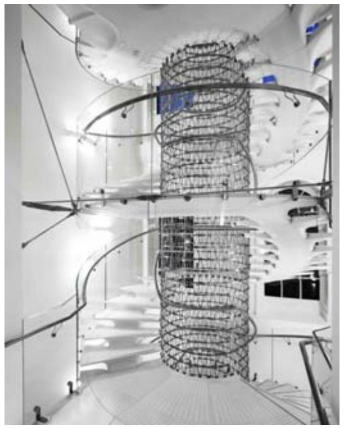
ARCHITECTURE
ET INGENIERIE DU BETON DE FIBRES





C&E ingénierie des structures

29 Juin 2017

AFGC
Association Française de Génie Civil

Cette présentation veut suggérer une illustration du processus de conception des éléments structurels ou non structurels réalisés en béton de fibres à ultra haute performance et tenter de proposer une méthode de conception associée.

Un matériau générique, le B.U.H.P deux déclinaisons

- Le B.U.H.P à fibres organiques

  Ductal Lafarge Holcim

  Vicat

- Le B.U.H.P à fibres métalliques

  BSI Eiffage

  Ductal Lafarge Holcim

  Smart-Up Vicat

BSI®

Ductal®

SMART UP

BÉTONS FIBRÉS ULTRA-HAUTES PERFORMANCES

ARCHITECTURE, DESIGN, STRUCTURES D'OUVRAGES D'ART ET DE BÂTIMENTS

MATERIAU / BUHP DE FIBRES METALLIQUES

MATERIAU / BUHP DE FIBRES METALLIQUES

1.Résistance à la compression f_{ck}	**150MPa ~ 250MPa**
2.Résistance à la traction $f_{ctk,el}$	**≥ 3.1 MPa**
3.Diamètre des agrégats	**1mm ~ 7mm**
4.Eau/ciment ratio	**≤ 0.2**
5.Superplastifiants	**0.5%~2%** (//du volume de ciment)
6.Proportions de fibres	**2%~5%** (//du volume total)
7.Longueur des fibres	**12 ~ 20mm**
8.Diamètre des fibres	**0.2mm ~ 0.3mm**
9.Densité	**2400kg/m^3 ~ 2800kg/m^3**

MATERIAU / BUHP DE FIBRES ORGANIQUES

MATERIAU / BUHP DE FIBRES ORGANIQUES (ALCOOL POLYVINYLIQUE)

Polymère obtenu par Hydrolyse de l'Acetate de polyvinyle

1.Résistance à la compression f_{ck}	**130MPa**
2.Résistance à la traction $f_{ctk,el}$	**≥ 2.85 / 5.1 MPa**
3.Diamètre des agrégats	**1mm ~ 7mm**
4.Eau/ciment ratio	**≤ 0.2**
5.Superplastifiants	**0.5%~2%** (//du volume de ciment)
6.Proportions de fibres	**2%~5%** (//du volume total)
7.Longueur des fibres	**12 mm**
8.Densité	**2500kg/m^3**

Gasholders triplets King's Cross, London / Thorp Préfabriquant

Panneaux à Sao Paulo, Bresil / stone Prefabriquant

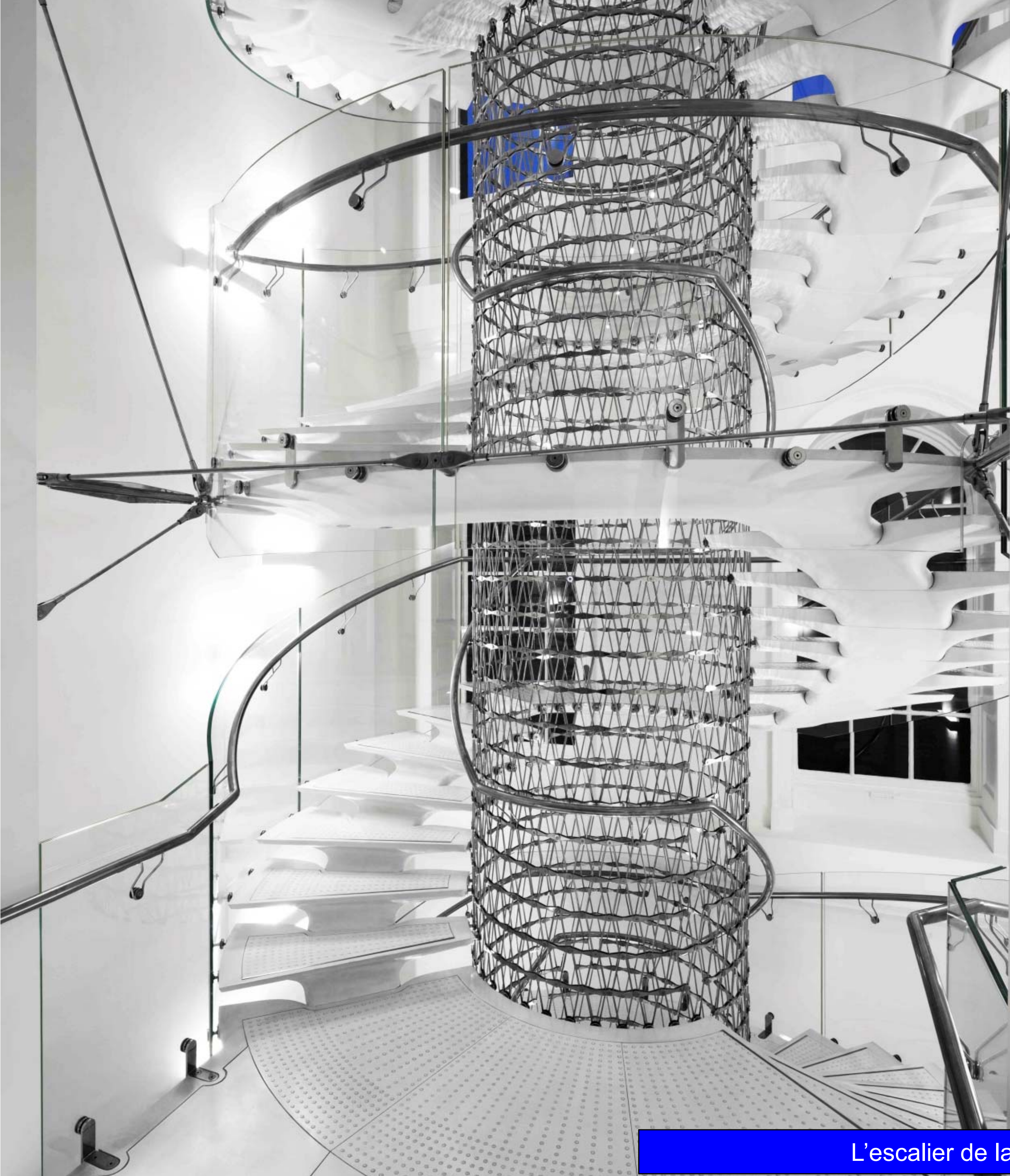
Panneaux de façade à Shenzen, Chine / e-grow Préfabriquant

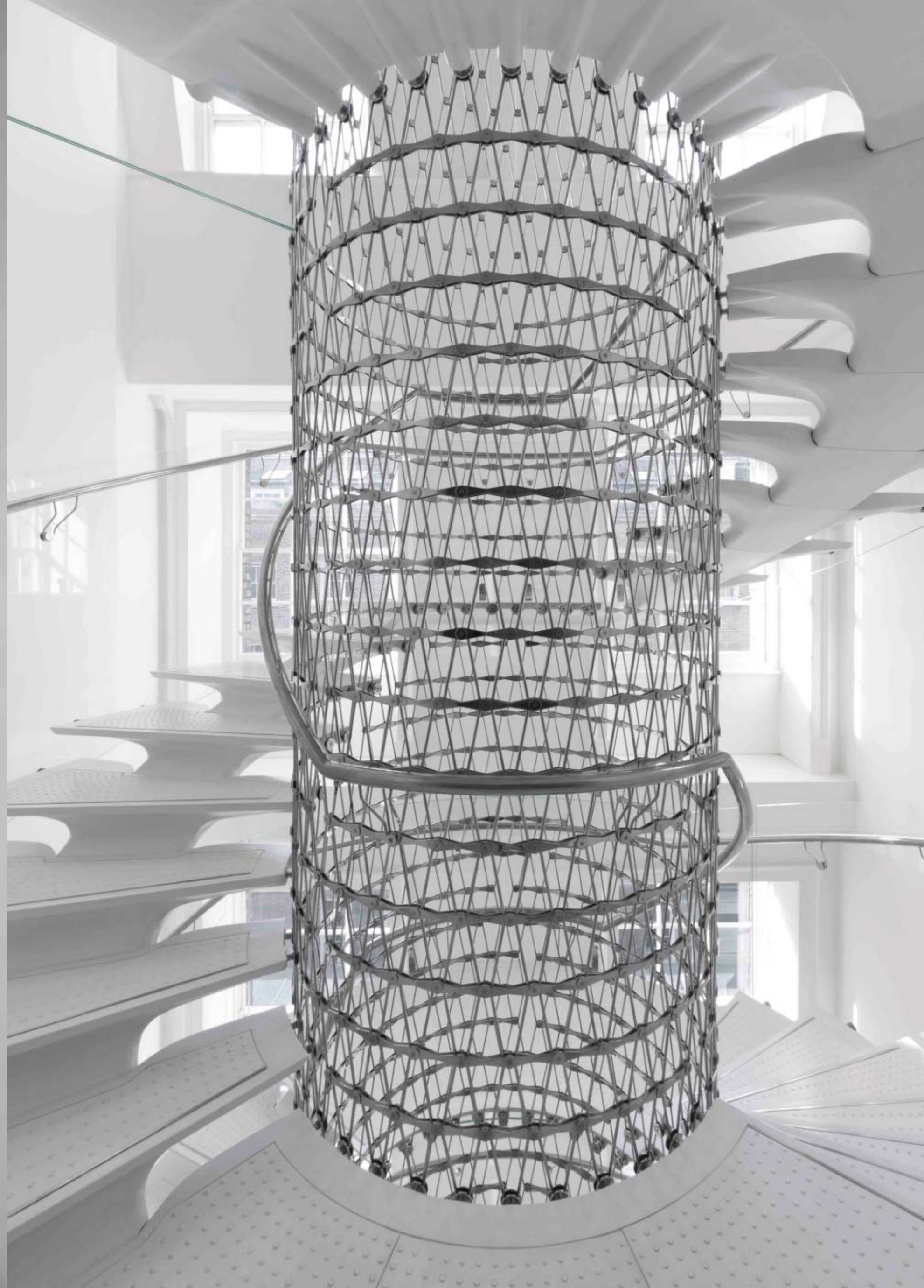
Dôme au Qatar / Premier Préfabriquant

Canopy, Pershing Square, Los Angeles USA / TER Paysagistes

« Panneaux de la « Crèche Budin », Paris France / Combarel Marrec Architectes / Il cantiere Prefabriquant

Show room Zaha Hadid / Londres / Il cantiere Prefabriquant





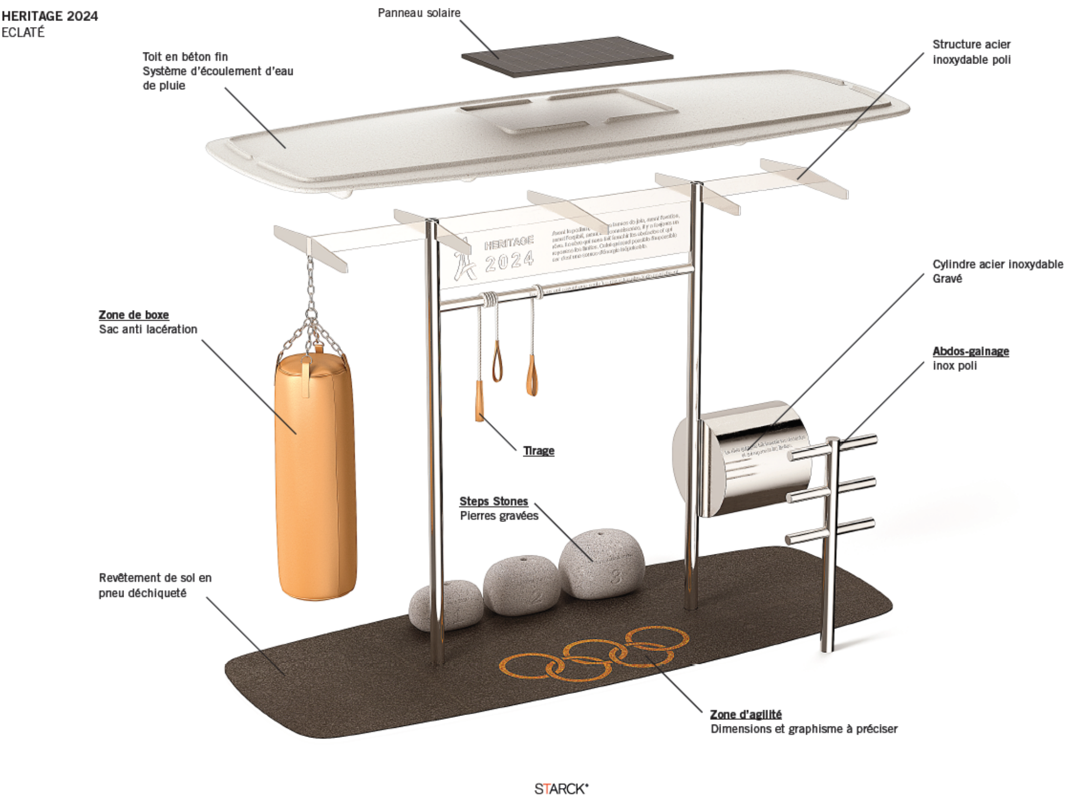
L'escalier de la Somerset House, London UK / Il cantiere Prefabriquant

Escalier fondations les Galeries Lafayettes, Paris / OMA Architectes / Jousselin Prefabriquant

C&E ingénierie des structures

Ductal®

AFGC
Association Française de Génie Civil


HERITAGE 2024
ECLATÉ
Panneau solaire
Toit en béton fin
Système d'écoulement d'eau
de pluie
Structure acier
inoxydable poli
HERITAGE
2024
Cylindre acier inoxydable
Gravé
Zone de boxe
Sac anti lacération
Abdos-gainage
inox poli
Tirage
Steps Stones
Pierres gravées
Revêtement de sol en
pneu déchiqueté
Zone d'agilité
Dimensions et graphisme à préciser
STARCK

Poutre en béton précontrainte, Chine / Huaxin Prefabriquant

L’anneau de la mémoire, Arras France / Eiffage Construction Entreprise

1- Matériau, quelques repères

2- Conception, quelques règles

3- Etude de cas

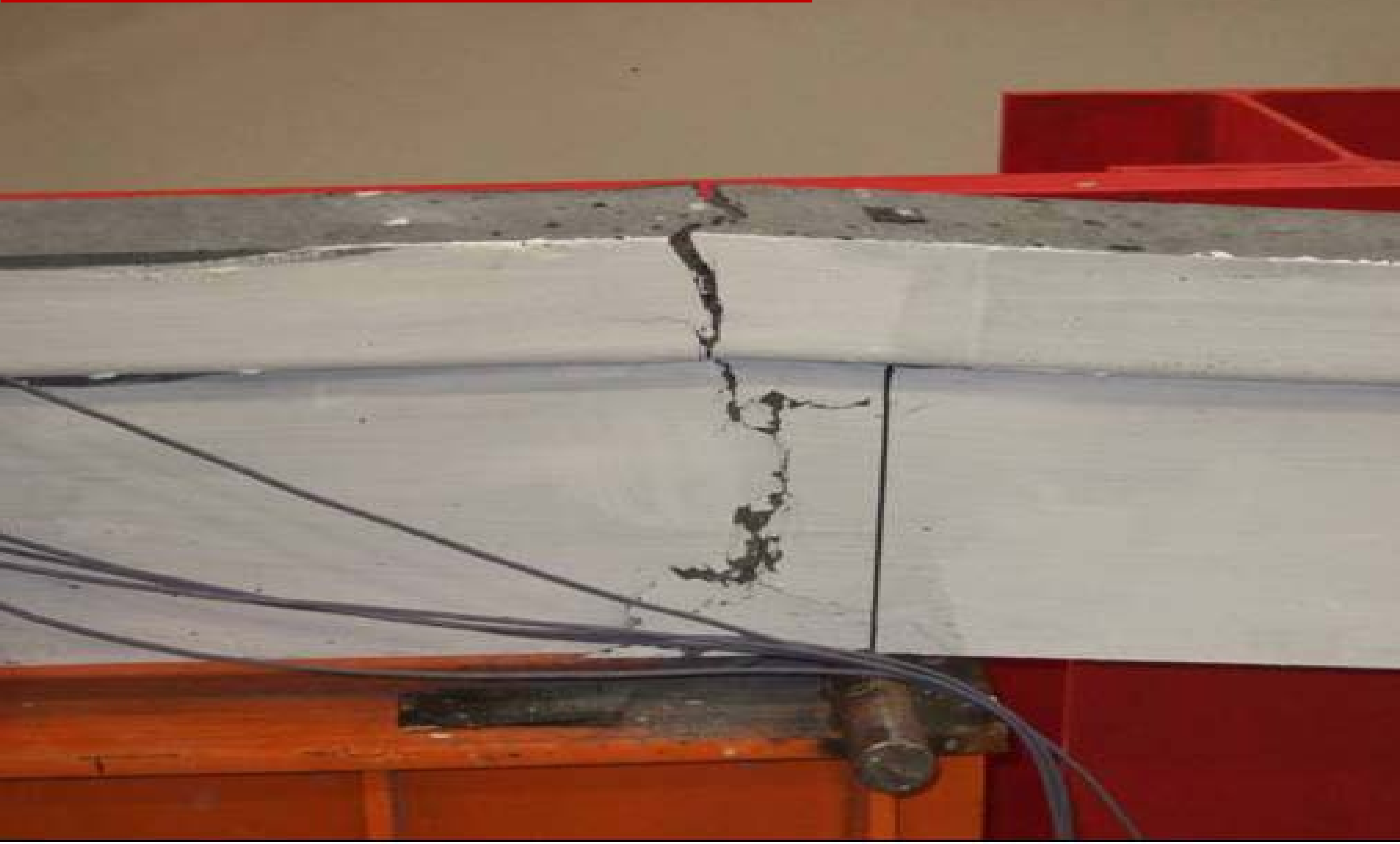
4- Synthese

1- Matériau, quelques repères

2- Conception, quelques règles

3- Etude de cas

4- Synthese



MATERIAU

Les qualités spécifiques des B.U.H.P qui ouvrent des possibilités de conception nouvelles..

Comportement

Minimisation du ferraillage mis en oeuvre
Utilisation de la résistance du béton à la traction
Etude du comportement post- élastique du matériau
Bonne résistance aux environnements agressifs
Reduction de l'enrobage $c \geq 1.5\ Lf \approx 2.5cm \sim 3.5cm$ (Lf = longueur de la fibre)
Porosité très faible

Géométrie

Finesse et élancement des pièces
Haute qualité de finition possible

Mise en oeuvre

Ouvrabilité permettant la conception de formes complexes
Résistance élevée au jeune age
Peu de maintenance

B.U.H.P de fibres organiques	B.U.H.P de fibres métalliques
PANNEAUX / VETURES ELEMENTS NON STRUCTUREL BRISE SOLEIL MARCHE / EMMARCHEMENT ESCALIER*[1]	PANNEAUX / VETURES ELEMENTS NON STRUCTUREL OSSATURE / DALLE ESCALIER / EMMARCHEMENT AUVENTS / COQUE

Propriétés typiques des B.U.H.P :

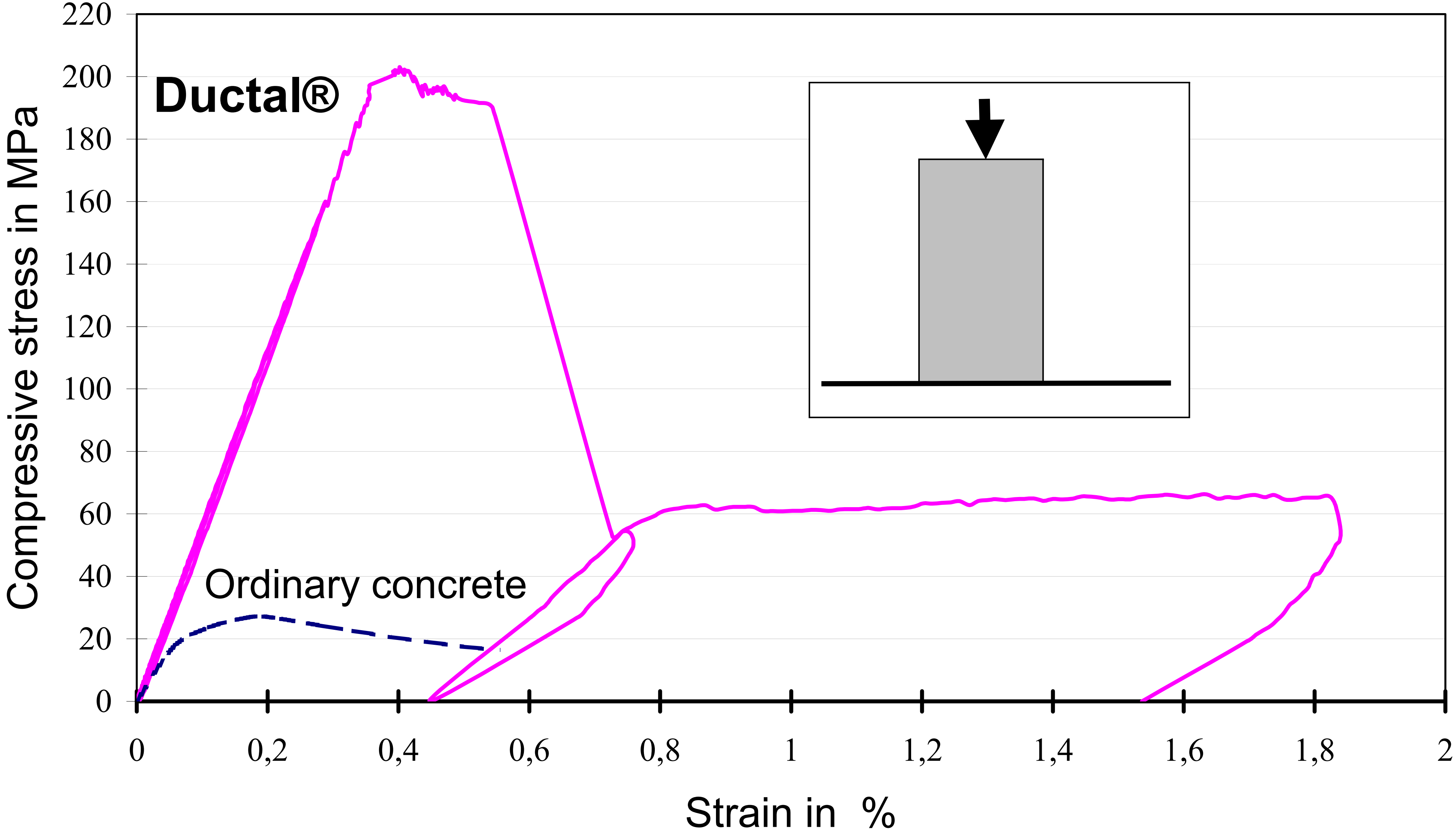
P1 : Resistance à la compression supérieure à 100 MPa

P2 : Résistance à la traction comprise entre 5 and 10 MPa. Le comportement à la traction est associé à une bonne ductilité liée aux fibres.

P3 : La proportion de ciment est importante. Le ratio moyen eau-ciment est égal à 0,2 du volume total.

P4 : Tres peu de porosité.

