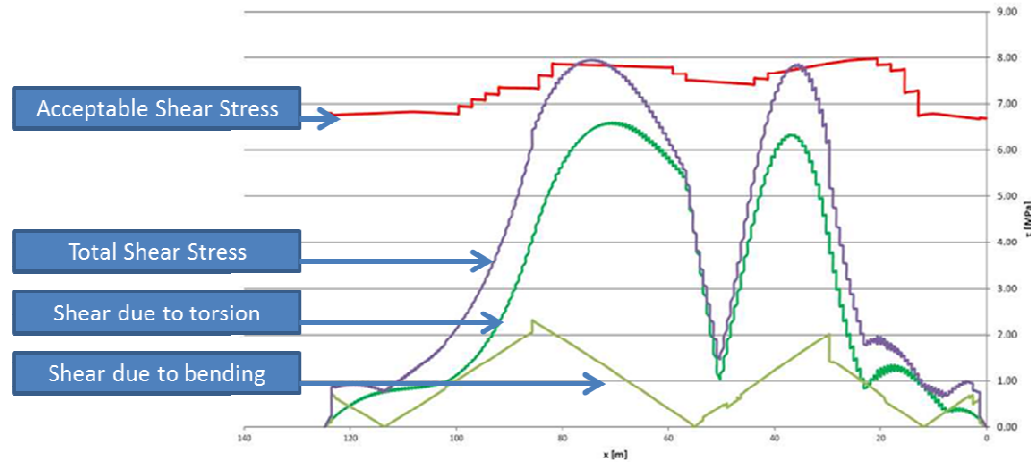


Fig.11: Torsion due to shear and torsion analysis (Analysis done from Eiffage Document)

4.2.5 Explanation of the stand out aspects of the curved footbridge

The behaviour of the curved footbridge was analysed and developed with the contractor, taking the following design criteria which consist on adjustment of the position of the supports to optimise the maximum shear stresses at the level of the interaction between the shear stress and the torsion moment, namely:

- L1 (between supports A and B) which goes from 25.8 to 28.3 metres
- L2 (between supports B and C) which goes from 66.2 to 56.1 metres
- L3 (between supports C and D) which goes from 30.3 to 37.9 metres

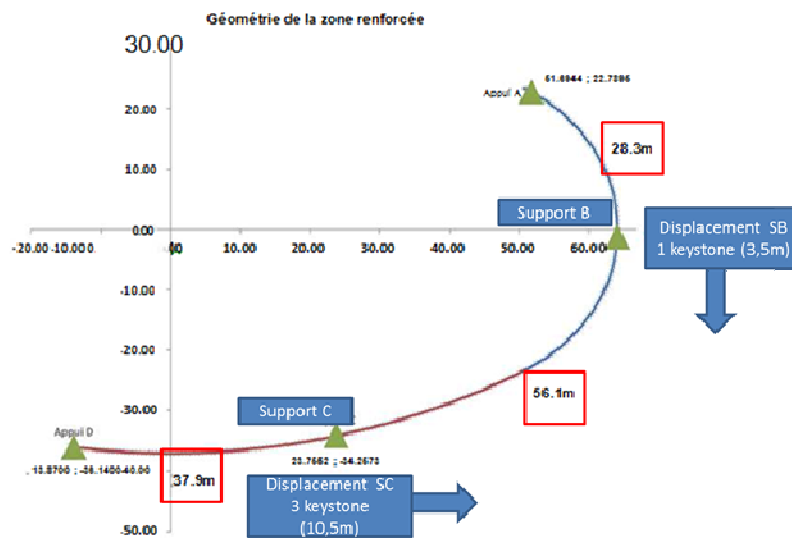


Fig.12: Diagram showing the displacement of the support to optimize the displacement.