Diagramme représentant la capacité en compression du béton



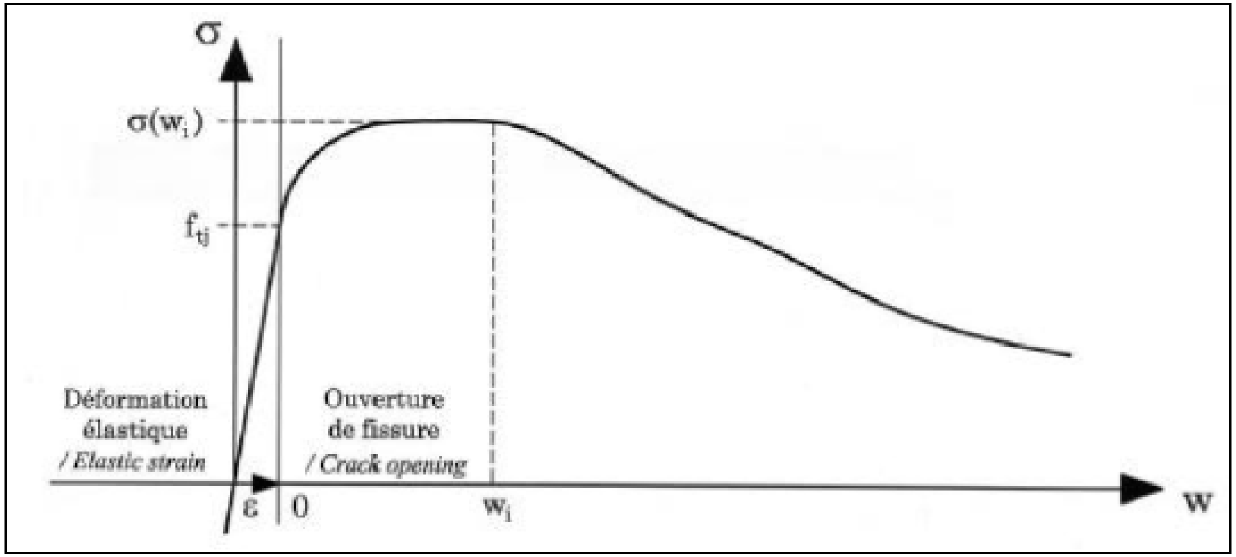


Figure 6 : Exemple de loi de comportement d'un BFUP de fibres métalliques

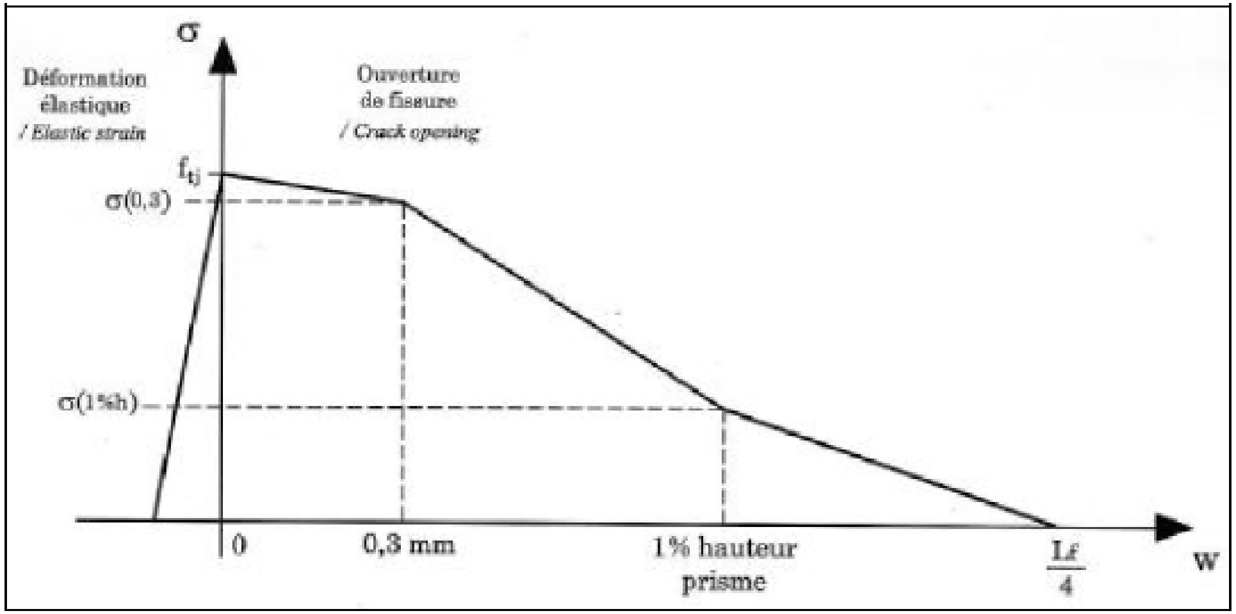
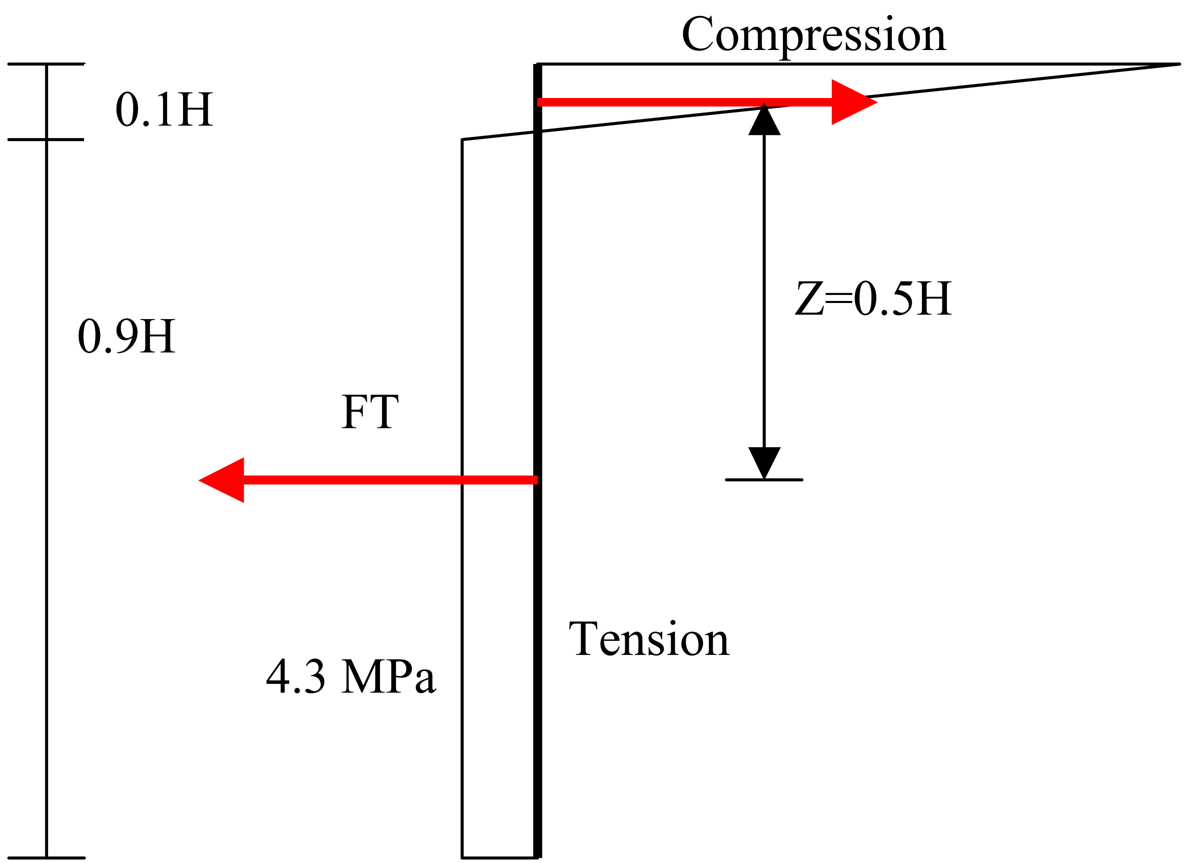


Figure 7 : Loi en traction simplifiée d'un BFUP de fibres métalliques ($\sigma = f_{(\varepsilon)}$)

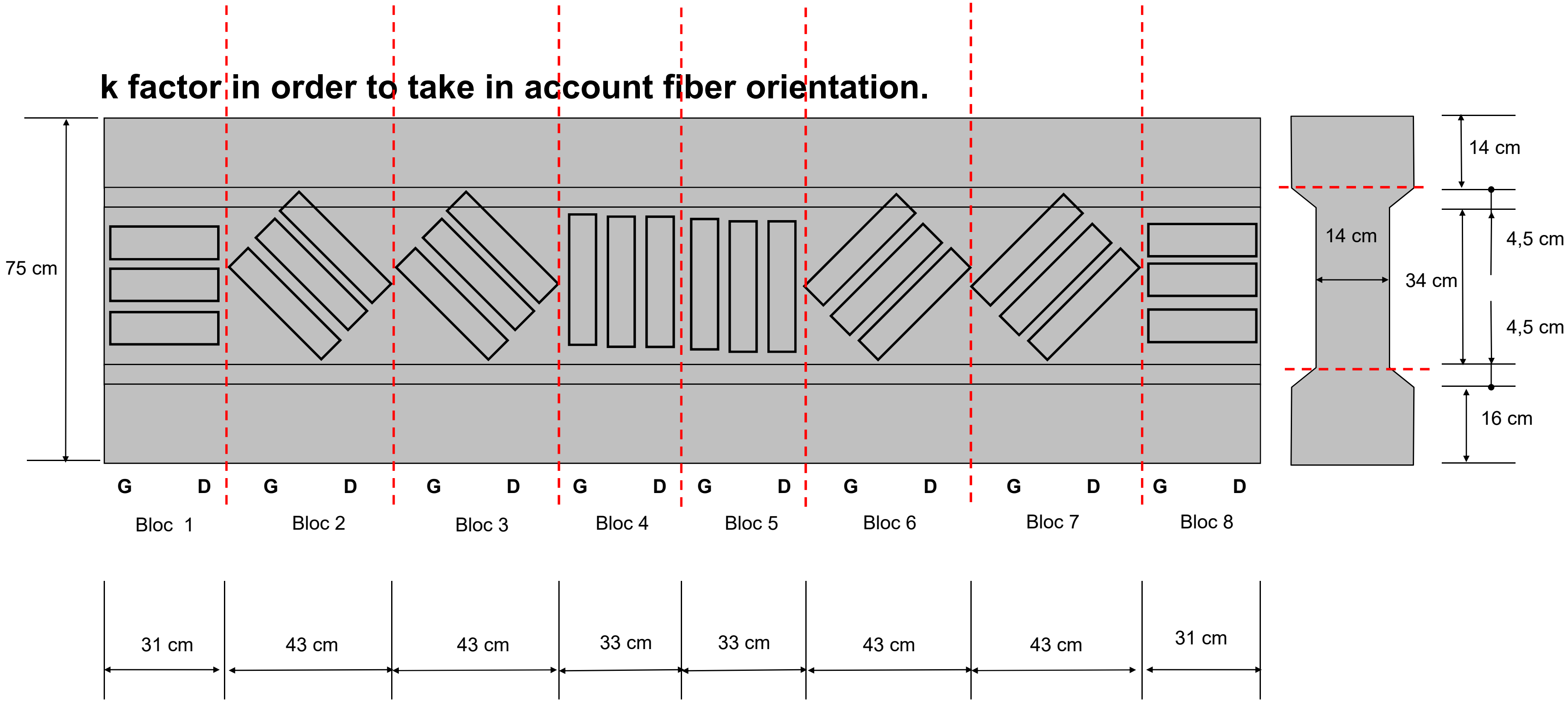
(Extrait des Recommandations provisoires de l'AFGC et du SETRA [1.1])

Distribution des contraintes dans la section



Importance de l'orientation des fibres

k factor in order to take in account fiber orientation.



1- Matériau, quelques repères

2- Conception, quelques règles

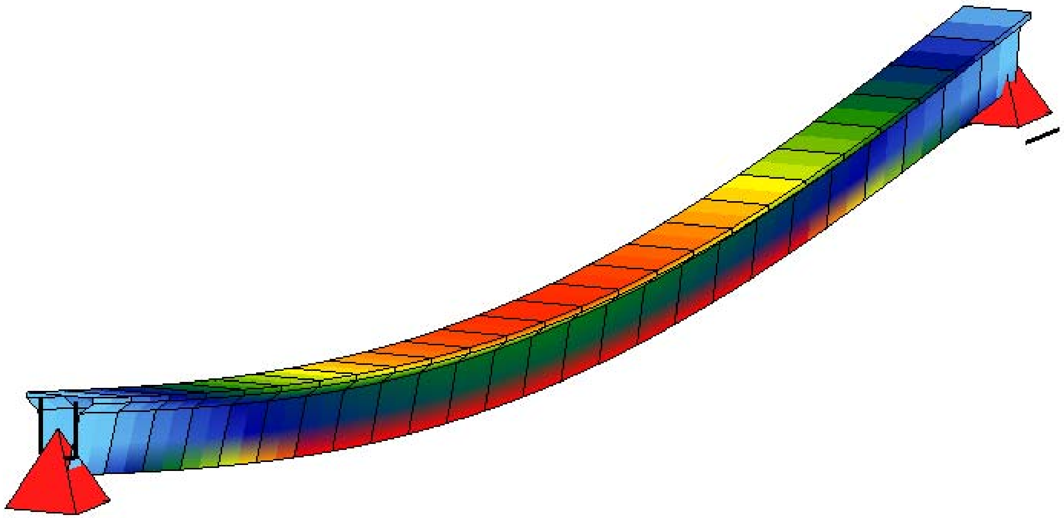
3- Etude de cas

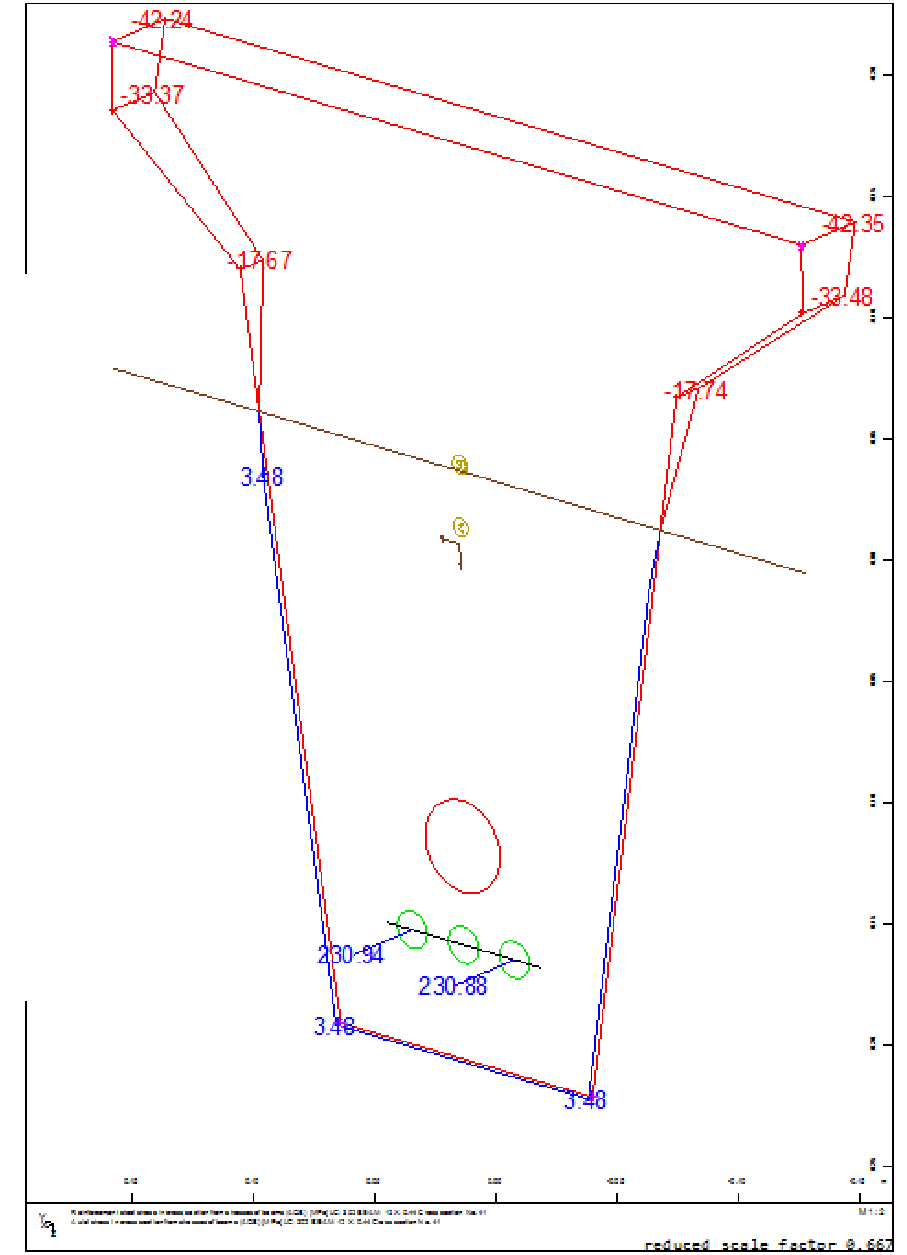
4- Synthese

	UHPFRC CALCULATION PROCESS / ROUGH SYNTHESIS					
	BENDING ELASTIC ANALYSIS	BENDING POST ELASTIC ANALYSIS	REBAR CONTRIBUTION	SHEAR ANALYSIS	DEFLECTION CONTROL	CRACK CONTROL ANALYSIS
UHPFRC FO	Average tensile bending stress with a safety factor of 3	Using stress crack width law	Depending on the design but this must remain local reinforcement	Considering fibers contribution	Calculation in a non cracked section With a specific material behavior law	Condition of non brittleness
UHPFRC FM	Following Code	Using stress crack width law	Following codes	Considering fibers contribution / section contribution / rebars contribution		

Conception, quelques règles

Etat d'équilibre après une analyse non linéaire



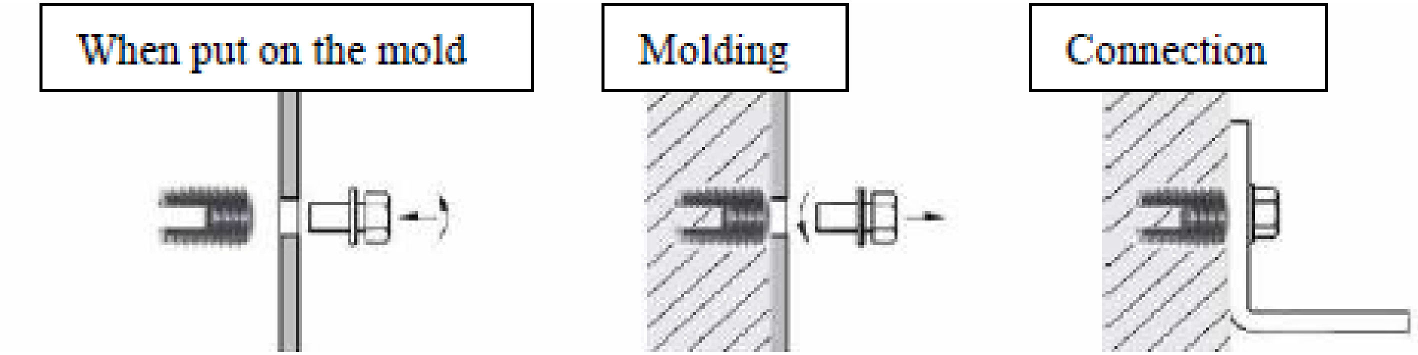


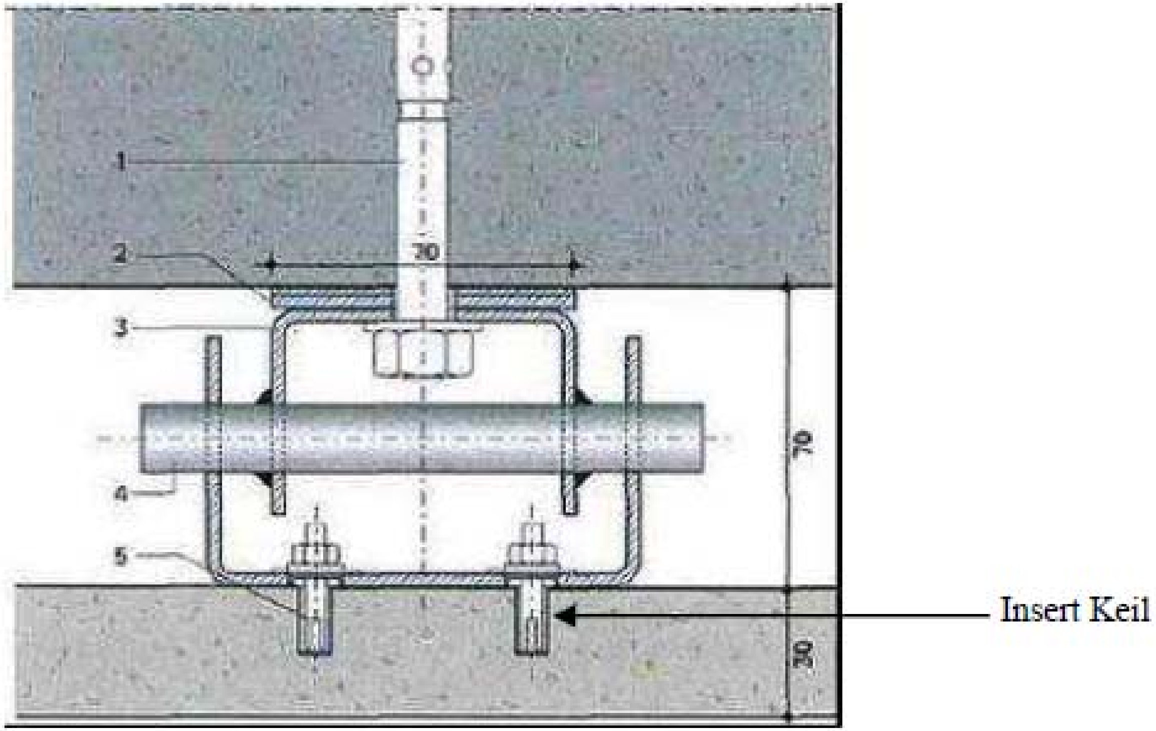
Calculation done with the software SOFISTIK AG

Conception, quelques règles

<table>
<tr><th></th><th colspan="6">UHPFRC TECHNOLOGICAL KEY POINTS / ROUGH SYNTHESIS</th></tr>
<tr><th></th><th>ENVIRONMENTAL CLASSES</th><th>MINIMUM THICKNESS AND WIDTH</th><th>PANEL DEAD WIEGHT TRANSFER</th><th>REBAR REINFORCEMENT</th><th>PANEL ANCHORAGE STRATEGY</th><th>HEAT TREATMENT</th></tr>
<tr><td>UHPFRC FO</td><td rowspan="2">If using reinforcing Ductal checking covering of rebar</td><td rowspan="2">30 mm (poured with no reinforcement) / 35mm (pourded with reinforcement) / 15 mm (spraid) / fiber length limit</td><td rowspan="2">If possible consider isostatic transfer to the primary structure.</td><td>To be used rarely. Cracking risk analysis</td><td rowspan="2">Connection systems have to allow both for thermal expansion and fitting tolerane</td><td rowspan="2">Rarely used in everyday project</td></tr>
<tr><td>UHPFRC FM</td><td>Acceptable and justified solution</td></tr>
</table>

Conception, quelques règles





	UHPFRC CONSTRUCTION PROCESS SPECIFICITIES / ROUGH SYNTHESIS					
	FORMWORK STRATEGY	HEAT TREATMENT	SHRINKAGE QUESTION	CONSTRUCTION STAGE ANTICIPATION	PREFABRICATION VERSUS PULLED ON SITE	UNEXPECTED EVENTS
UHPFRC FO	Complexity of the molds / number and repetition of the molds	Ralely used in everyday projects / depending of the dimension and contractof capacity	0.8 mm/m. Almost all the shrinkage at the beguinning	The anchorage used for construction stage must be different. The construction step must be checked with the contractor	Only prefabrication.	Deflexion during molded process / unexpected cracking near reinforcement
UHPFRC FM			0.5 mm/m. Almost all the shrinkage at the beguinning		Prefabrication and pulled on site for specific structural element	corrosion / unexpecting cracking near reinforcement

Conception, quelques règles

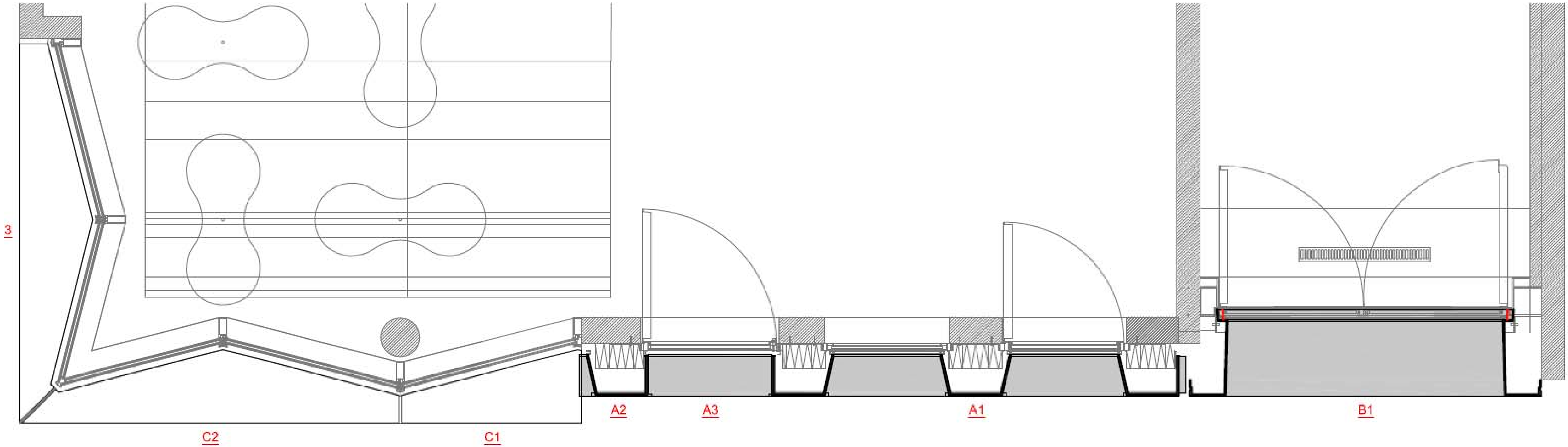
Ductal projeté ® / EDF Orsay

Conception, quelques règles

Ductal projeté ® / EDF Orsay

Design process

Ductal projeté ® / EDF Orsay



1- Matériau, quelques repères

2- Conception, quelques règles

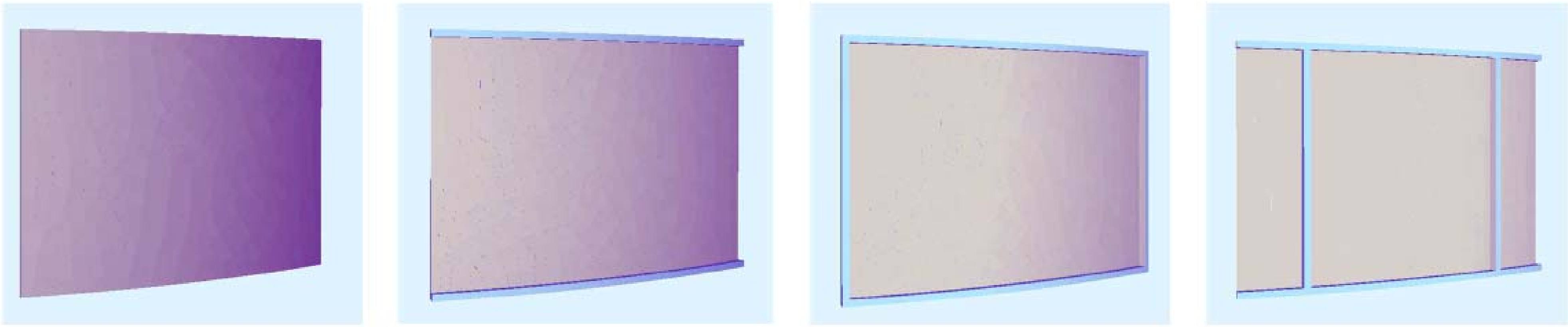
3- Etude de cas

4- Synthese

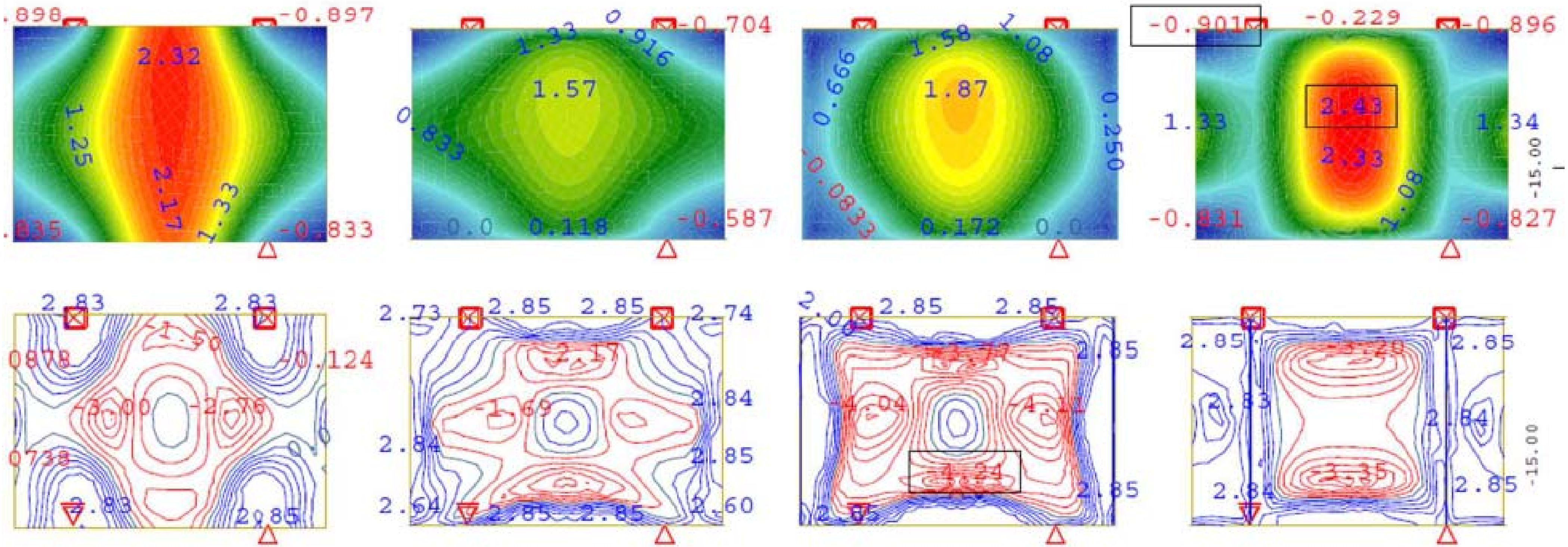
THORP PRECAST DUCTAL FO PANELS

Localization : Gasholder triplets King's Cross, London
Building typology : R+10
Dimensions of the panels : 3973x3205mm
Function : Façade panels
UHPFRC : Ductal® FO

Design hypothesis _ Preliminary design analysis

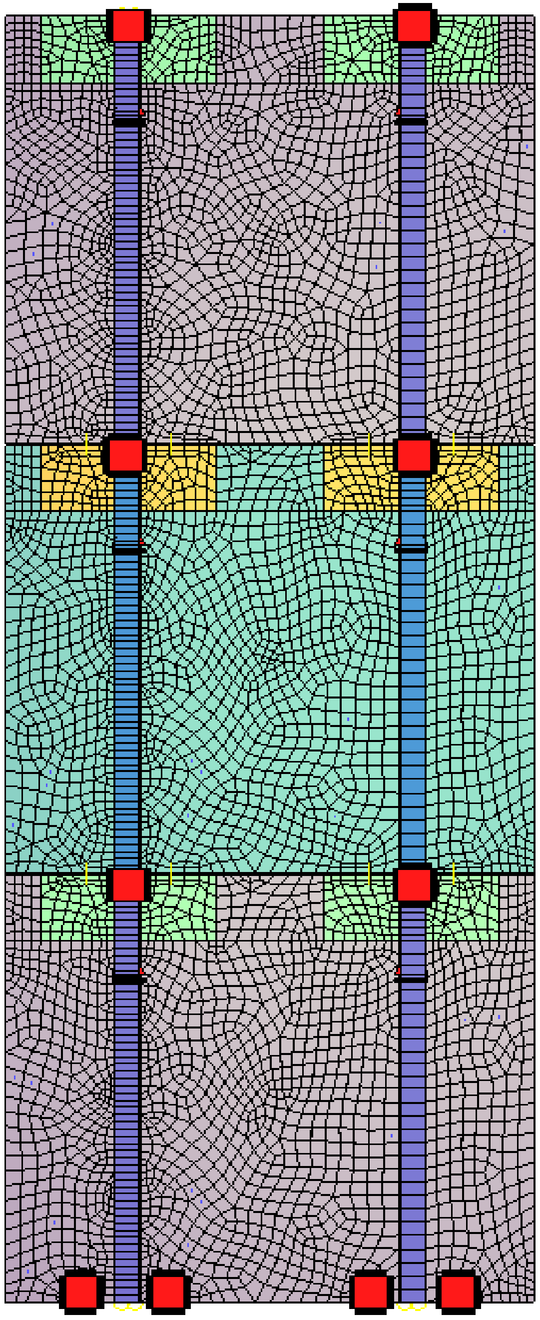


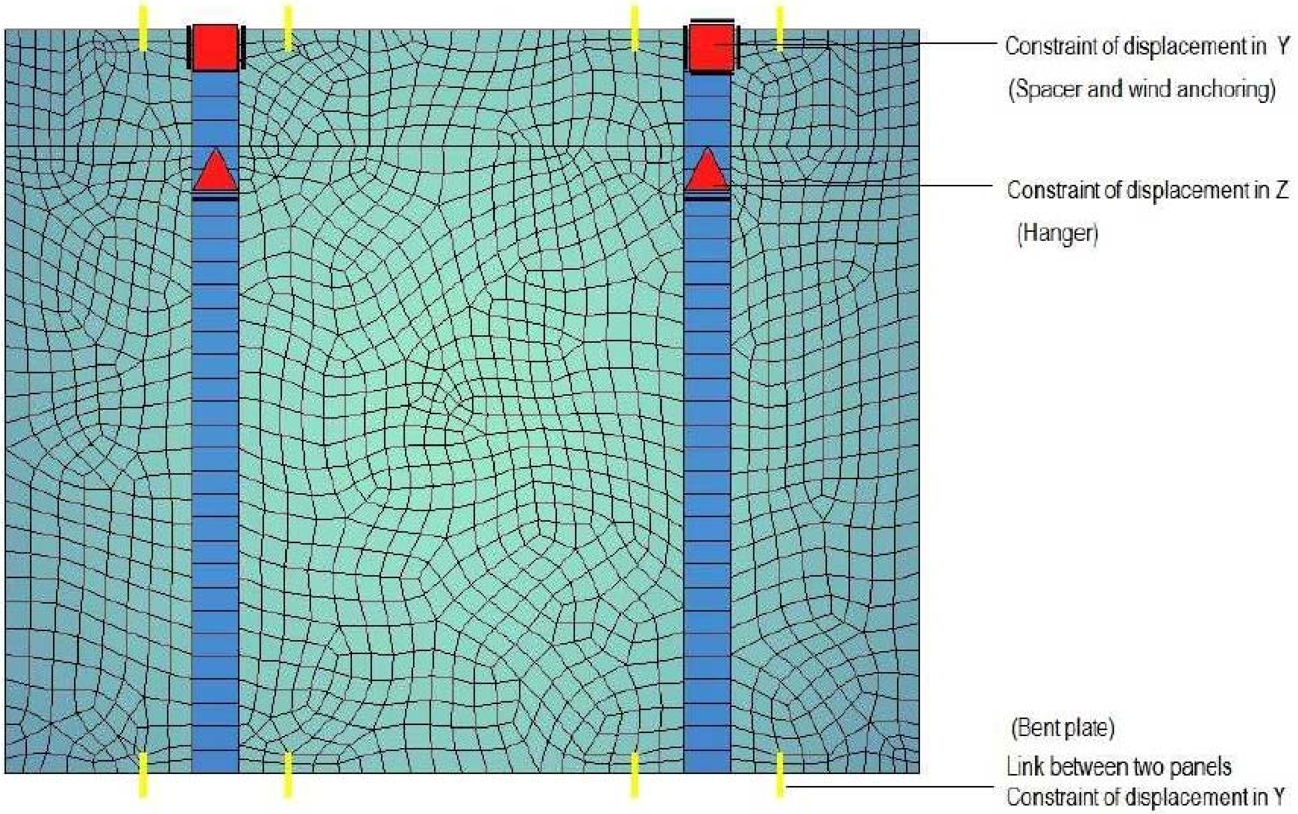
Option 1 *: Simple panel* ***Option 2*** *: Panel with horizontal ribbon* ***Option 3*** *: Panel with peripherical frame* ***Option 4*** *: Panel with intermediate stiffeners*



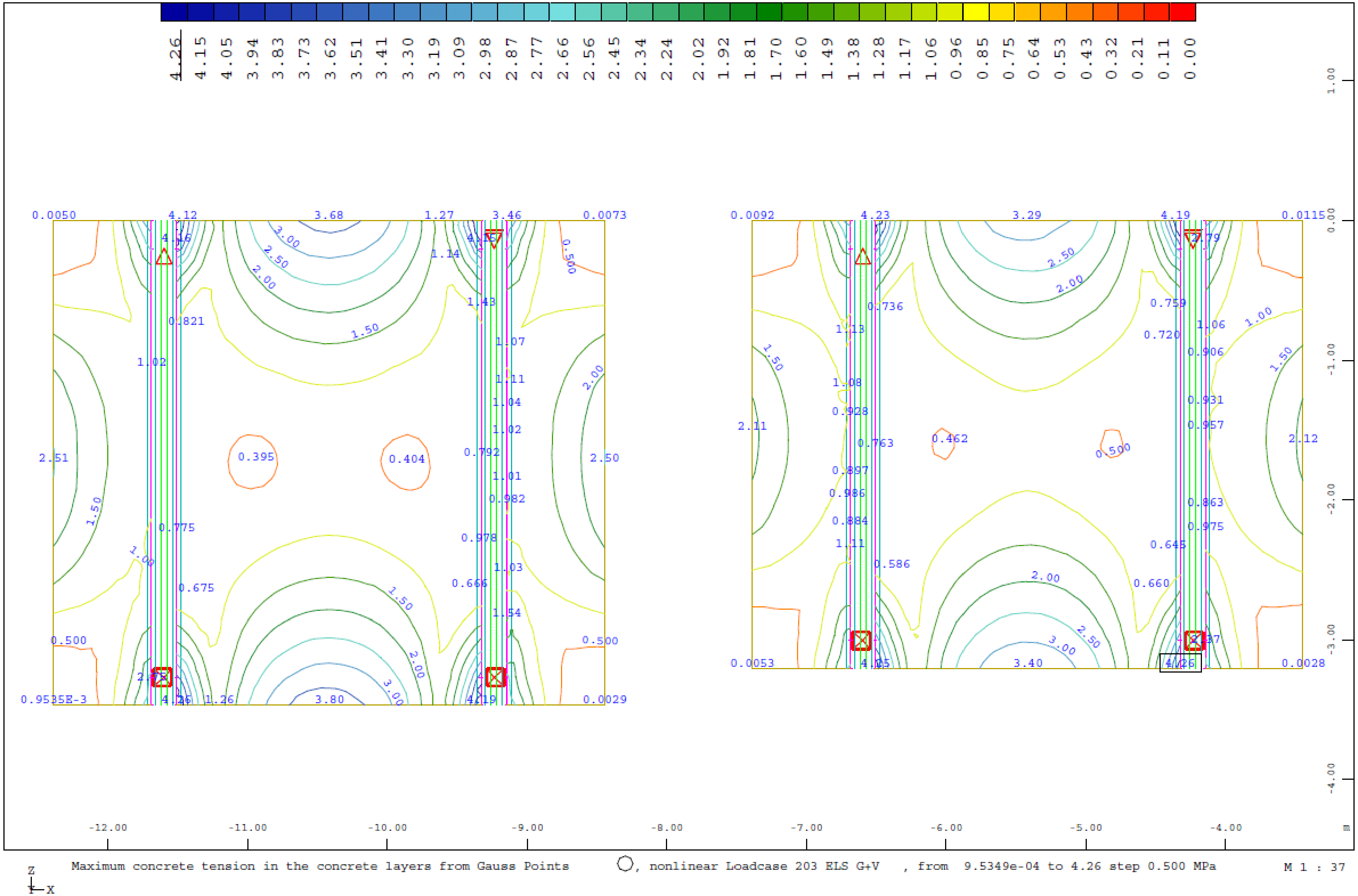
Option 1 Option 2 Option 3 Option 4

Design hypothesis _ Static Scheme



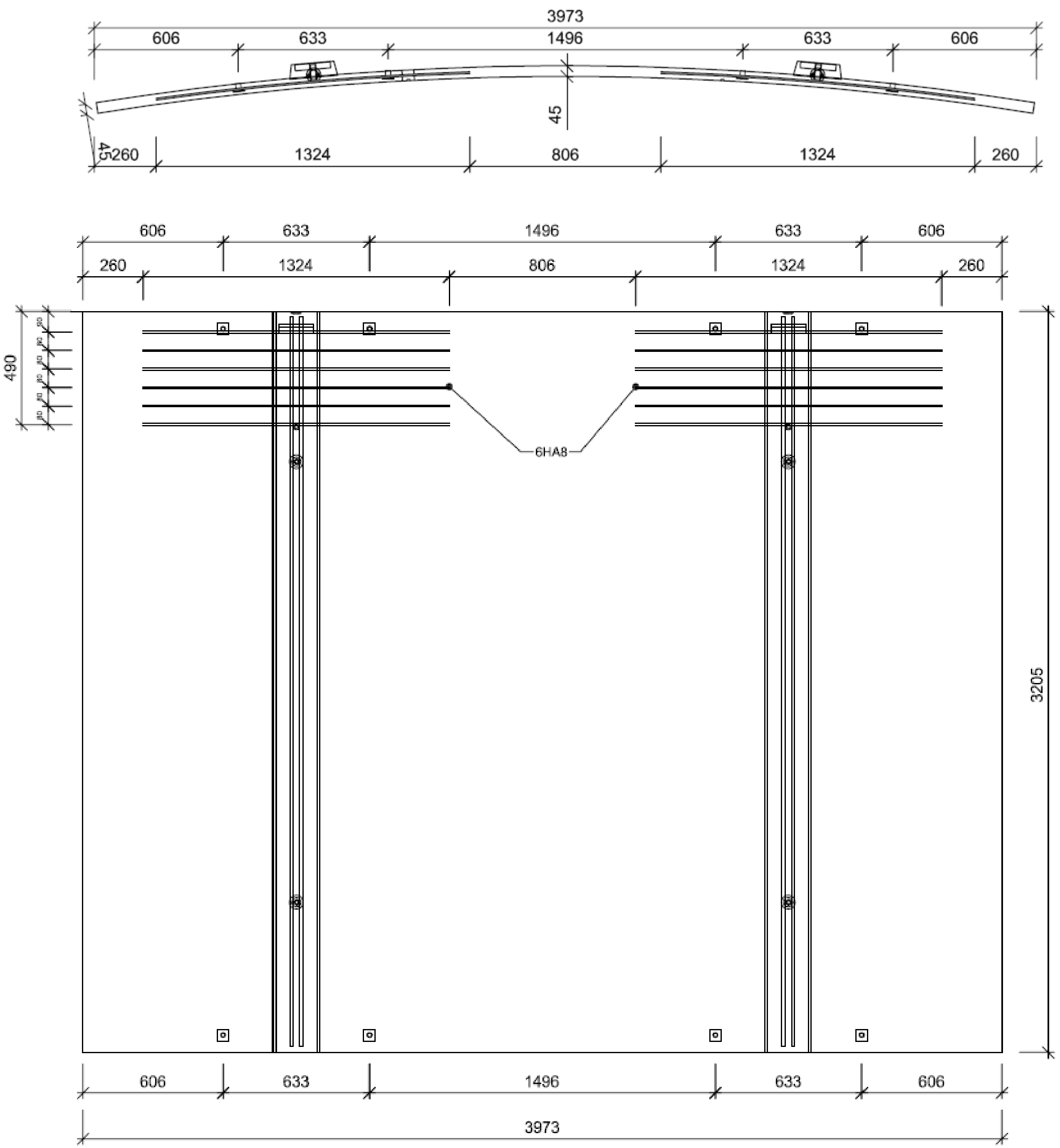


Design hypothesis _ Static Schema

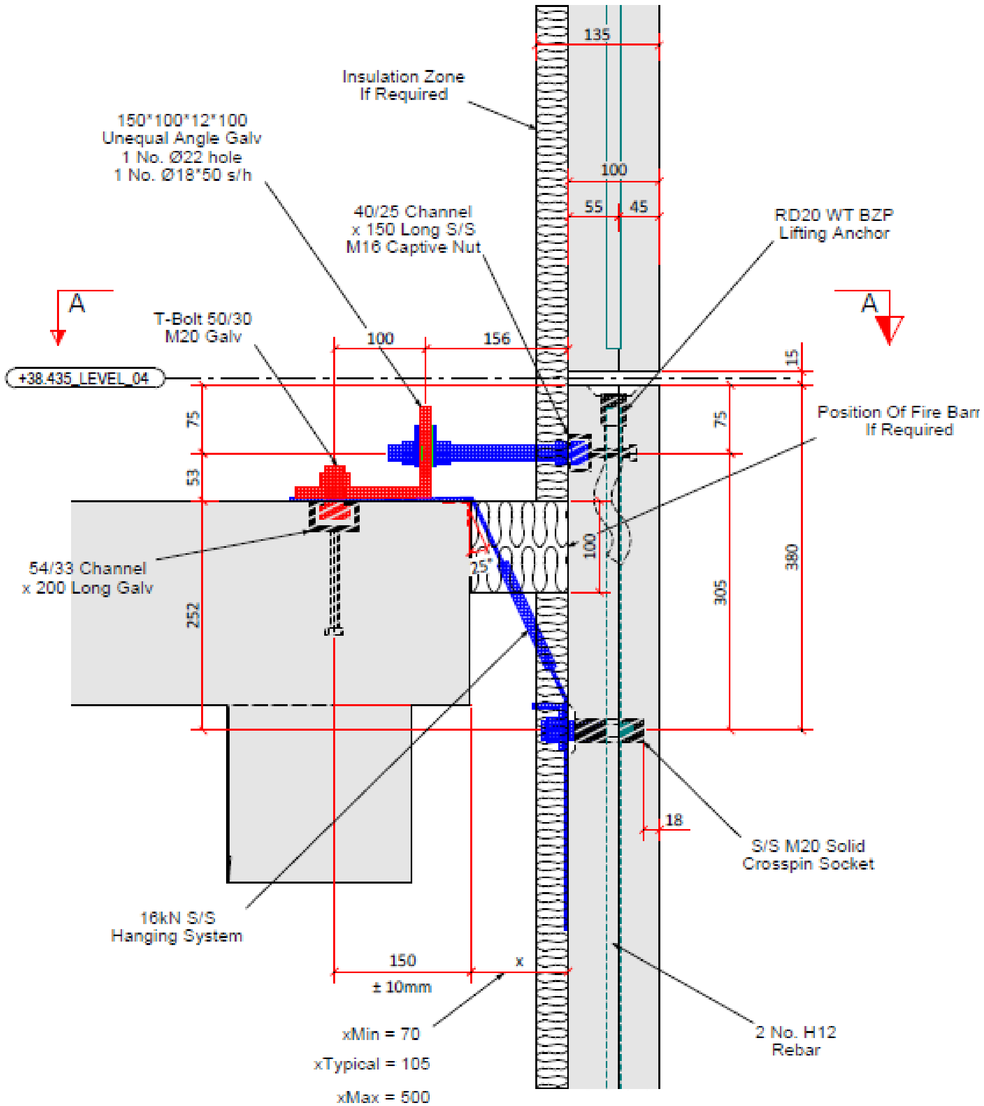


Maximum tensile stress for Ductal NaW3 FO under the combinaison SLS G+W non - linear anlysis
Tensile stress is limited to 4.3MPa
Representation : ISO-LINE

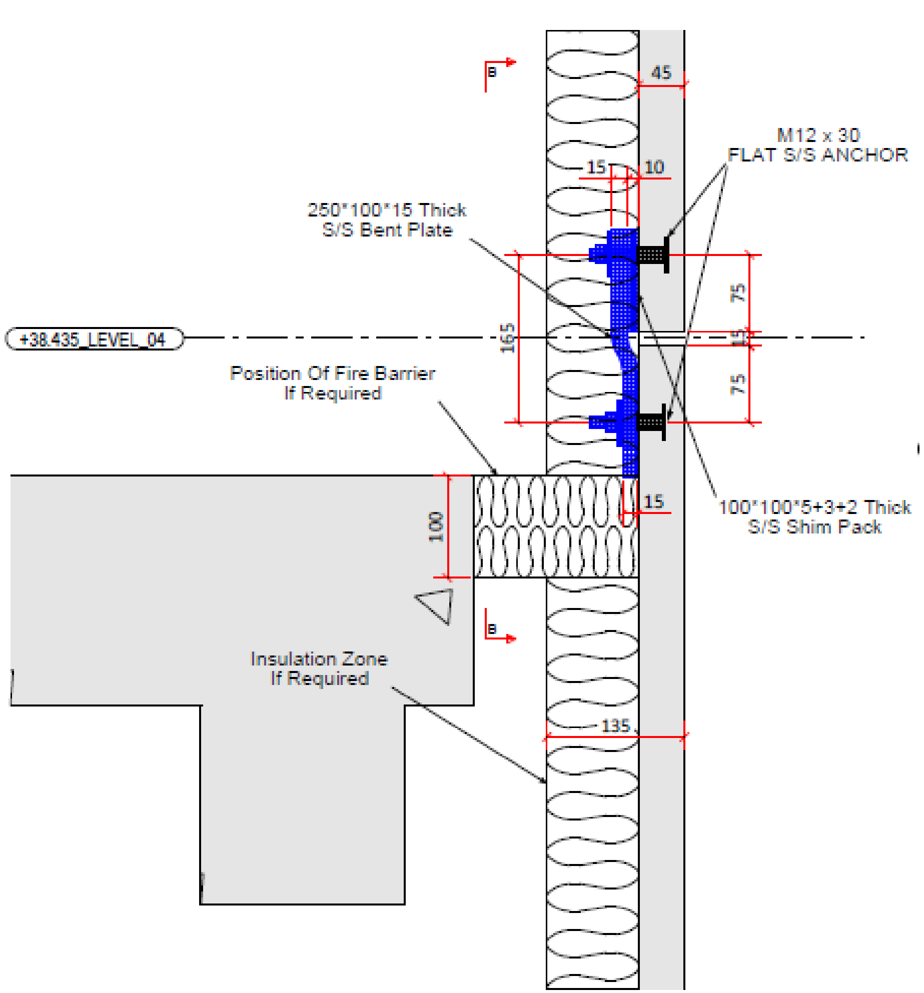
Design hypothesis _ Static Schema



Anchorage details



DETAIL A
1:3



DETAIL B
1:3

Thorp contractor drawings

Hanger, spacing and wind anchoring

Bent plate

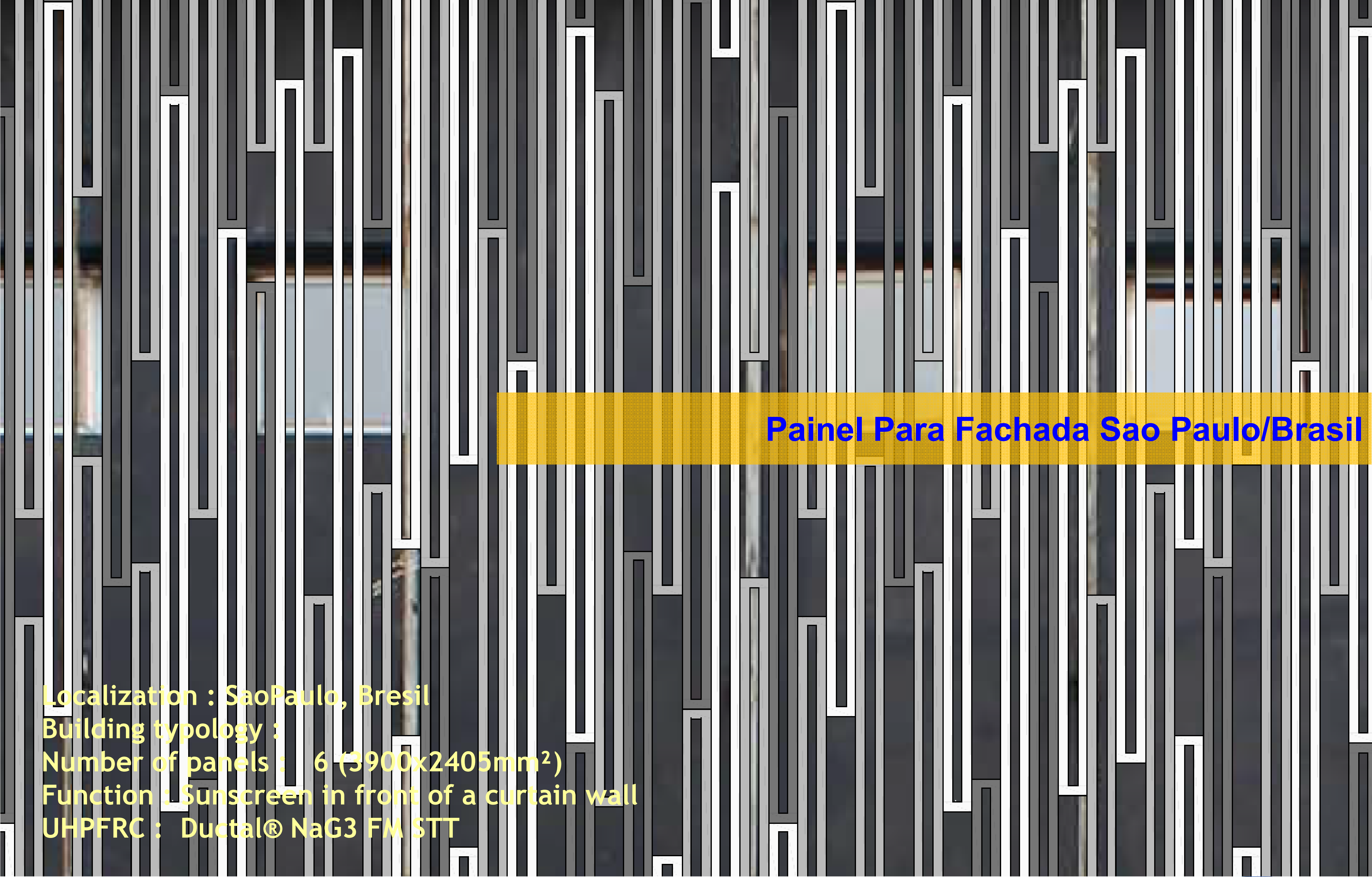
Construction process analysis

Option 1

Option 2

Option 3

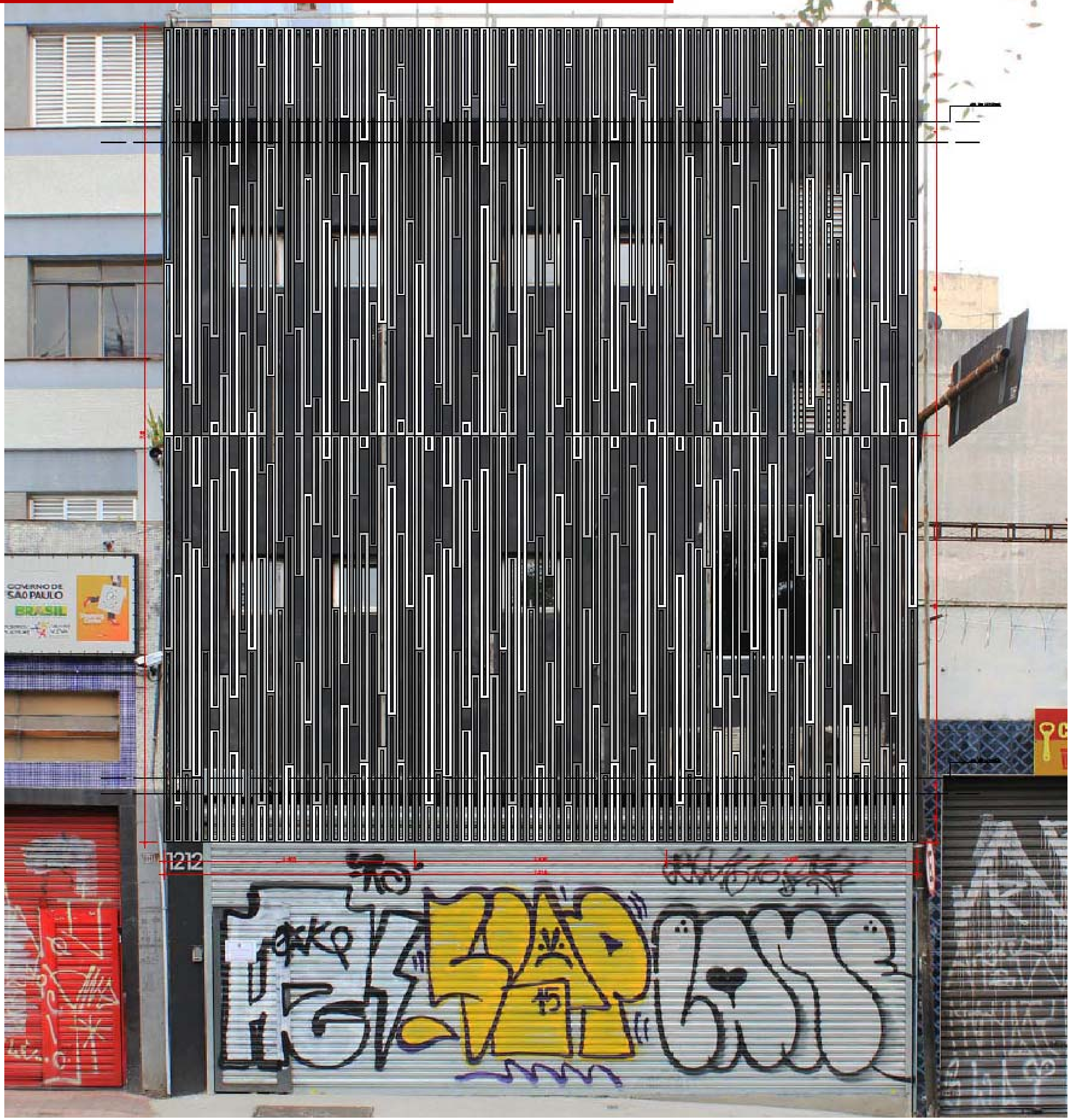
Option 4



Painel Para Fachada Sao Paulo/Brasil

Localization : SaoPaulo, Bresil
Building typology :
Number of panels : 6 (3900x2405mm²)
Function : Sunscreen in front of a curtain wall
UHPFRC : Ductal® NaG3 FM STT