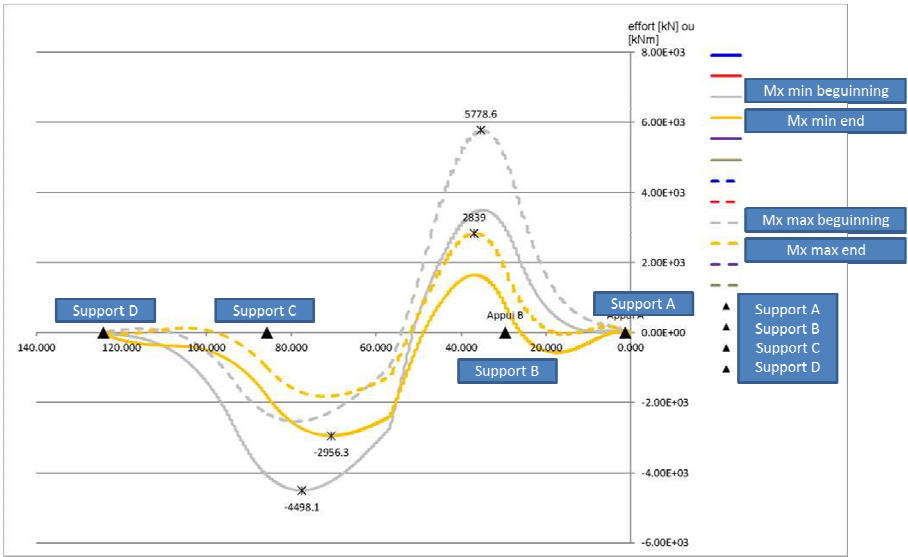


Fig. 13:
Optimising the torsion moment value in line with the adjustment to the support position between the start and the end of the execution studies (Analysis done from Eiffage Document)

4.2.6 Two windows in the ring

The windows integrated into the calculation model measure 95 cm. The prestressing triggers very high normal loads on the structure, especially at the window level where the segments are crossed by all of the cables. At the window level, the normal force spread through the cores must run through connecting rods to the lower and upper window ledges: these connecting rods have to be balanced by tie-bars that bring the window walls to work in traction.

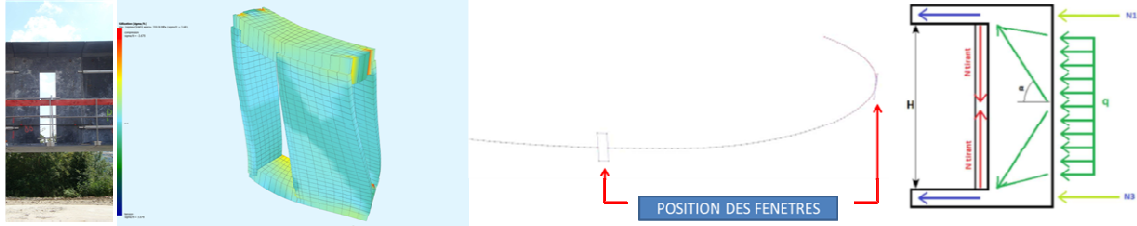


Fig. 14:
Document showing the analysis of the opening in the curve beam (Source C&E + Eiffage)

5. Building the ring-ellipse

The segments that are simply resting on the ground were anchored to the foundations with 500 anchor rods.



Fig. 15: View of the construction site (source Eiffage)

Building the segments forming the curved footbridge in line with the following protocol:

Segment delivery and visual geometry check / Storage flat on the ground / Fitting and gluing the reinforced segments on a supporting structure resting on a temporary raft foundation / Tightening down the reinforced segment / Tensioning with jacks / Releasing the retaining after tensioning and injecting the grout / Fitting the canopy and the floor slabs.

6. Dynamic measurement campaign



The analysis of these results shows that:

- The maximum acceleration levels are recorded during waking in step at frequencies close to that of the mode at 1.85 Hz,
- All of the vertical acceleration levels are below 0.5 m/s², the maximum comfort threshold in the sense of the SETRA guide.