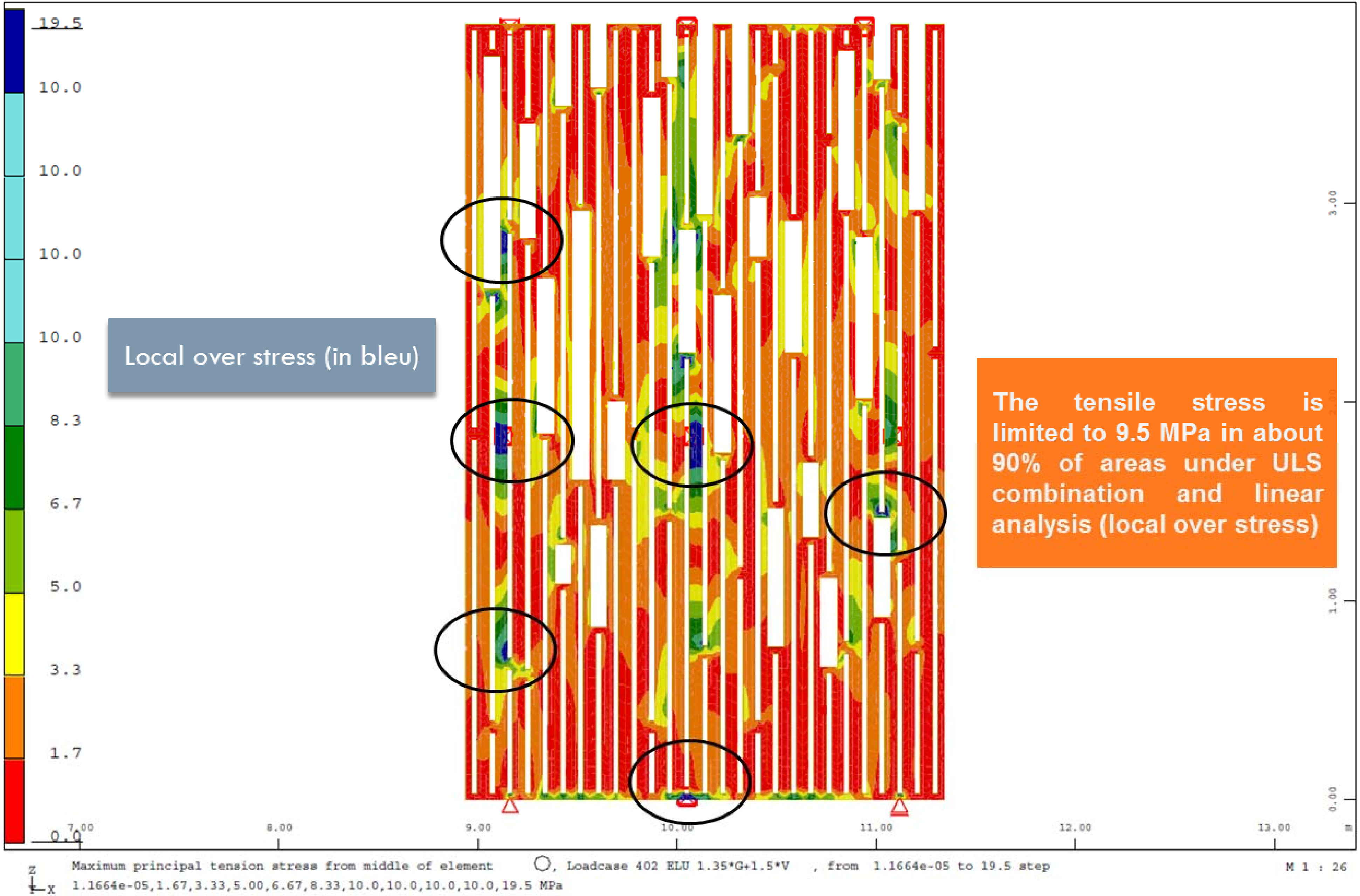
Design hypothesis _ Geometry



Design hypothesis _ Preliminary design analysis

Design hypothesis			Analysis			Classification
	PANEL	STEEL SUPPORT	Maximum tensile stress / ULS linear analysis (max 9,5 Mpa)	Displacement / SLS linear analysis	Comments	Efficiency
HYP 1	Initial Panel design with a thickness varying between 2/3/4 cm	3 Columns / vertical hollow sections with 12 supports	over 100MPa	20mm	The solution is not efficient	**4**
HYP 2	Initial Panel design with a constant thickness of 6,5 cm	3 Columns / vertical hollow sections with 9 supports	90% under 9.5MPa	2.4mm	Local renforcement are necessary	**3**
HYP 3	Initial Panel design with a thickness varying between 2/3/4 cm	4 linear supports built with steel hollow sections	under 9.5MPa	0.9mm	**The stress are acceptable but complex to be built**	**1**
HYP 4	Initial Panel design with a thickness varying between 4/5/6 cm	3 Columns / vertical hollow sections with 9 supports	80% under 9.5MPa	7.6mm	Local renforcement are necessary	**2**

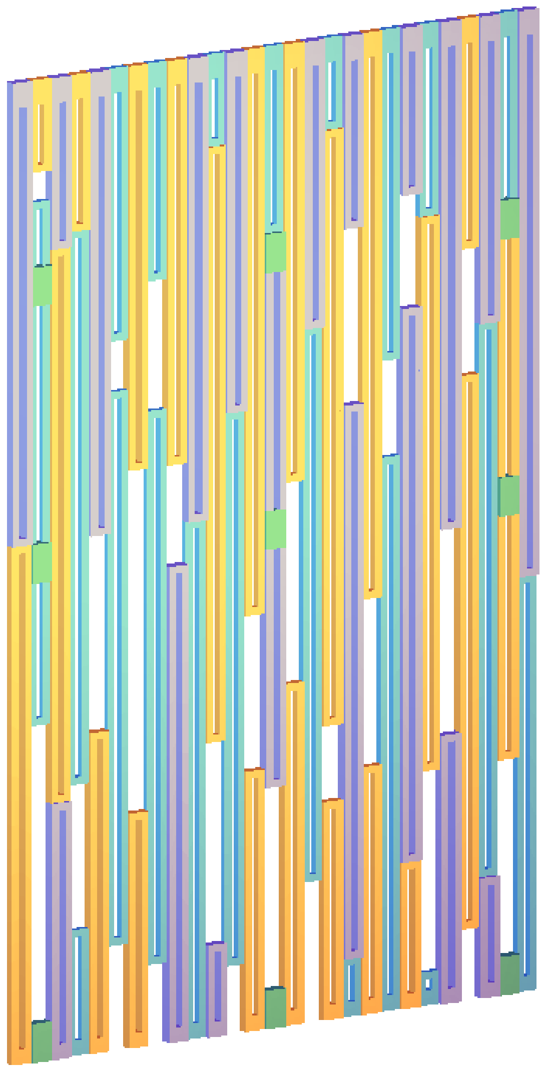
Design hypothesis _ Optimisation

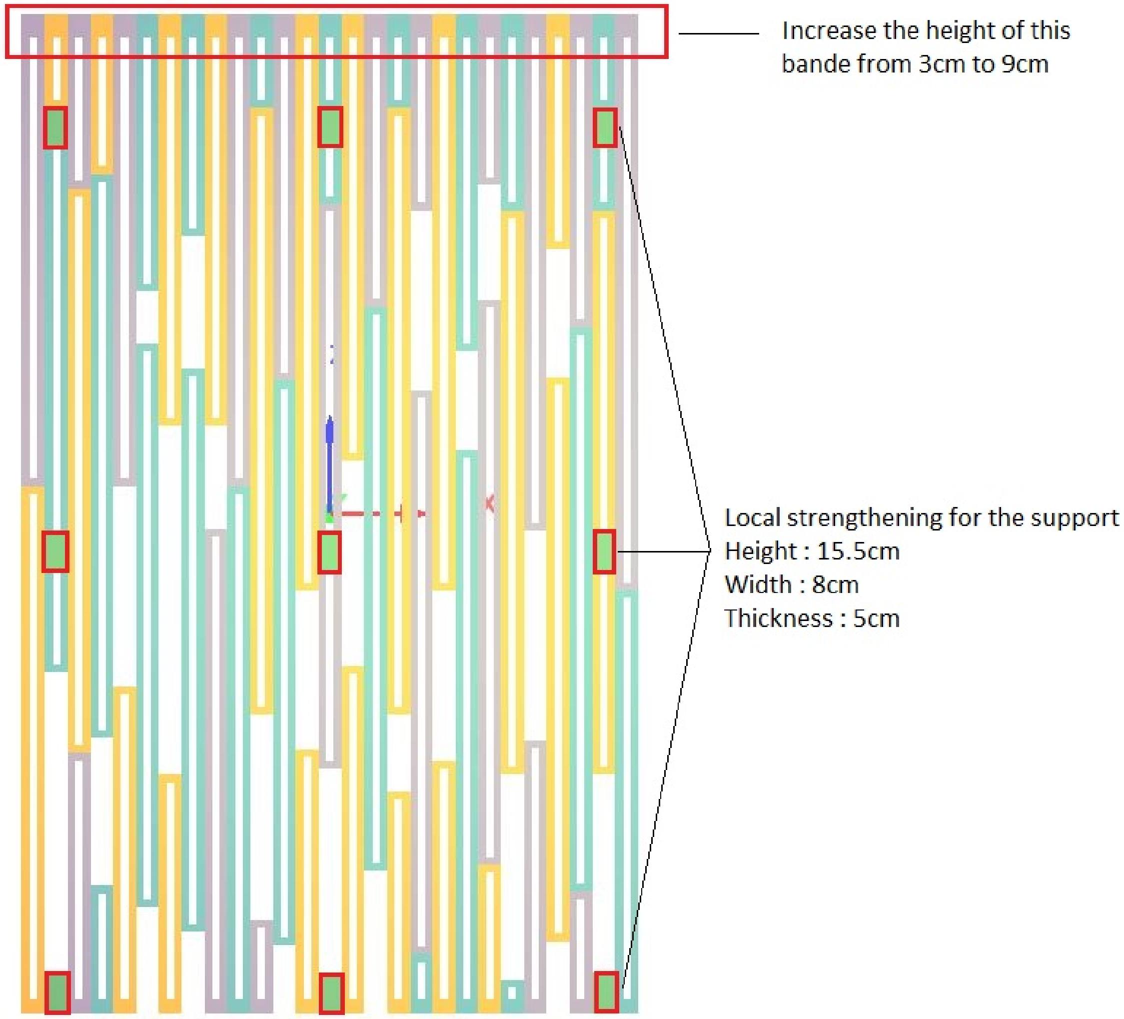


Local over stress (in bleu)

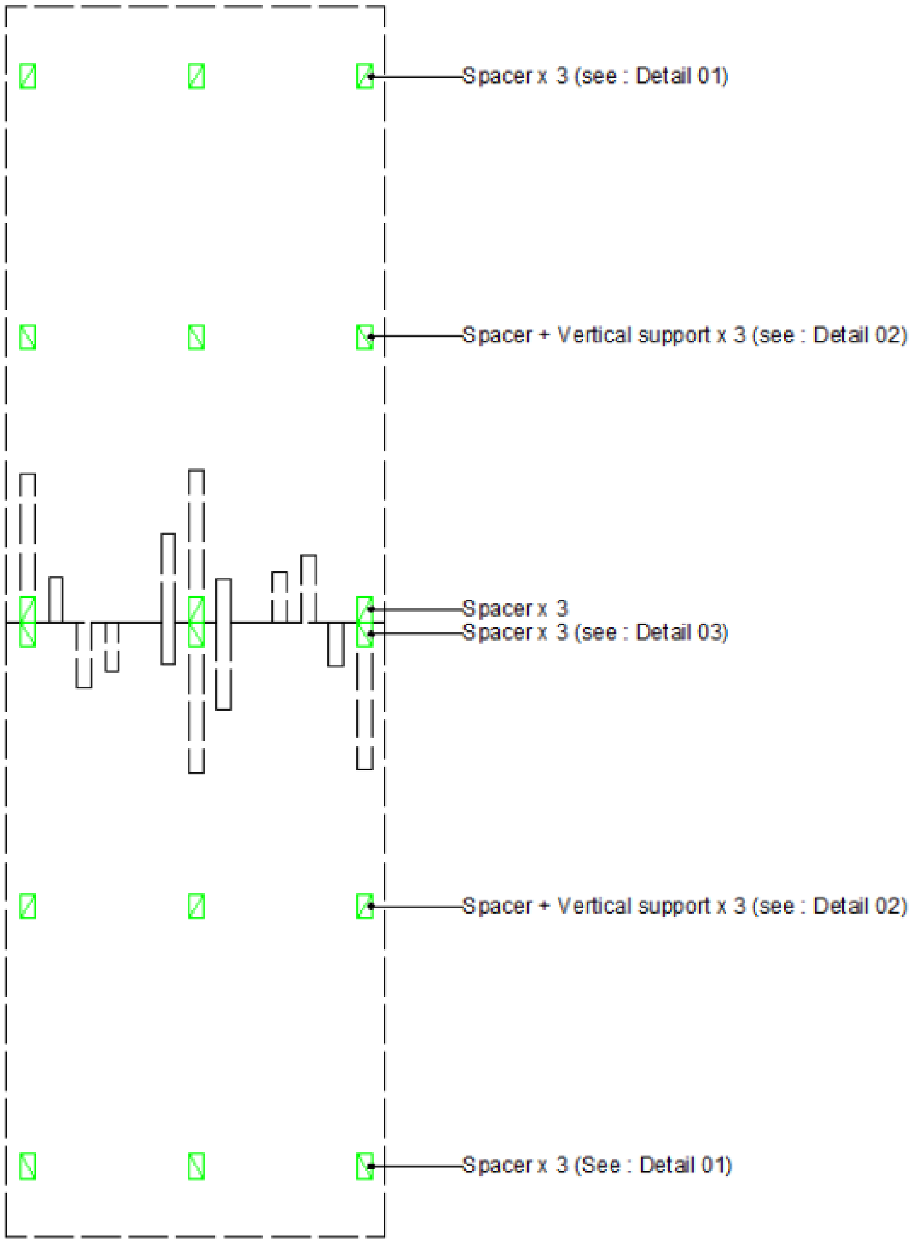
The tensile stress is limited to 9.5 MPa in about 90% of areas under ULS combination and linear analysis (local over stress)

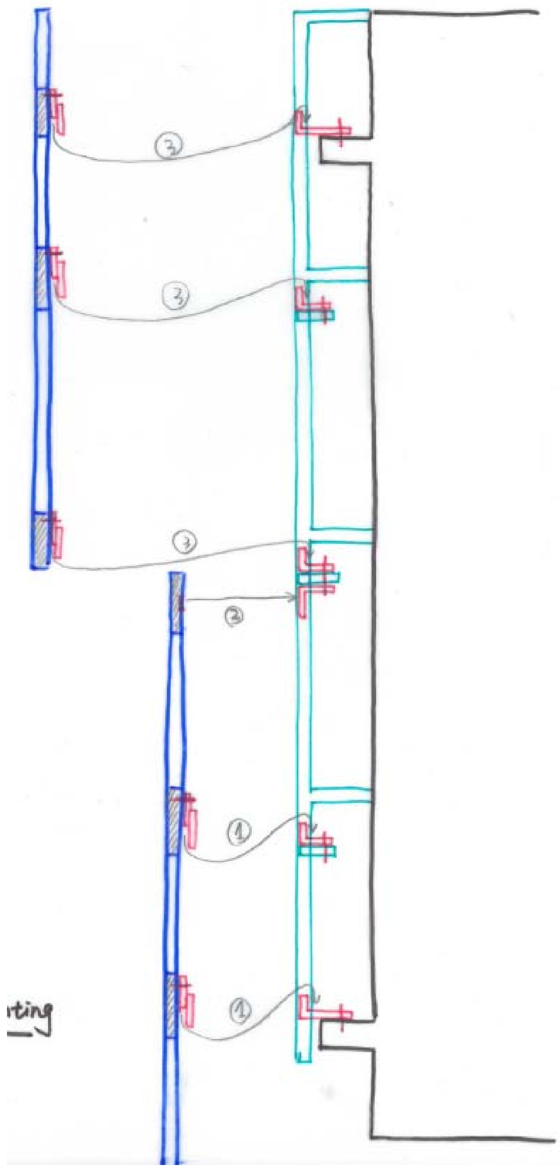
Design hypothesis _Optimisation





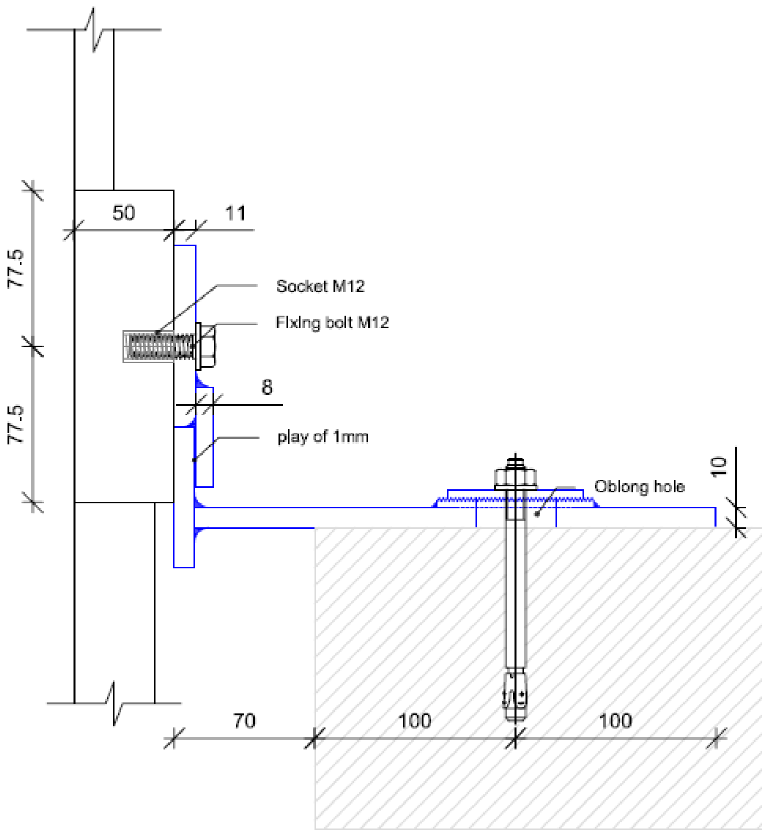
Construction process analysis



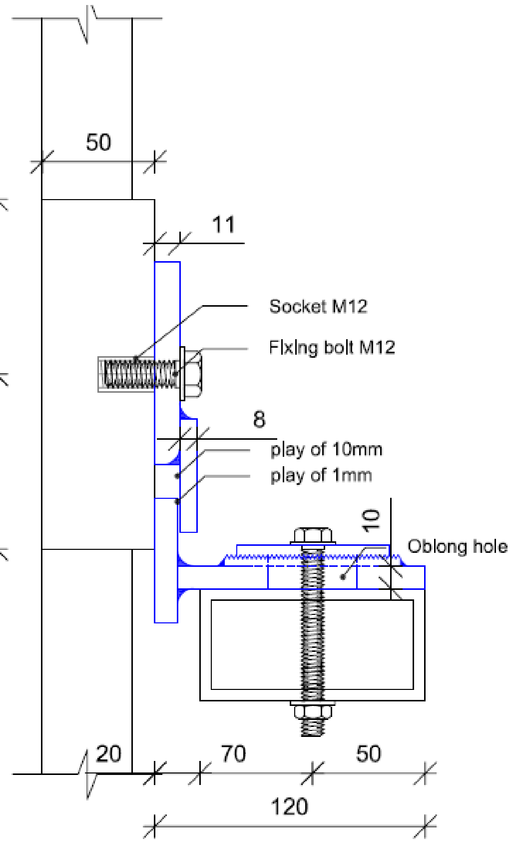


Construction process analysis

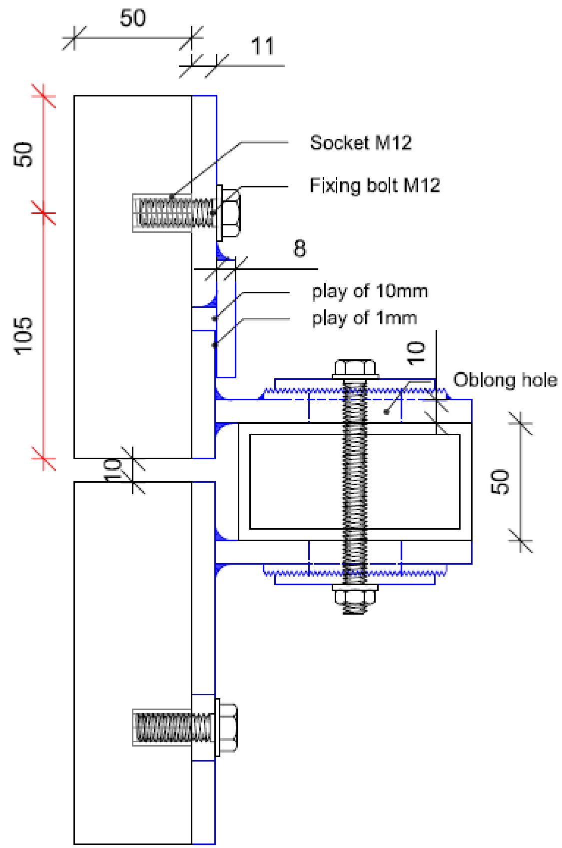
Vertical, horizontal and lateral ajustements



Detail 01 Spacer + Verical support



Detail 02 Spacer



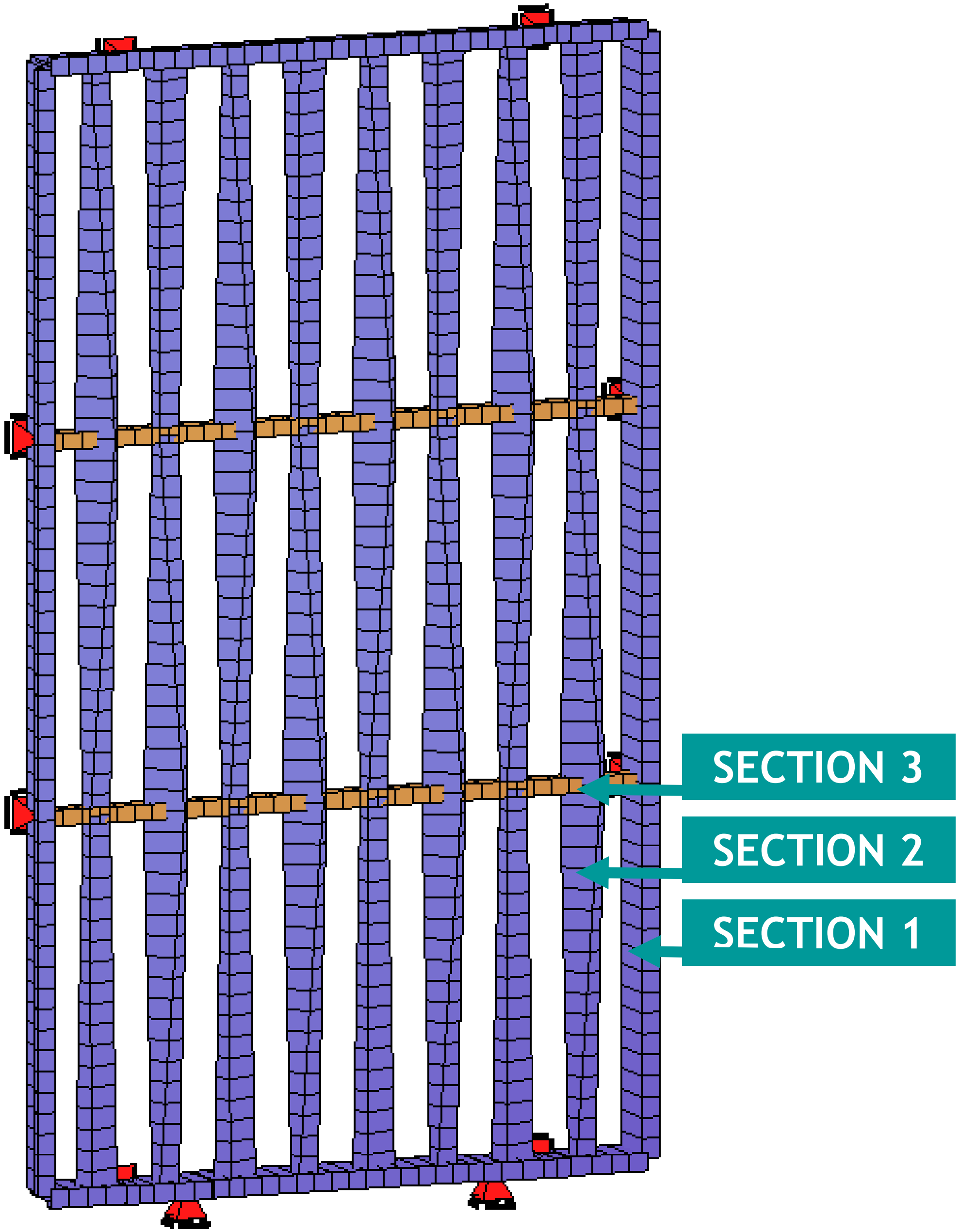
Detail 03/04 Spacer

SHENZHEN UPPER HILL PANELS

Localization : Shenzhen Upper Hill
Building typology : Office
Number of panels : 2000m²
Function : Sunscreen in front of a curtain wall
UHPFRC : Ductal® NaW3 FO STT

Shenzhen Panel / Design hypothesis _ Geometry

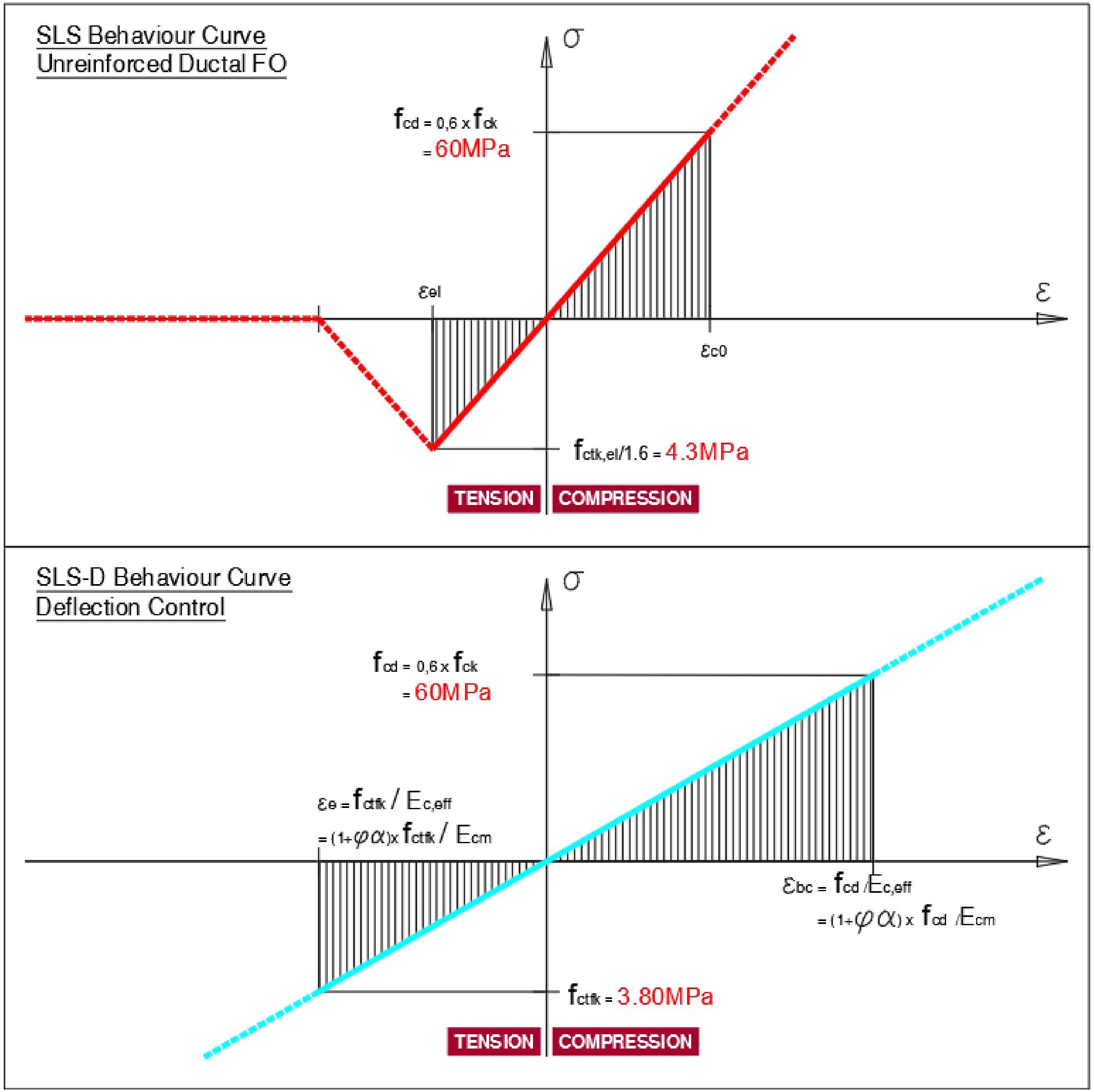
Design hypothesis _ Geometry



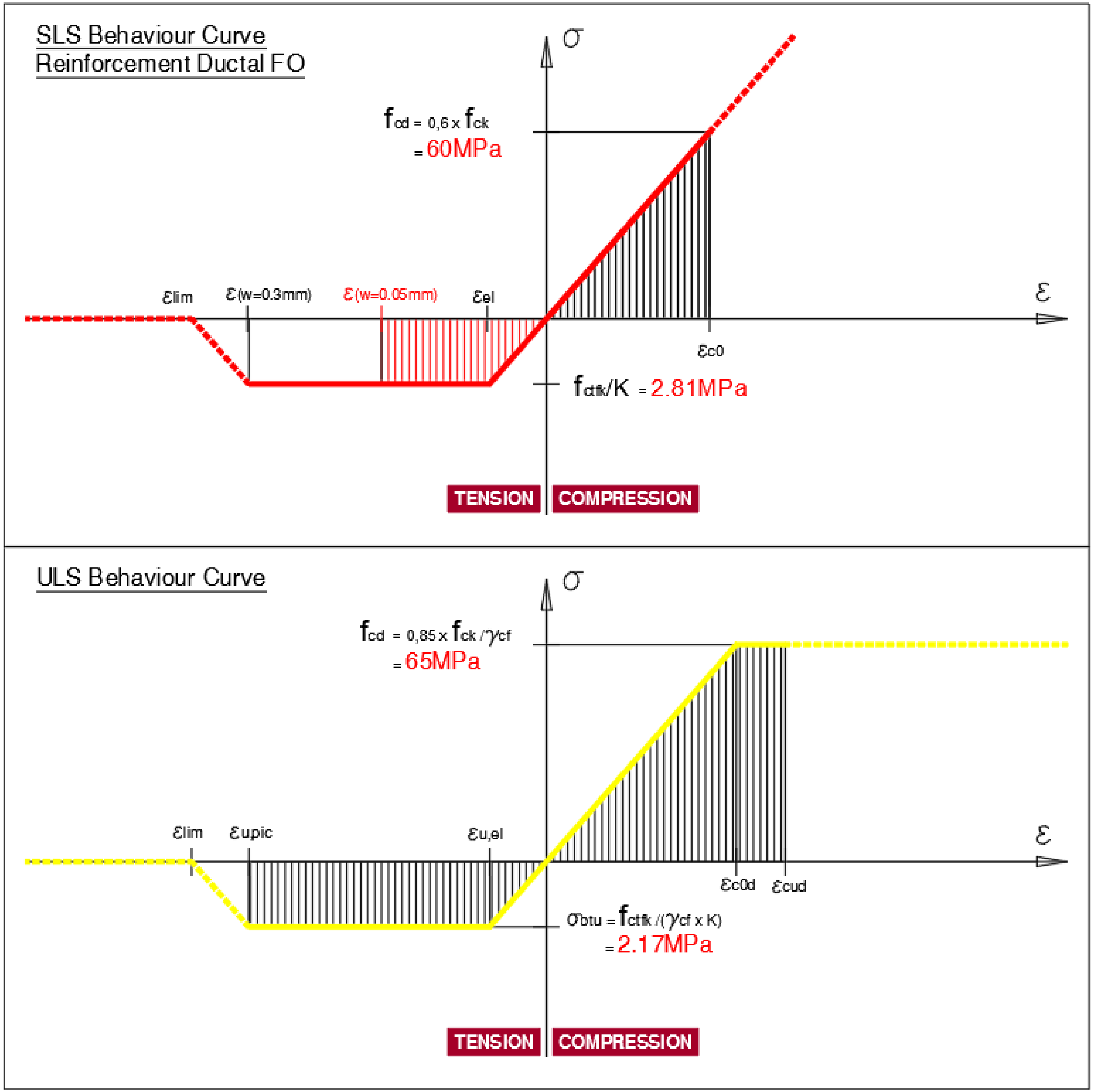
PARTICULARITIES OF PANEL

Height	**2.8m**
Width	**1.5m**
Peripheral frame L 140mm x 45mm x 20mm	**SECTION 1**
Twisted shape of jamb Rectangular 100mm x 50mm Square 50mm x 50mm	**SECTION 2**
Intermediary horizontal ribbon Rectangular 50mm x 50mm with rebar HA10	**SECTION 3**

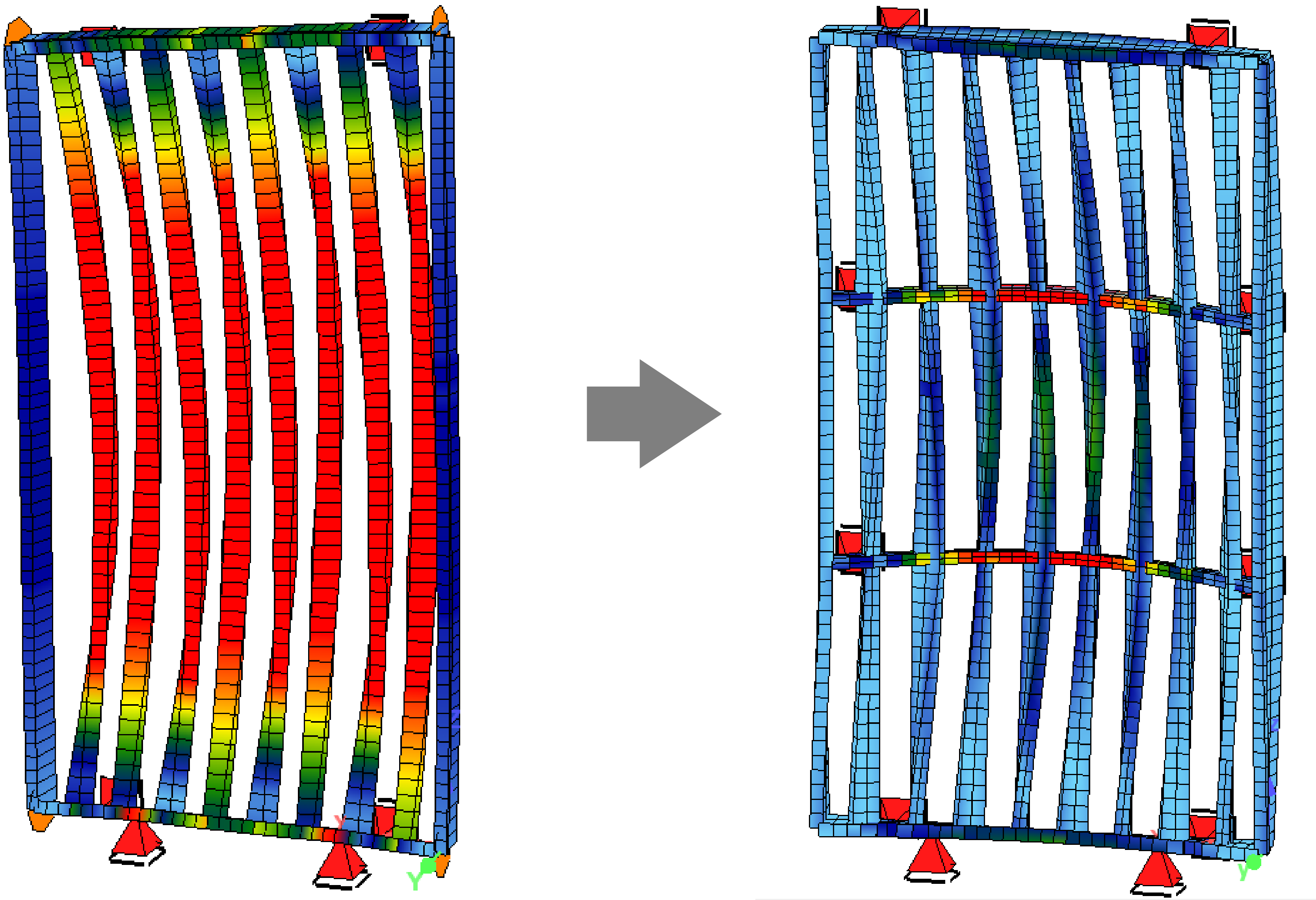
Design hypothesis _ Material_SLS



Design hypothesis _ Material_ULS



Design hypothesis _ Static Scheme

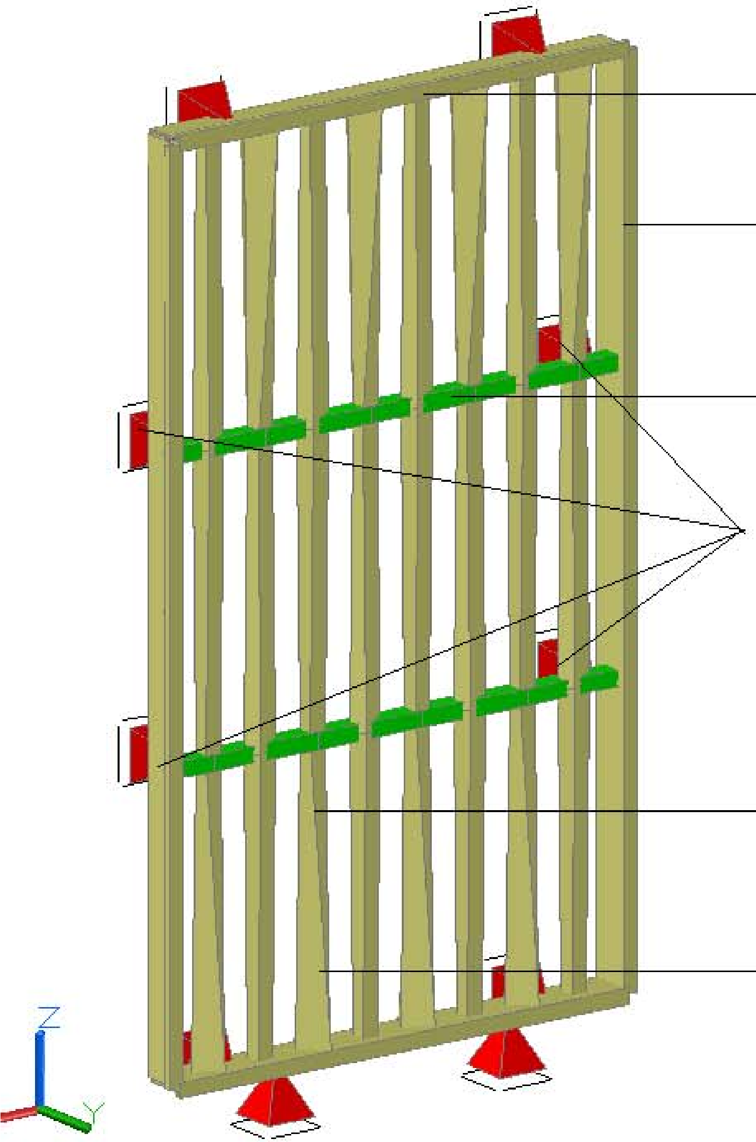


Calculation done with the software SOFISTIK AG

Design hypothesis _ Static Scheme

Sud facade Wind Load 2.6kN/m²

Unreinforced Ductal NaW3 FO
(Partially reinforced on horizontal bars)



Frame - Top and bottom
Cross section L
140mm x 30mm

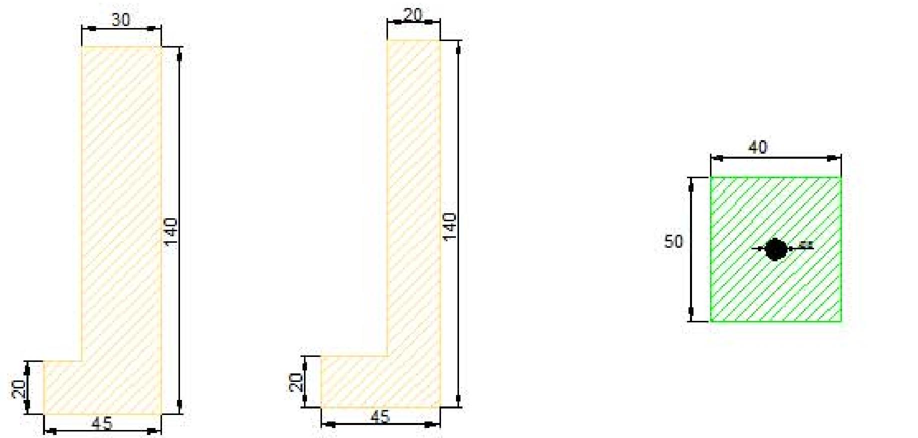
Frame vertical bars
Cross section L
140mm x 20mm

Intermediary horizontal bars
Rectangular cross section with rebar D8
50mm (depth) x 40mm (height)

4 additionnal horizontal supports to the main structure

Square vertical cross section
50mm x 50mm

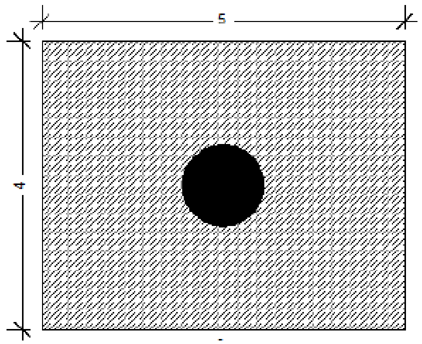
Rectangular vertical cross section
100mm x 50mm



Cross section L
Top and bottom

Cross section L
Frame vertical bars

Cross section
Intermediary horizontal bars



Cross-section 40mm x 50mm
with reinforcement rebar HA10 (positioned at the center of gravity)

REQUIREMENTS FOR DURABILITY

Requirements for durability

- Environmental conditions

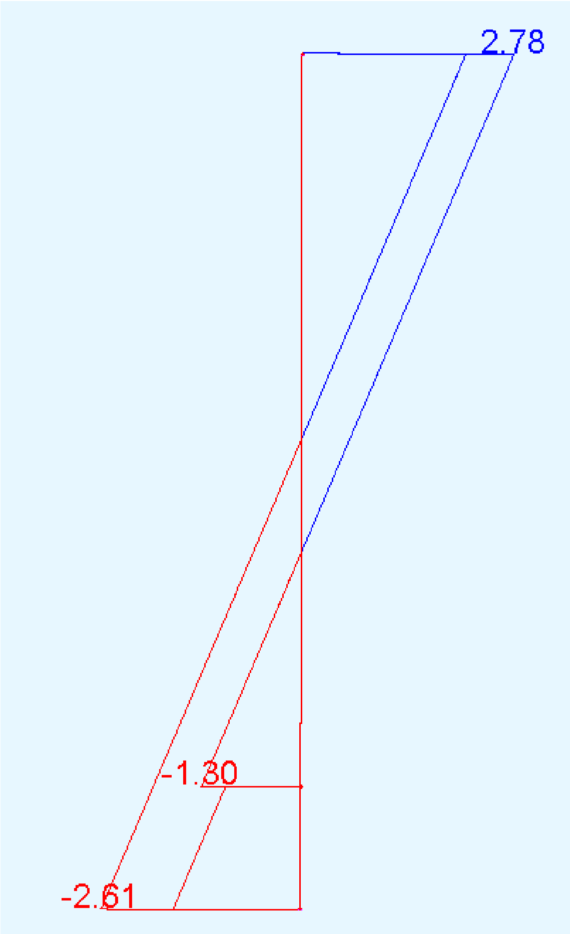
Exposure classes following French regulations: **XC1**

- Concrete cover =15 mm (NF P18-710 §4.4)

Tableau 4.203 - Valeurs de l'enrobage minimal $c_{min,dur}$ requis vis-à-vis de la durabilité dans le cas des armatures de précontrainte

Classe structurale	Exigence environnementale pour $c_{min,dur}$ (mm)						
	Classe d'exposition suivant le tableau 4.1						
	X0	XC1	XC2/XC3	XC4	XD1/XS1	XD2/XS2	XD3/XS3
S1		5	10	15	15	20	20
S2		10	15	15	20	20	20
S3	-	10	15	20	20	20	25
S4		15	20	20	20	25	25
S5		15	20	20	25	25	30
S6		20	20	25	25	30	30

Extract for the minimum concrete cover of NF P18-710[2.2]



Stress limitation

Non-reinforced Ductal FO

•Compressive stress ≤ 0.6 fck =60MPa
•Tensile stress ≤ fctk,el/1.6=4.3MPa

Reinforced Ductal FO

•Compressive stress ≤ 0.6 fck =60MPa
•The opening of cracks is controled by limiting the stress in the reinforcement

Reinforcing bars

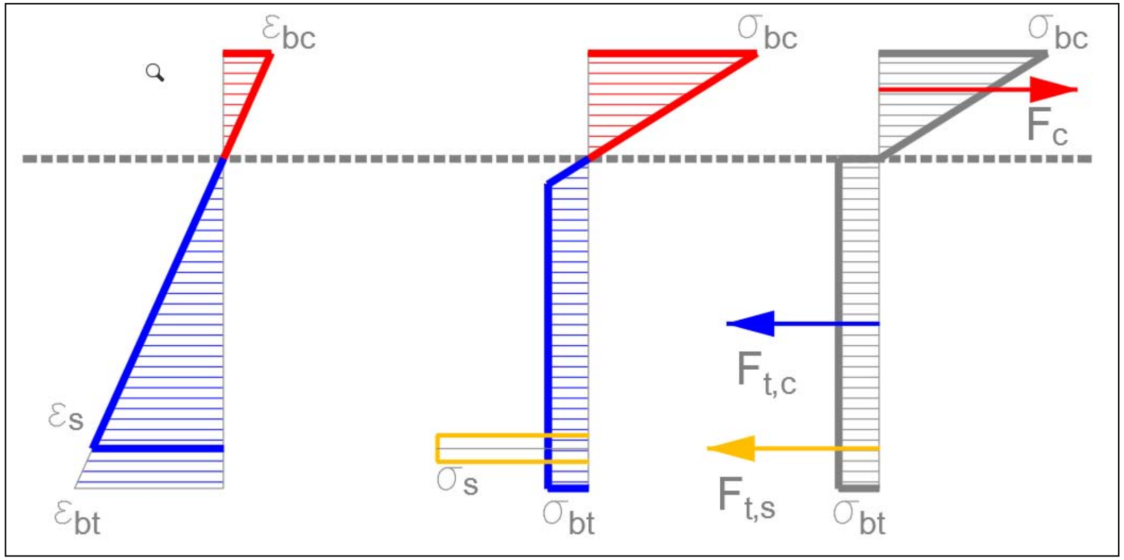
•**Compressive stress** ≤ fyk
•Tensile stress ≤ 0.8 fyk to avoid unacceptable cracking or deformation

Crack control

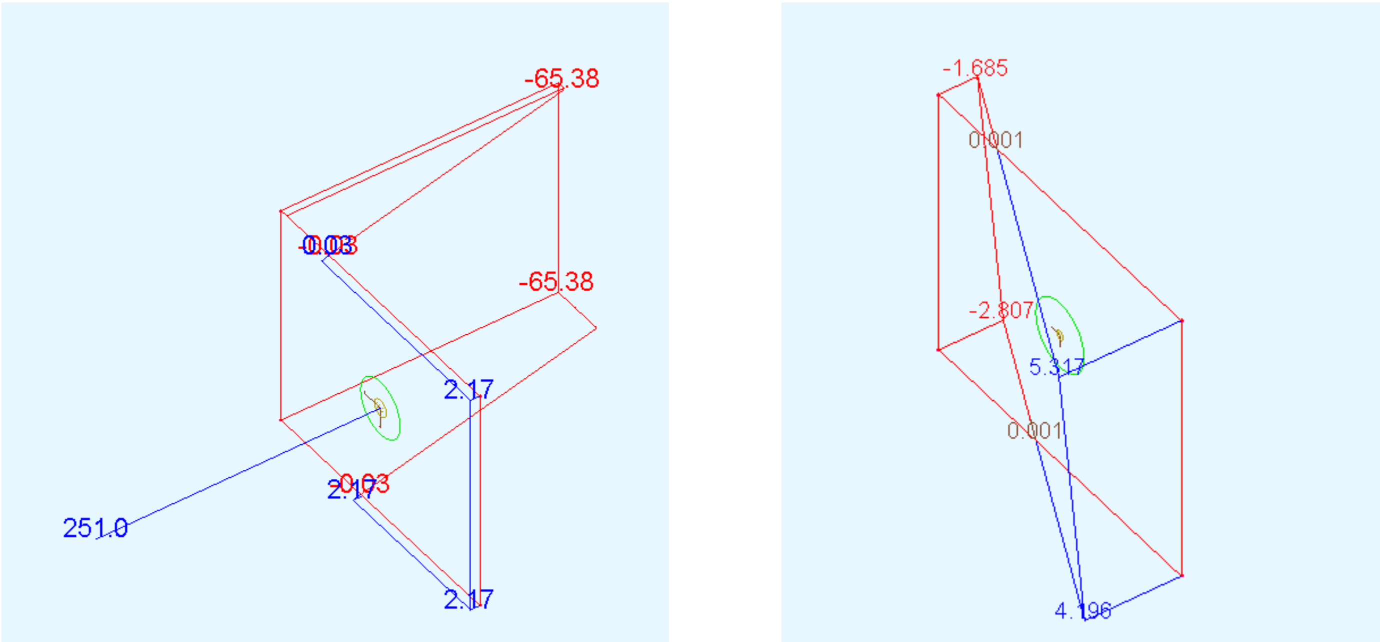
Members in UHPFRC do not require a minimum quantity of steel reinforcement to control cracking. This is assumed to be provided by the crack control and the ductile character under tension of the UHPFRC.