7. Discussion, Conclusions and Acknowledgements

The international memorial at Notre-Dame de Lorette was a unique experience of achievement between a brilliant conceptual hypothesis and its construction. Several questions were answered during the process which goes from design to site construction. From more than anything else this very ambitious project was a success because of the exceptional attitude from all the team (designer and contractors) and the confidence of the client. I would like then to express my gratitude to:

Philippe Prost and Lucas Monsaingeon (AAPP Architects) / Pierre di Sciullo Graphist Designer / David Besson-Girard Landscape Designer / Yann Toma Light Designer / Raphael Fabbri, Engineer in charge of the Structural Design (C&E Consulting Engineers) / Victor Davidovici (Dynamique Concept) Expert Engineer in charge of quality control of the structural design / Jean-Marc Gley (BTP Consultant) Technical Director of the Control Engineers Compagny / Eiffage TP Group in charge of the fabrication and construction / Biep Engineers (Eiffage group) in charge of the workings drawings development / Cerema Engineers in charge of the calculation analysis of the risks

8. References

- [1] PROST P., ORTIZ A., *Memorial International Notre Dame de Lorette*, Les Edifiantes Editions 2014
- [2] PROST P., *Text written for the competition submission*,
- [3] SETRA, *Guide for Pedestrian footbridge*,
- [4] AFGC, *Béton fibrés à ultra-hautes performances-Recommandation – Edition révisée*, 2013

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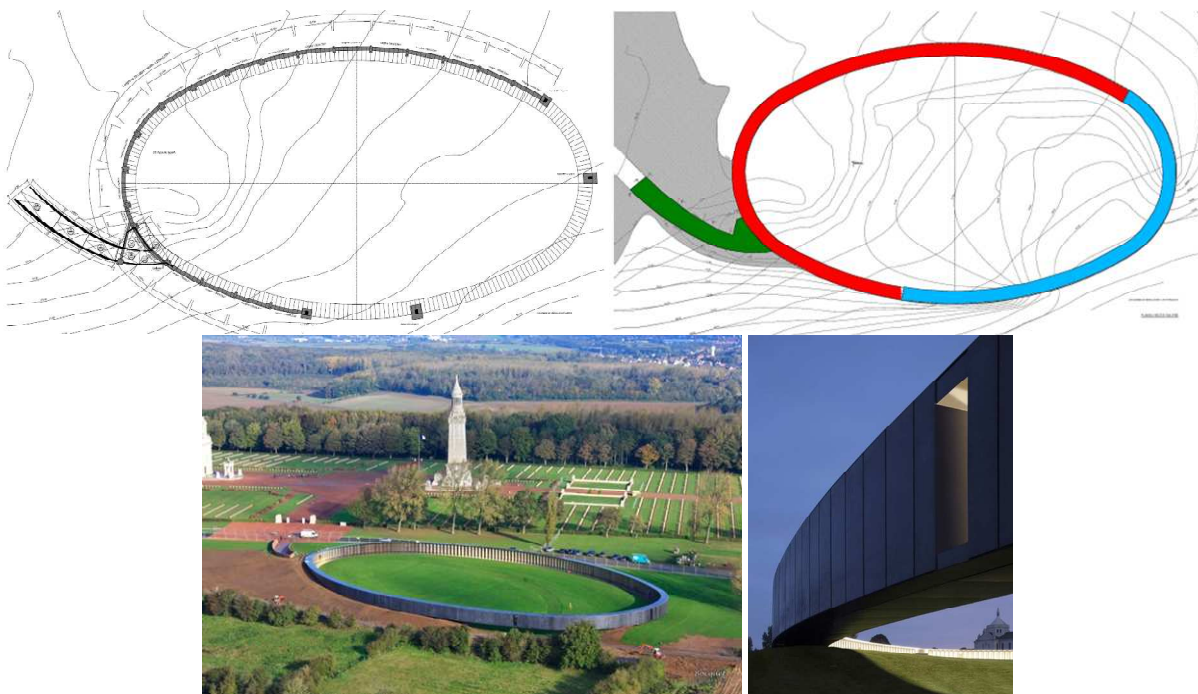


Fig.2: Visualisation of the two supported conditions of the ring.

On the left side the ring is continuously supported (red)

On the right side the ring is a 125 meters long curved footbridge.