(NF P18-710 §7.3.2)

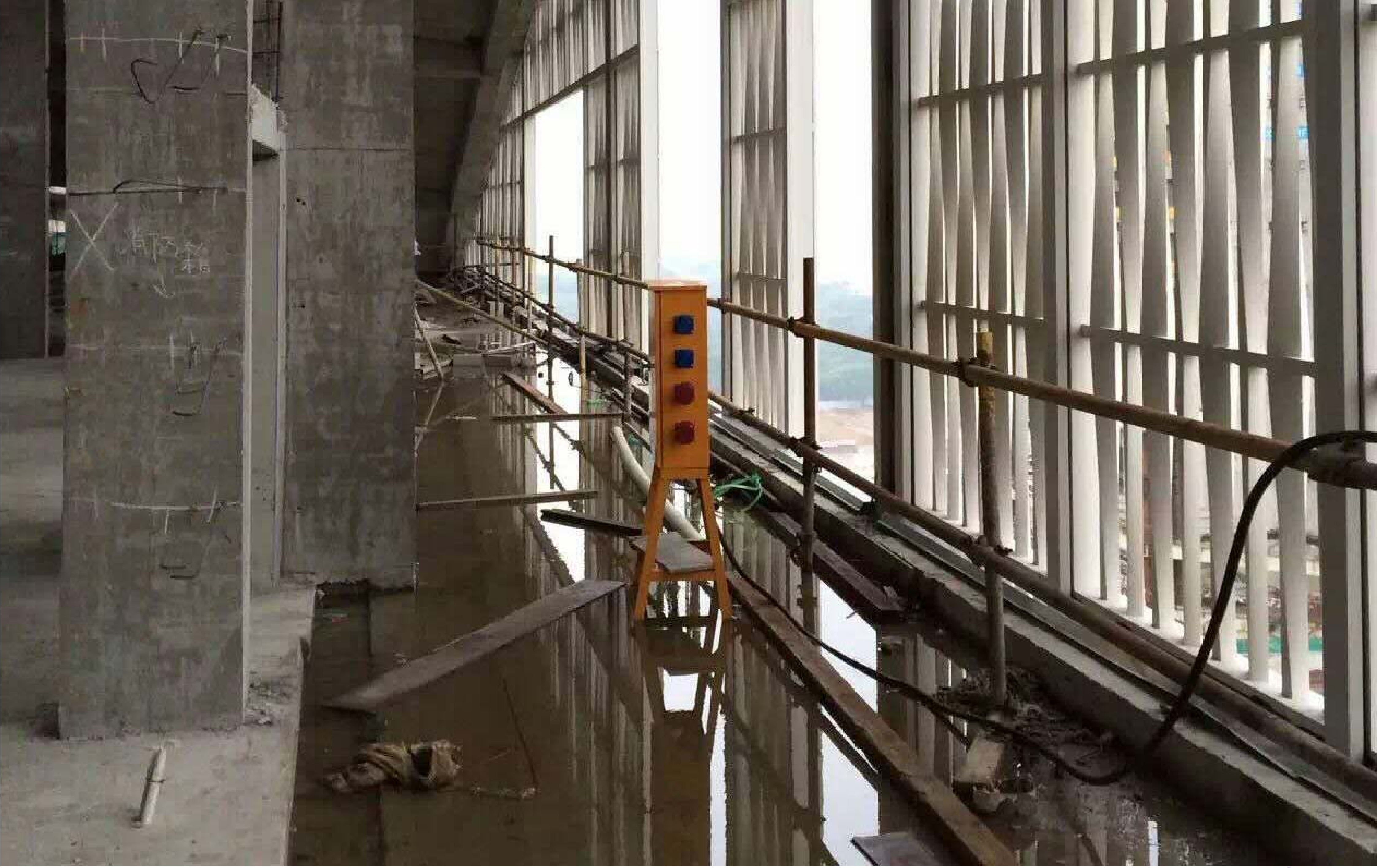
Structural Analysis_ ULS



Stress and strain distribution at ULS



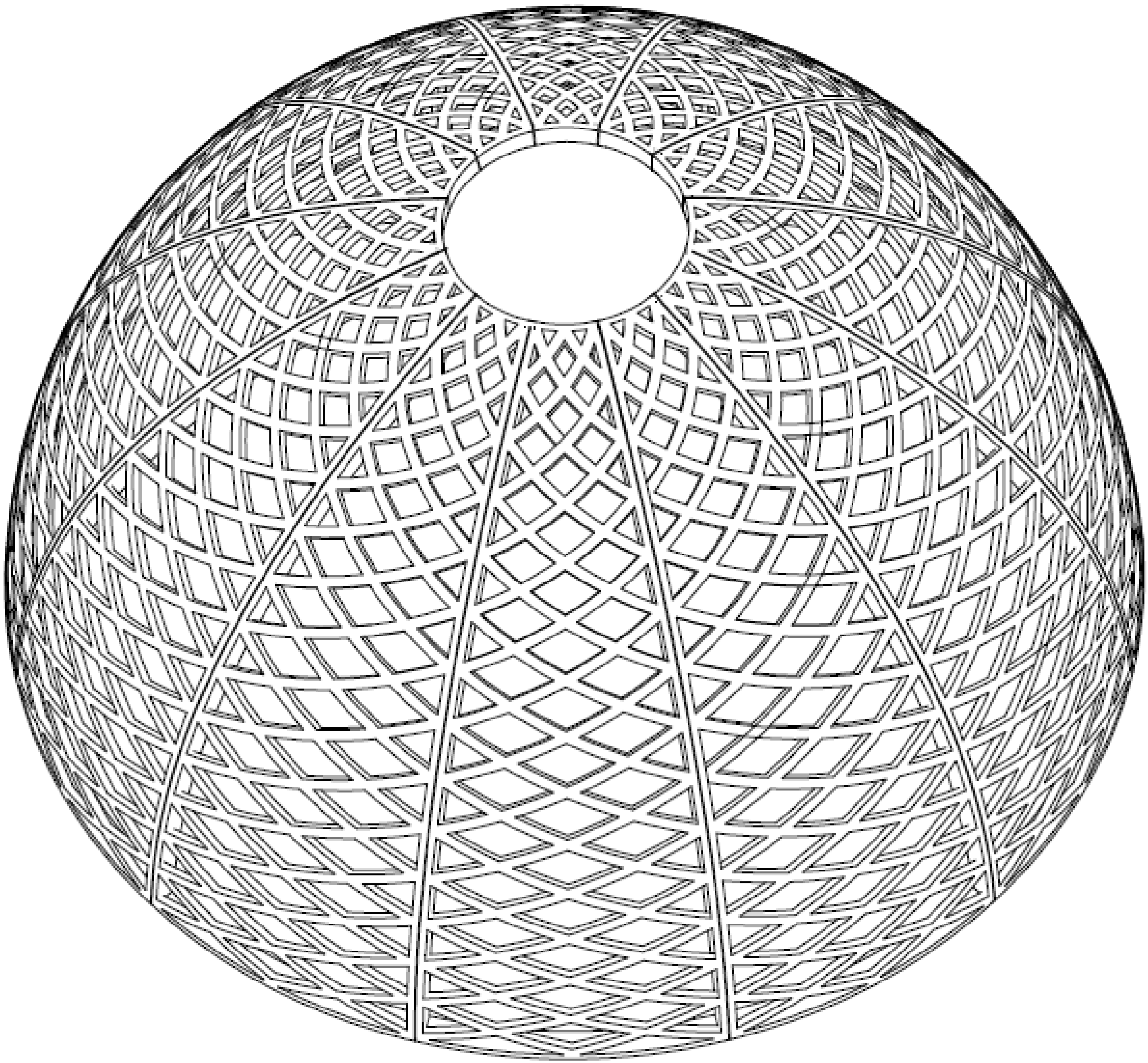
Stress and strain distribution at ULS in the model of calculation



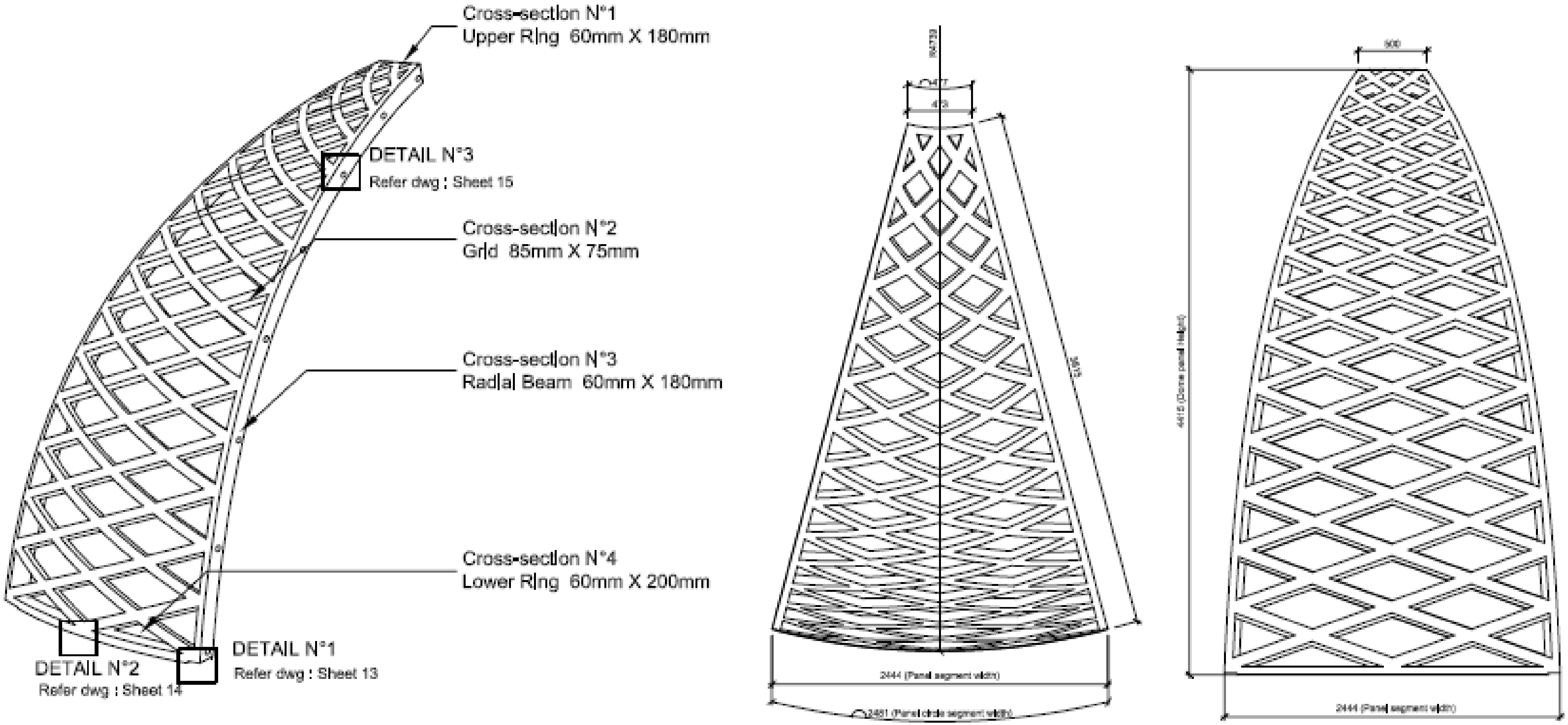
Al Rayyan Palace Dome, Qatar

Localization : Al Rayyan Palace Qatar, Doha / Premier prefabricator
Building typology : Palace private
Quantity :
Function : Roof
UHPFRC : Ductal® FI STT

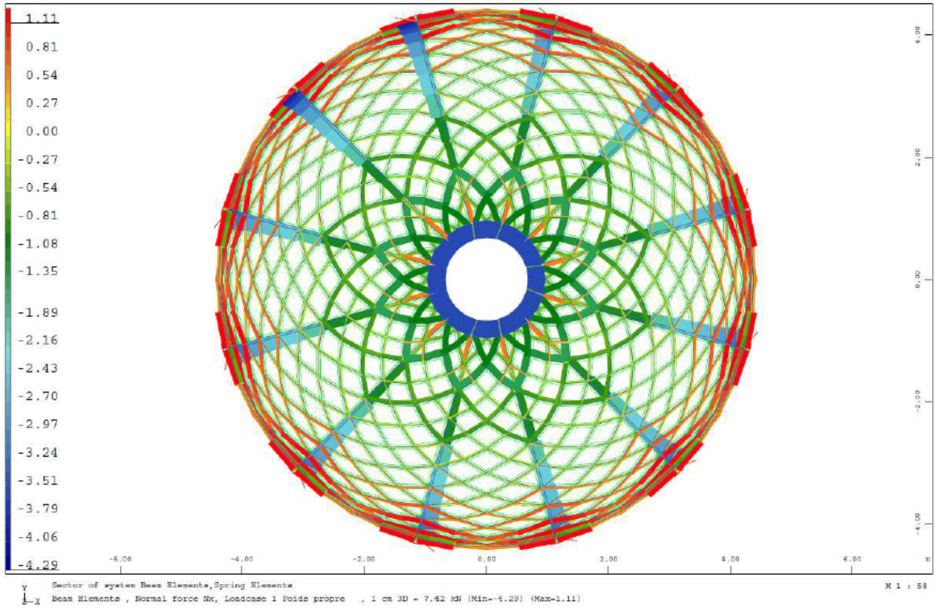
Dome Qatar/Design hypothesis _ Geometry

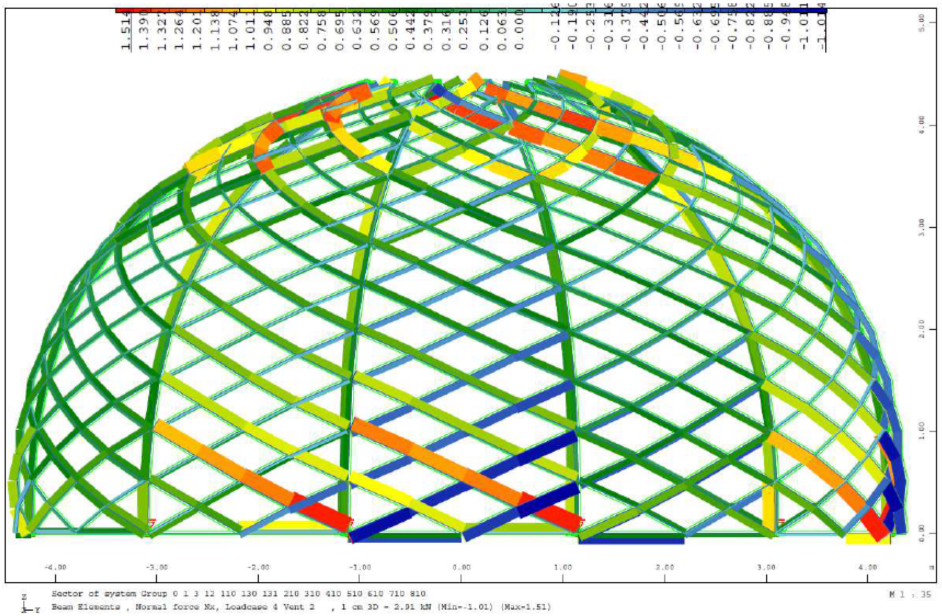


Dome Qatar/Design hypothesis _ Geometry

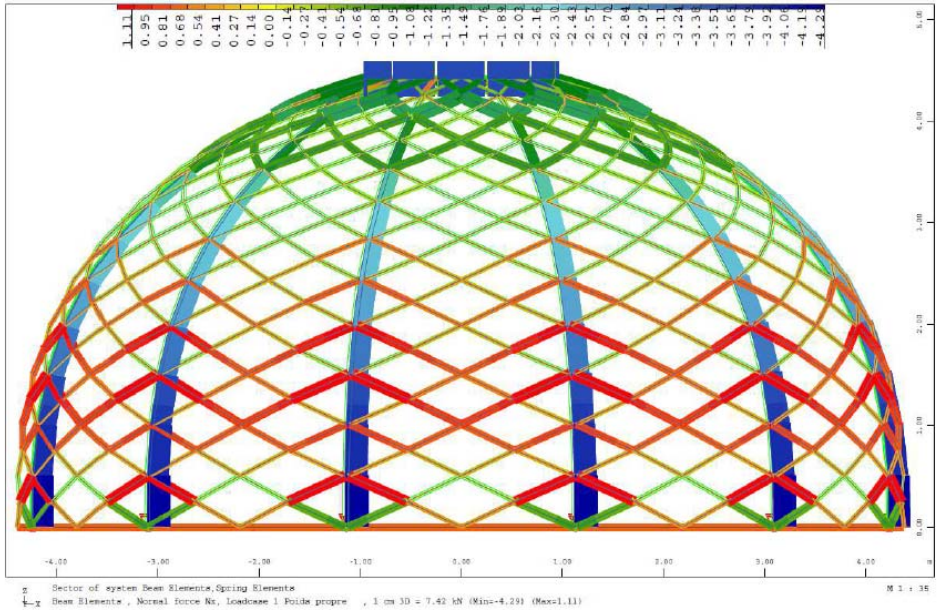


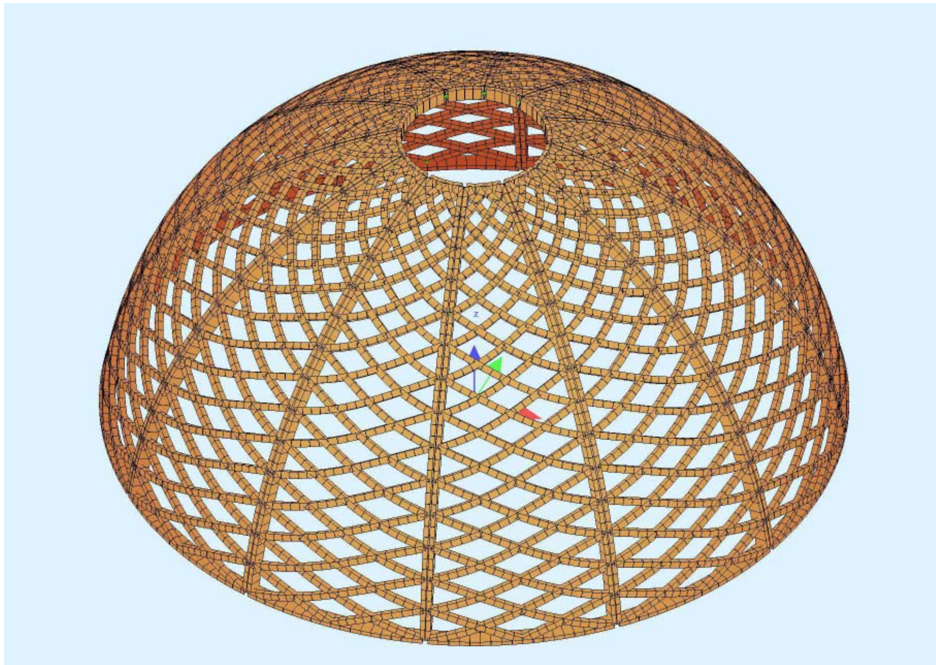
Design hypothesis _ Static Scheme



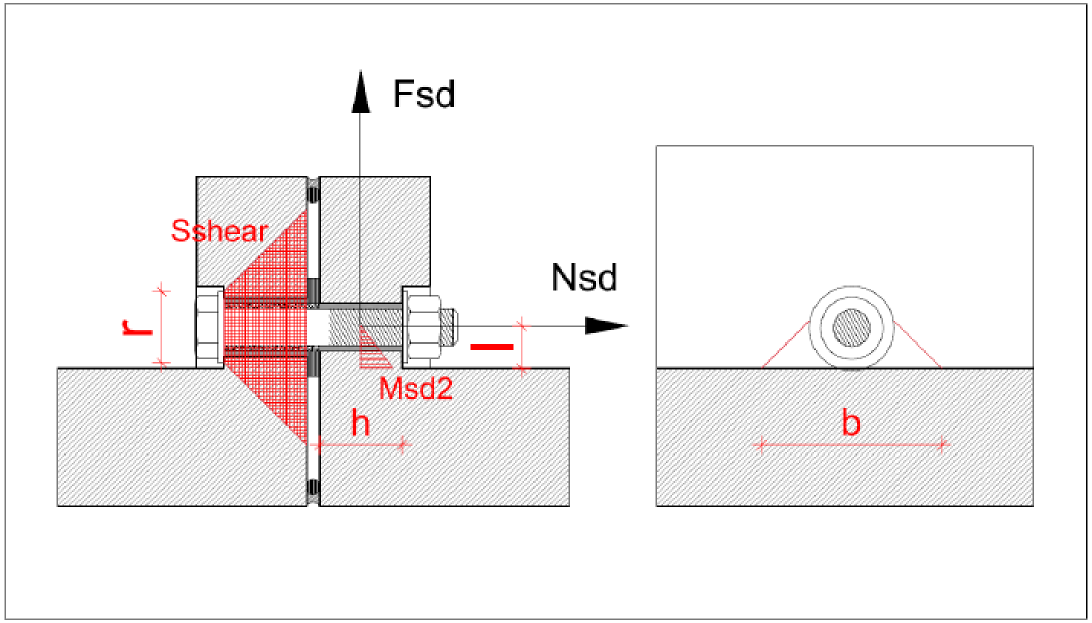


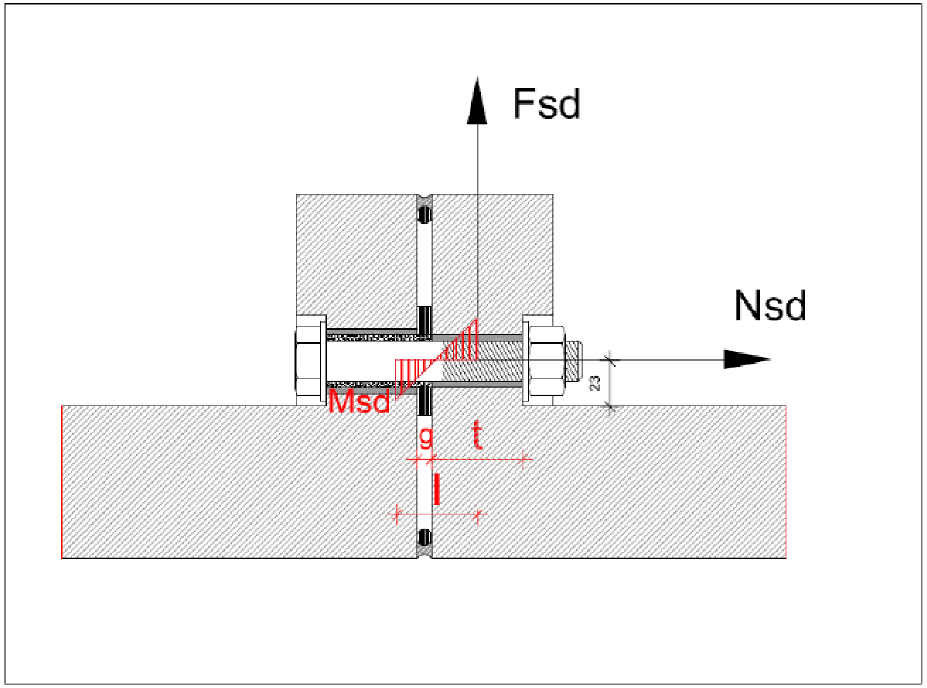
The horizontal load (wind + seismic) are transferred by the grid around each side of the structure. The force is dissipated.





Design hypothesis _ Static Scheme





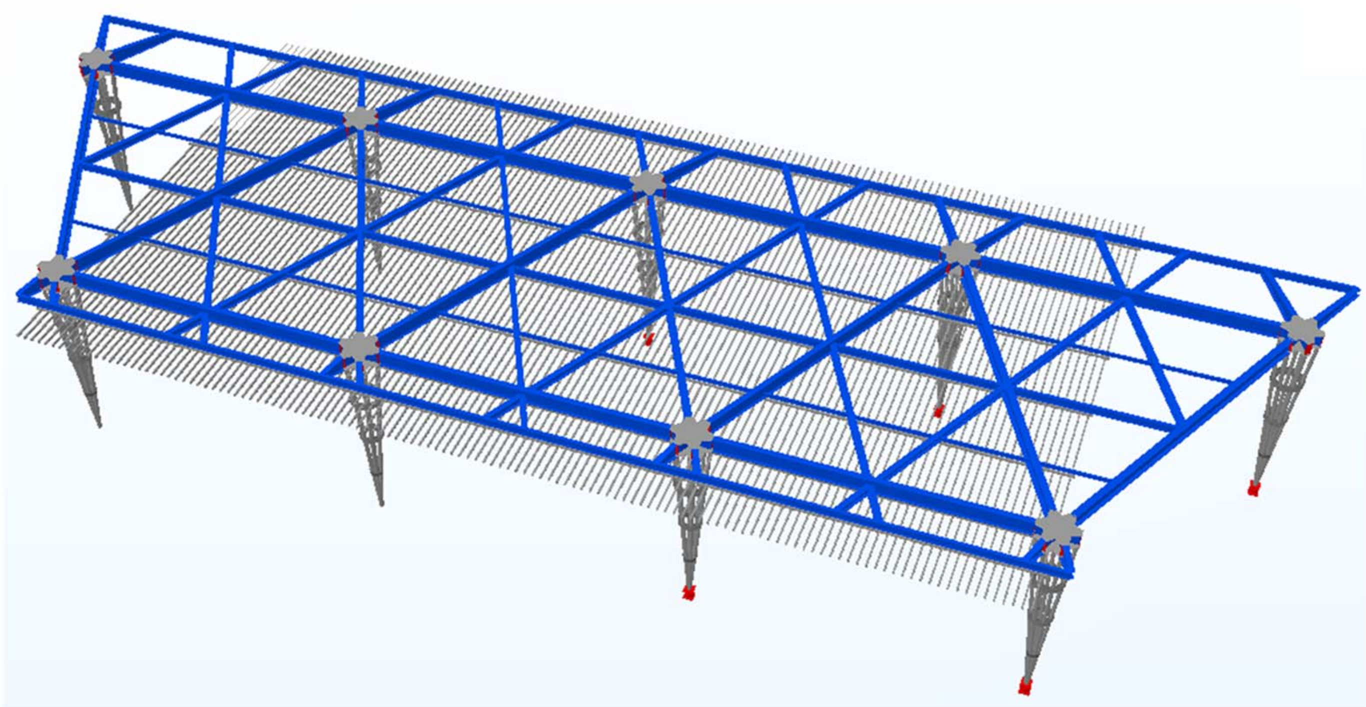

Pershing square, Los Angeles, USA / TER Landscape designer
Localization : Los Angeles
Building typology : Canopy
Quantity : 300 m long
Function : Roof
UHPFRC : Ductal® FI FM STT

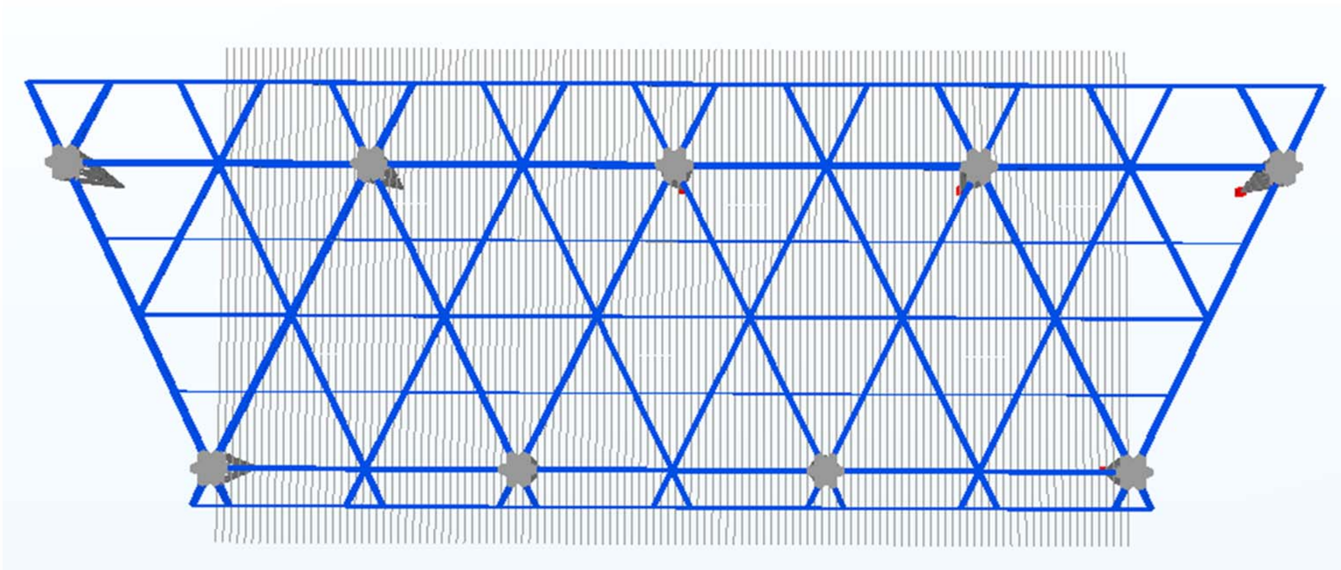
Preliminary design stage

Agence Ter and Team: Pershing Square Renew Proposal

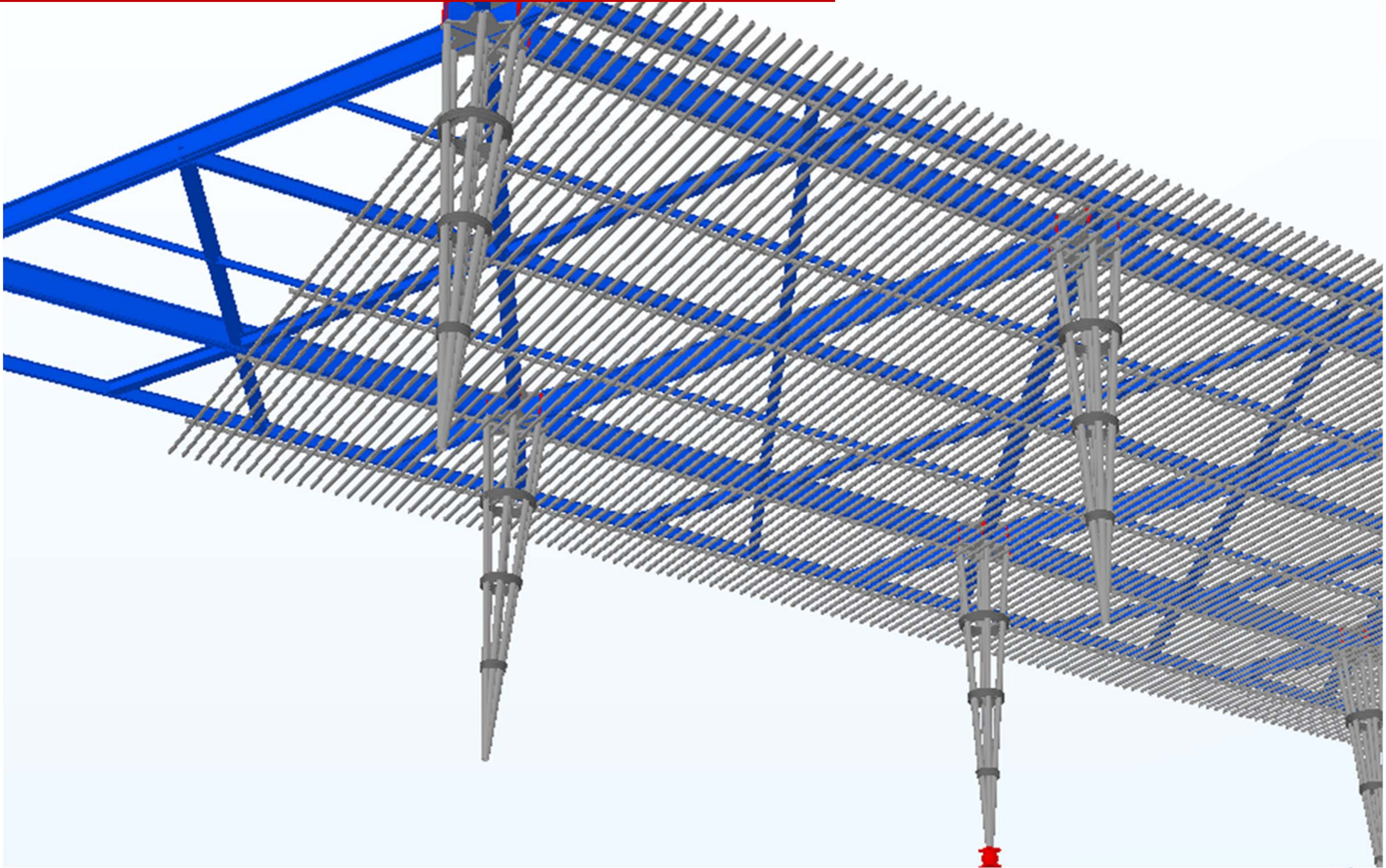
22

Preliminary design stage

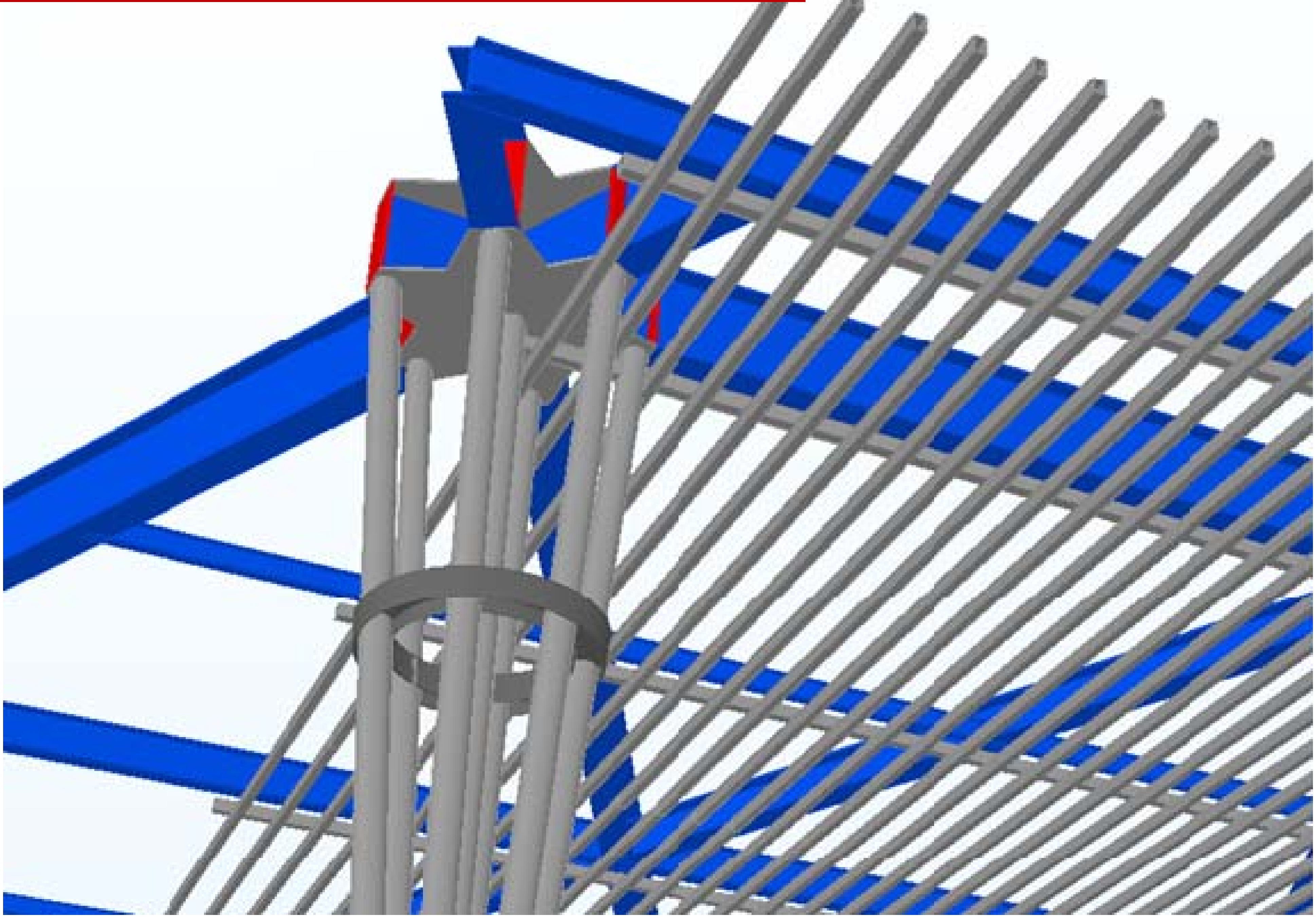




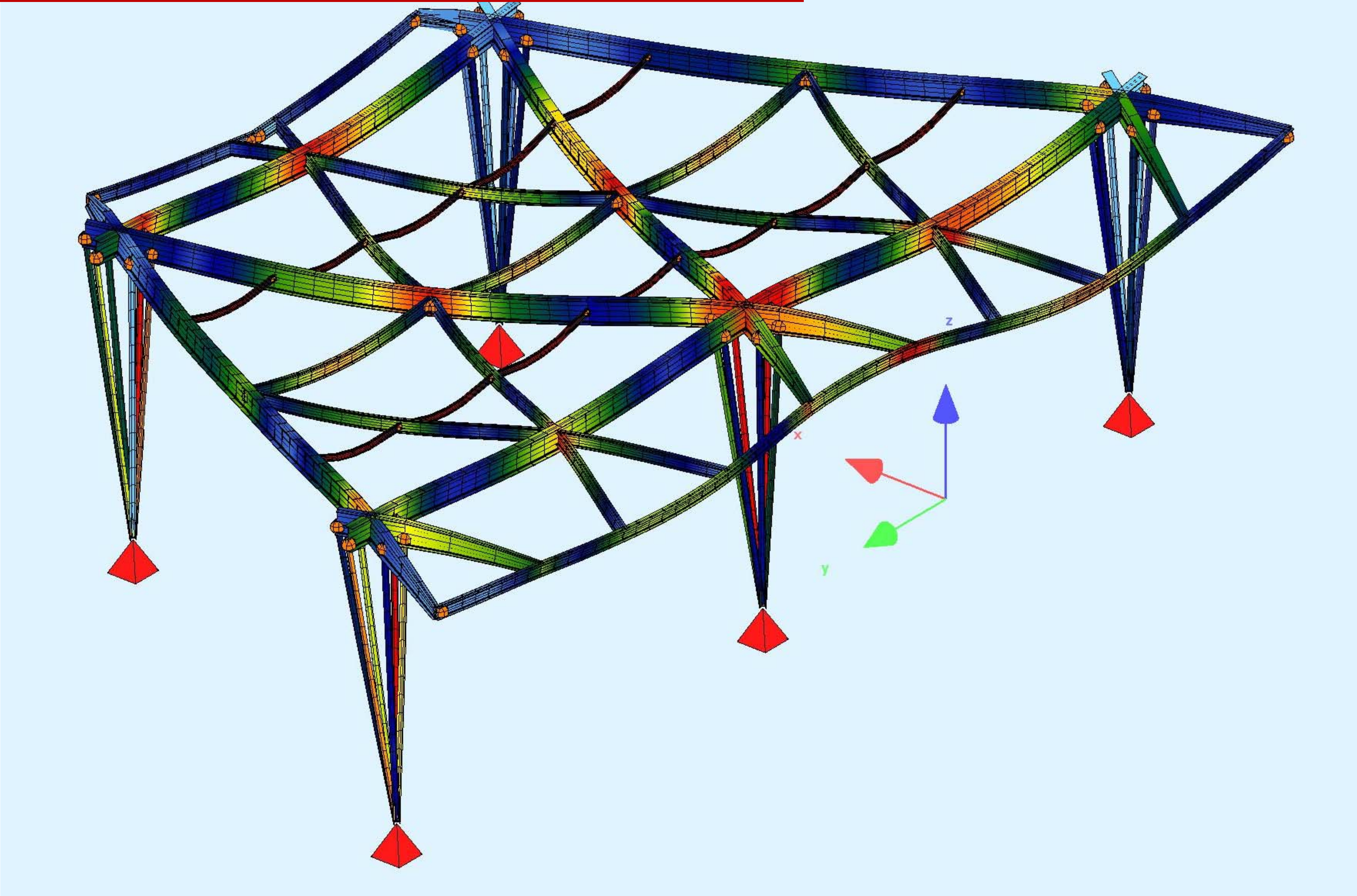
Preliminary design stage



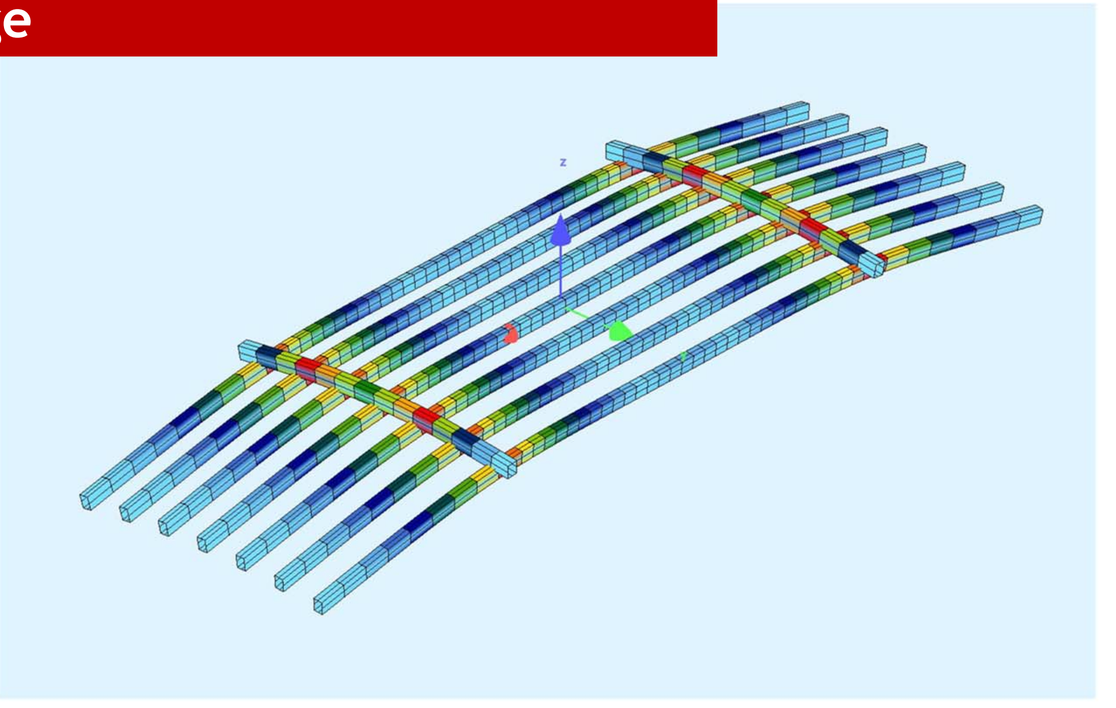
Preliminary design stage

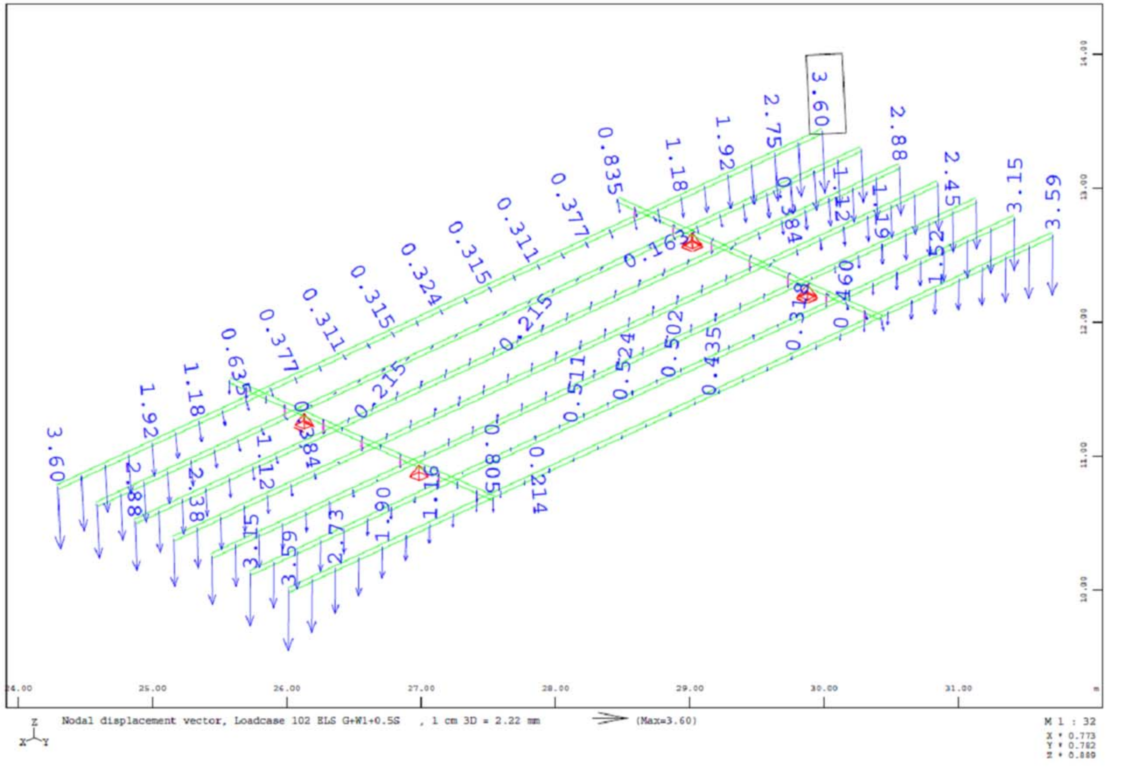


Preliminary design stage



Preliminary design stage



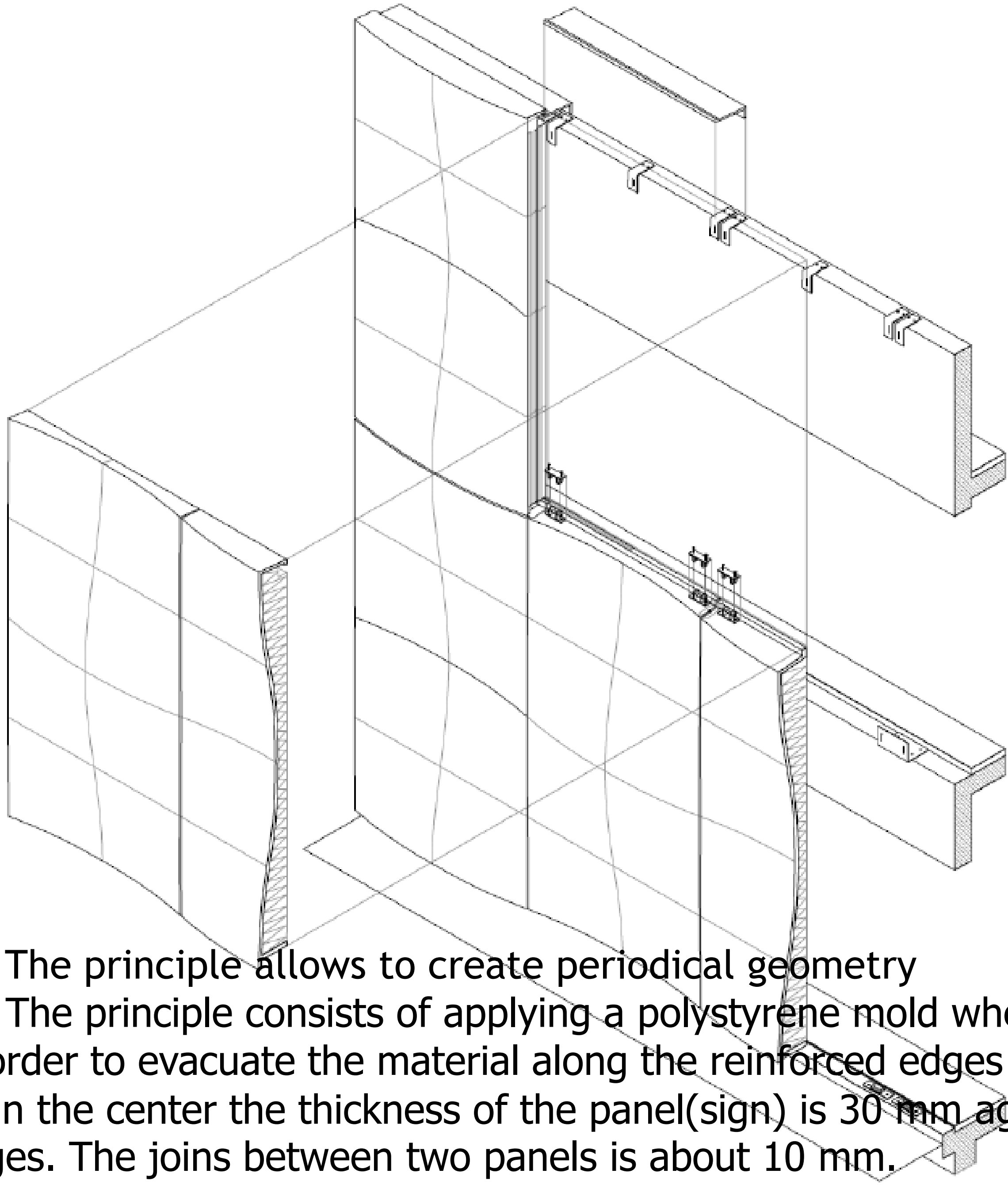


Localization : Paris
Building typology : Panel with integrated insulation
Function : Façade
UHPFRC : Ductal® NaW3 FO STT

Les panneaux de la crèche Budin / TER Combarel&Marrec Architectes

Design process

Formwork strategy



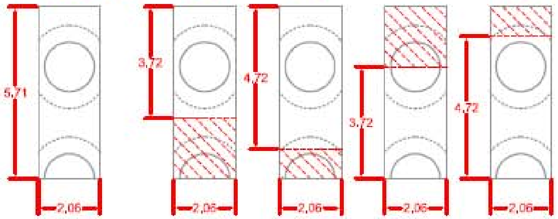
Comment 1 : The principle allows to create periodical geometry
Comment 2 : The principle consists of applying a polystyrene mold when Ductal is still liquid in order to evacuate the material along the reinforced edges of the panel.
Comment 3: in the center the thickness of the panel(sign) is 30 mm against 235 mm along the edges. The joins between two panels is about 10 mm.

Formwork strategy

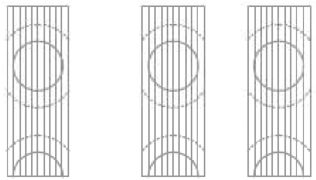
Displacement Casting/ Paris Crèche Budin

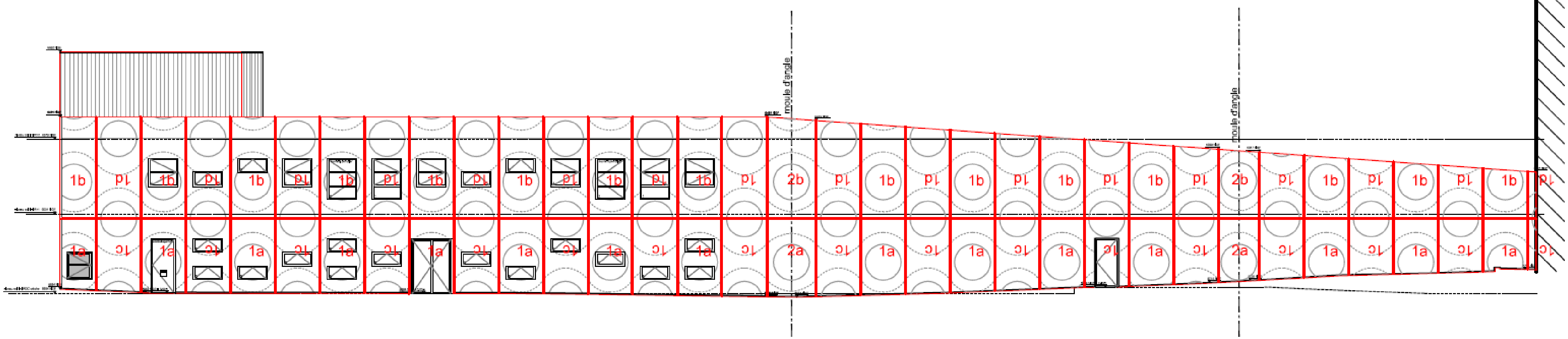
DECOUPAGE ENVISAGE :

- Type 1 : 64 pièces - Moule - 1a - 1b - 1c - 1d

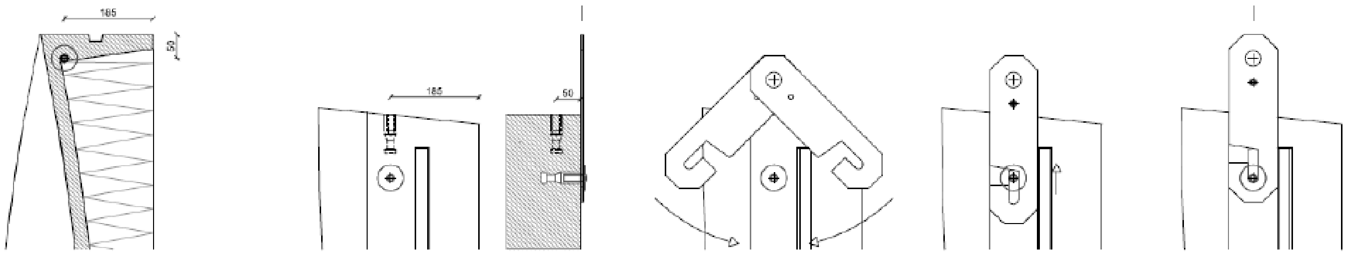


- Type 2 : 4 pièces - Moule - 2a - 2b



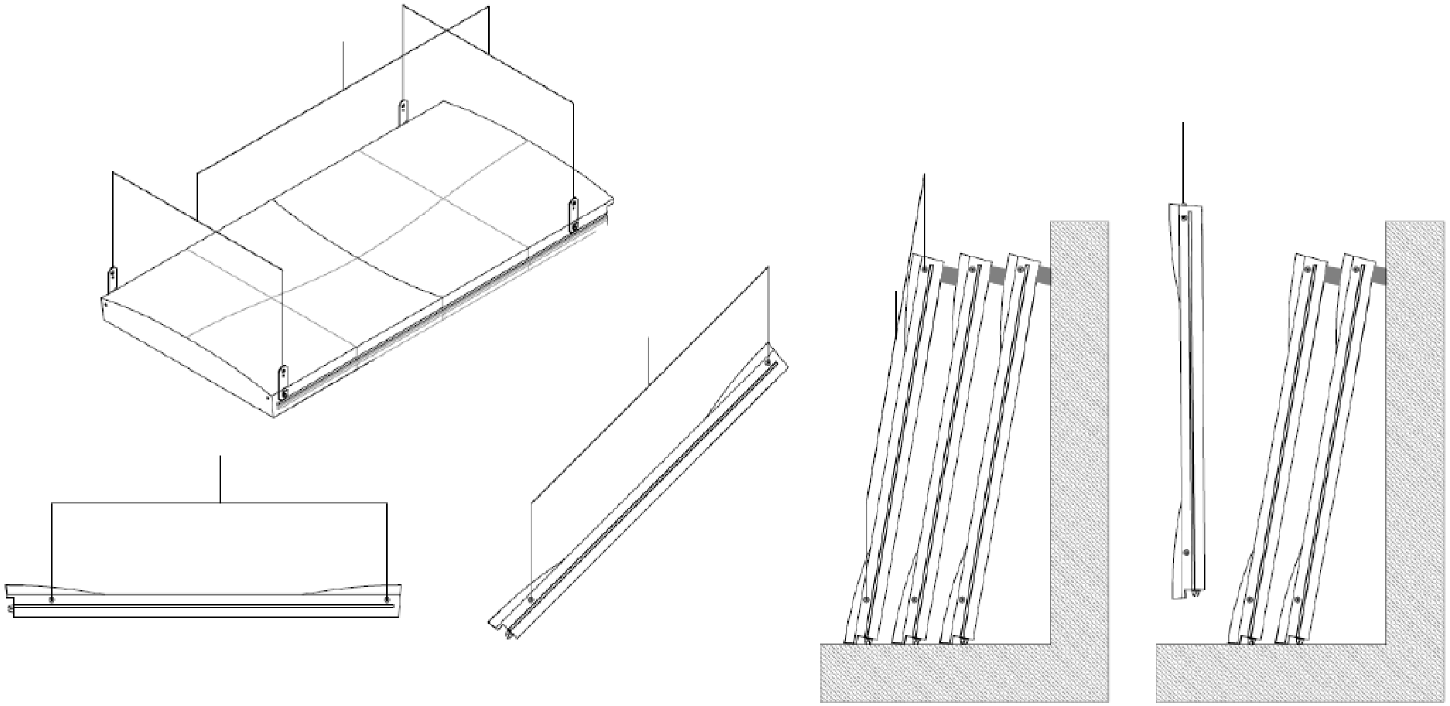


Formwork strategy



Dispositif de levage 1/10e
Douille de Fixation HALFEN DEHA-6380 M16

Séquence d'accroche pour le levage 1/10e

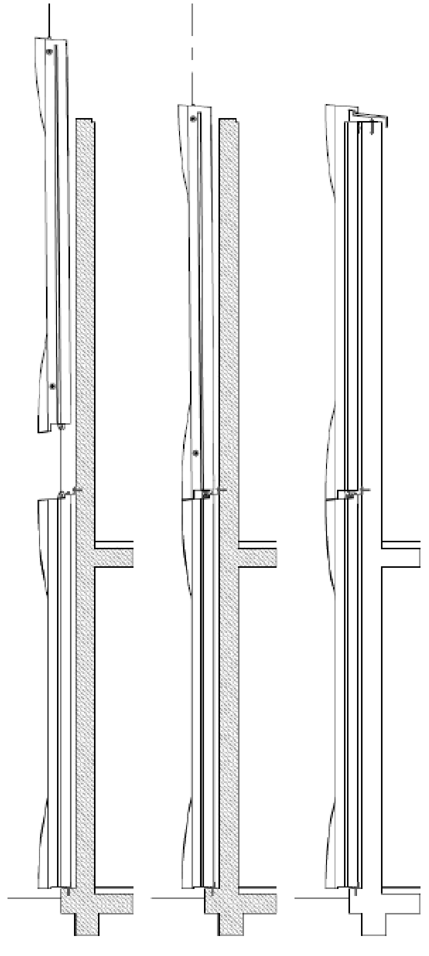


Levage à l'horizontal 1/50e

Basculement 1/50e

Stockage des panneaux 1/50e

Levage à la verticale des panneaux 1/50e

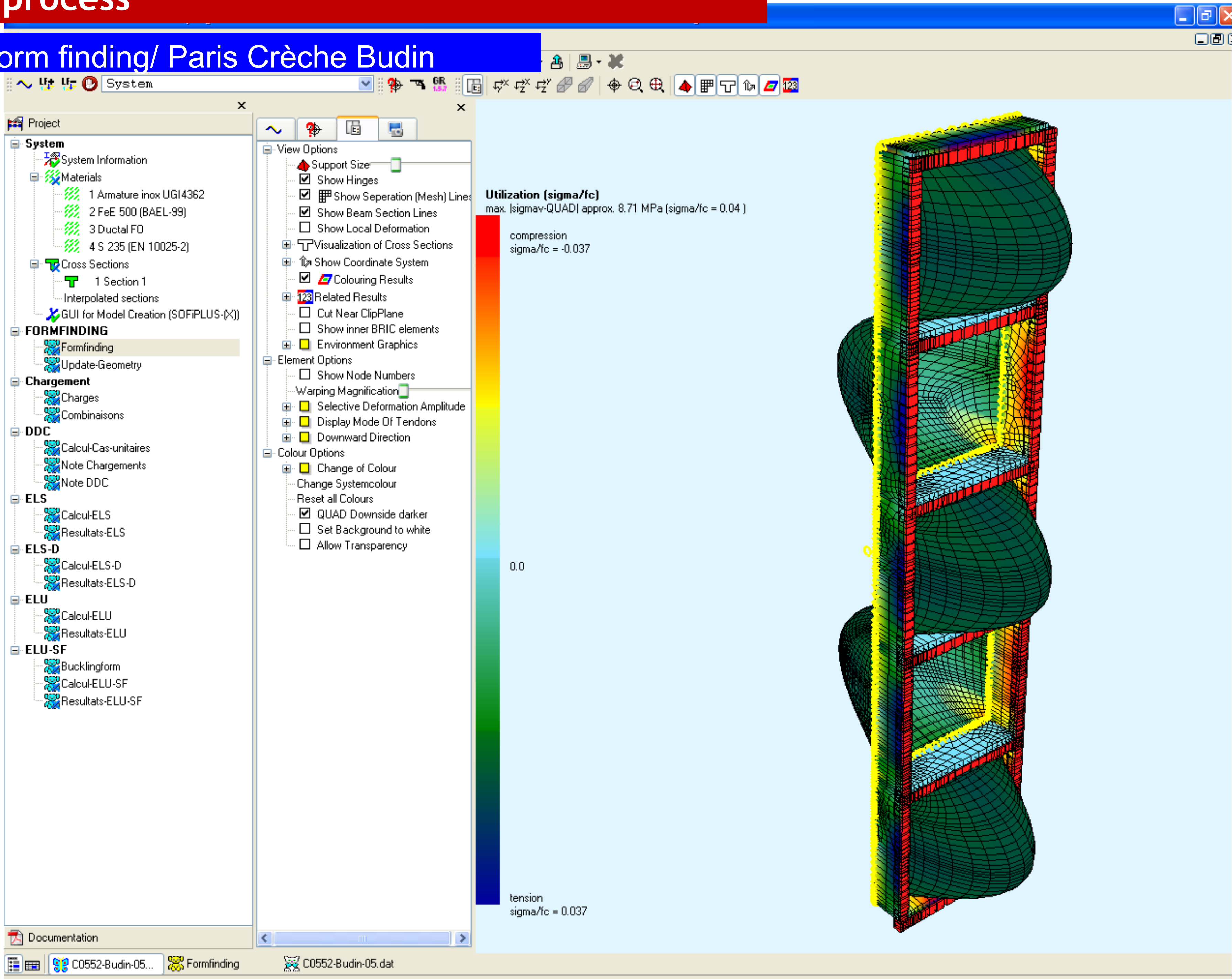


Mise en oeuvre des panneaux 1/50e

0 100cm

Design process

Form finding/ Paris Crèche Budin

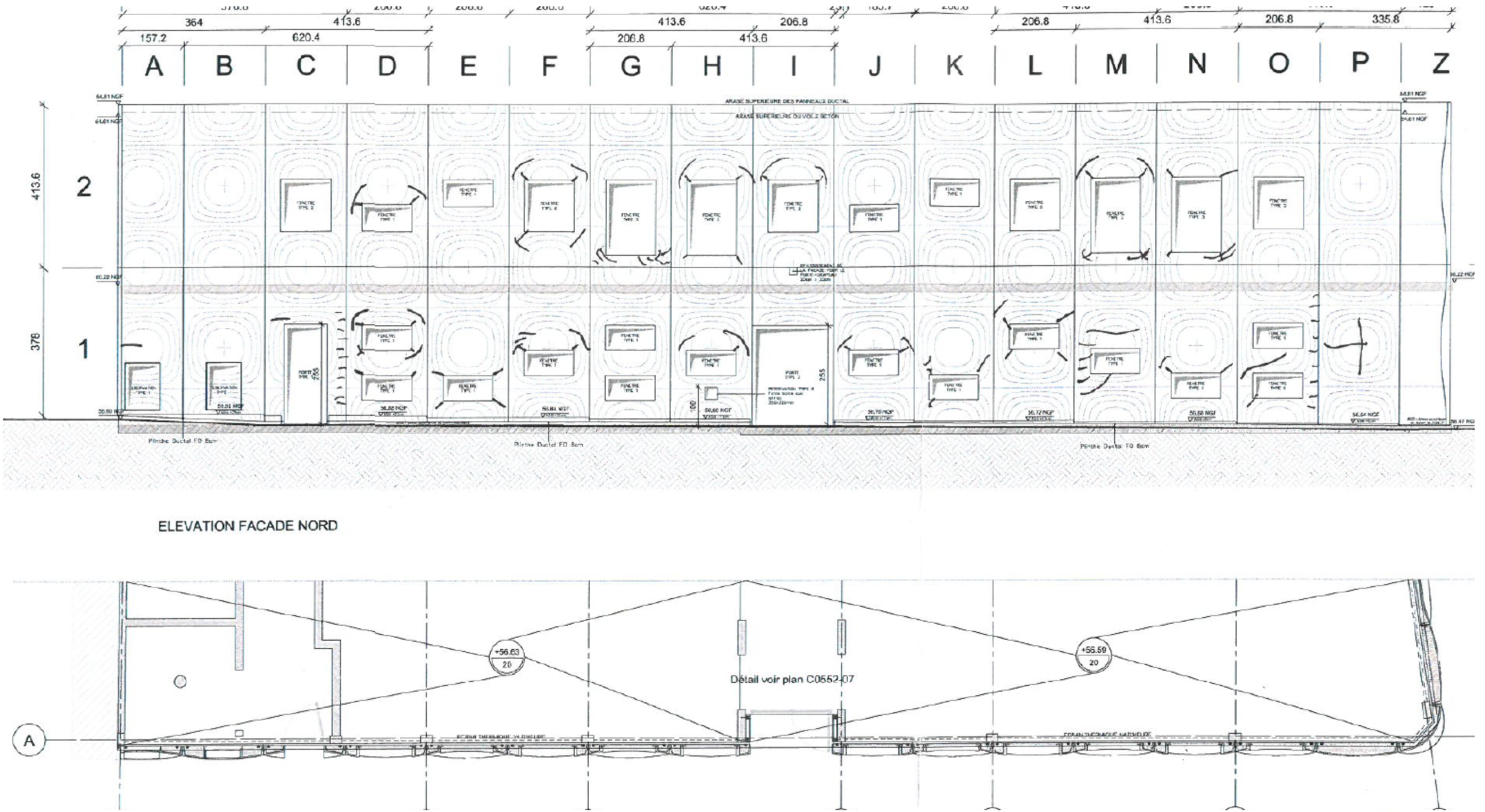


Calculation done with the software SOFISTIK AG

Design process

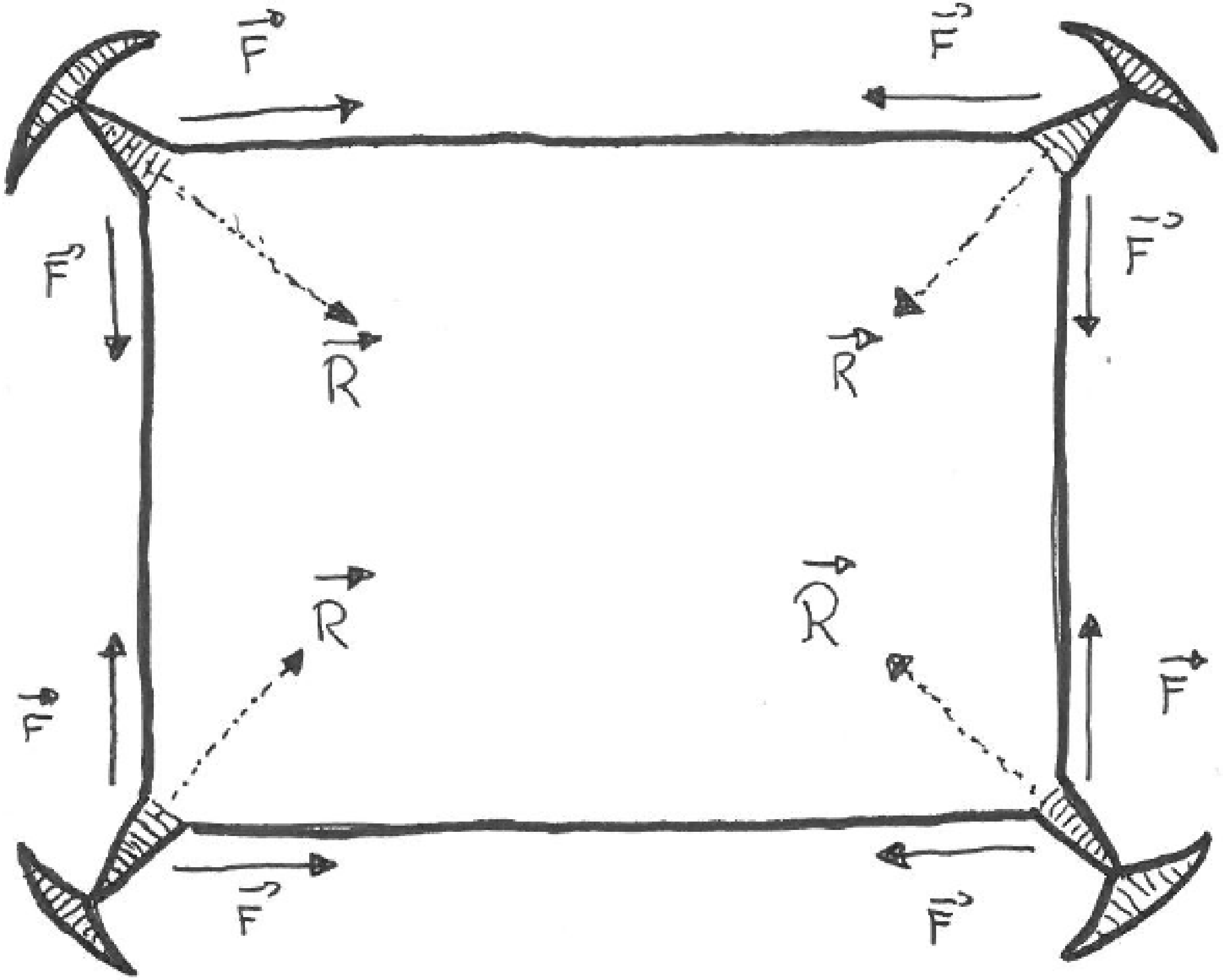
Design process

Shrinkage / Budin creche Paris



Design process

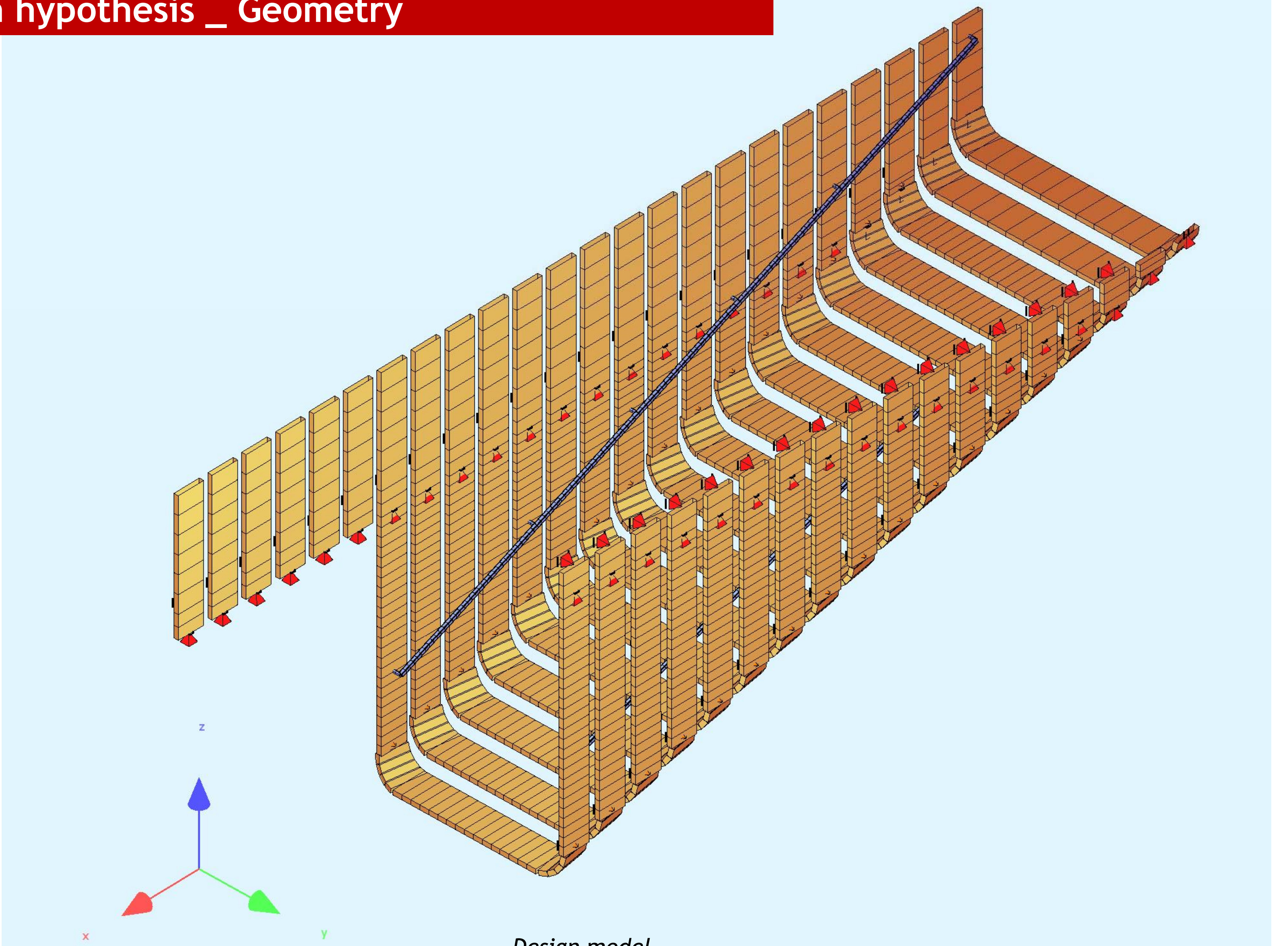
Shrinkage / Budin creche Paris



Zaha Hadid office Staircase / Zaha Hadid Architect

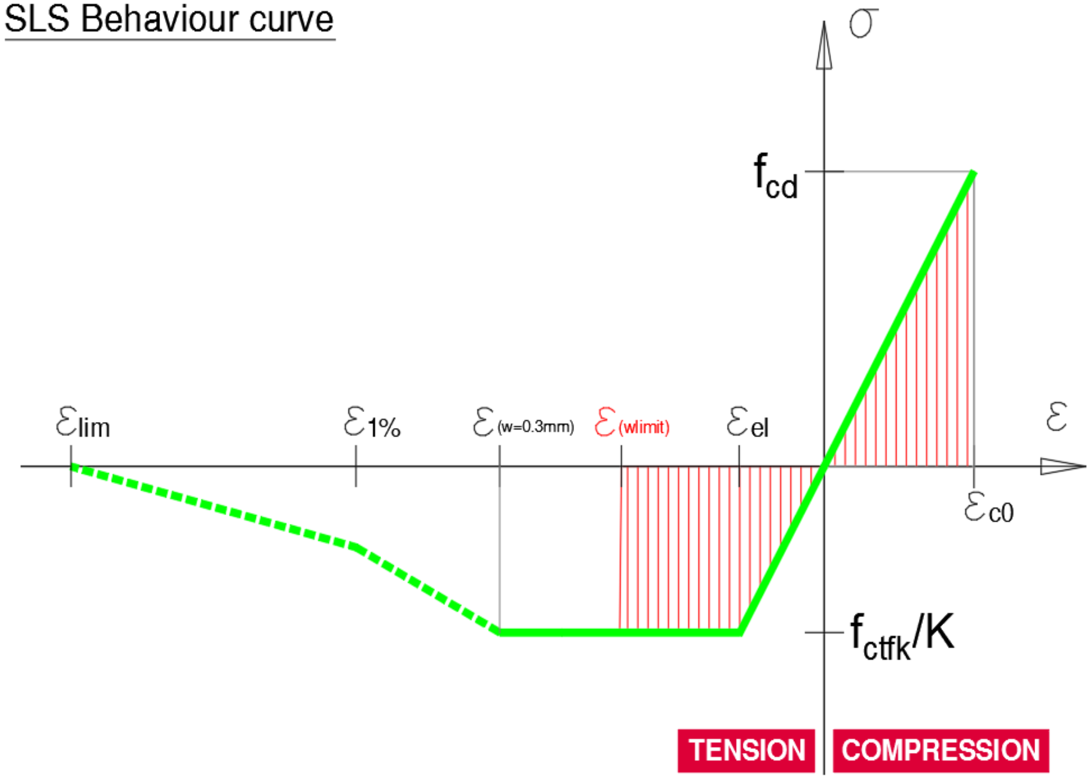
Localization : Zaha Hadid Office, Londre / Contractor : Il cantiere
Building typology : Office
Quantity : 18 steps
Function : Public staircase
UHPFRC : Ductal® NaW3 FO STT

Design hypothesis _ Geometry



Design model

SLS Behaviour curve



Stress limitation

Non-reinforced Ductal FO

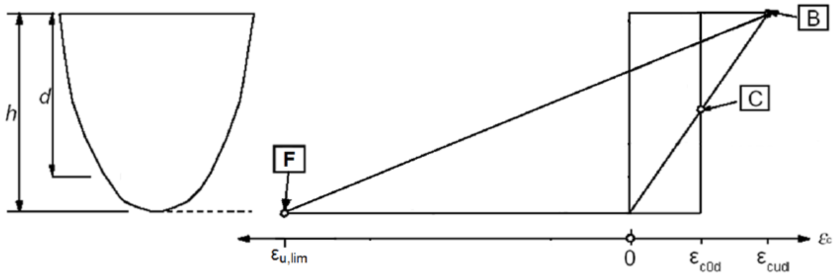
- Compressive stress ≤ 0.6 fck
- Tensile stress ≤ fctfk/K

Crack control - Limitation of plastic plateau

Table 7.201 — Recommended values of w_{max} (mm)

Exposure class	Members in reinforced UHPFRC and members in prestressed UHPFRC with unbonded tendons	Members in prestressed UHPFRC with bonded tendons	Members in non-reinforced and non-prestressed UHPFRC	
	Quasi-permanent load combination	Frequent load combination	Characteristic load combination	Frequent load combination
X0, XC1	0.3	0.2	0.3	0.3
XC2, XC3, XC4	0.2	0.1	0.2	0.1
XD1, XD2, XD3 XS1, XS2, XS3	0.1	Tensile limitation to 2/3.min($f_{ctm,el}$, f_{ctfm}/K_{global})	0.1	0.05

Extract of NF P18-710[2.2]



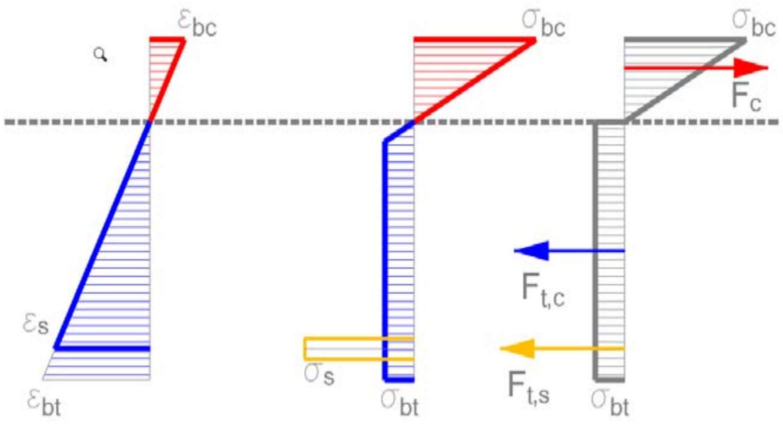
B - UHPFRC compression strain limit

C - UHPFRC pure compression strain limit

F - UHPFRC tension strain limit

Figure 6.201 — Diagram of relative deformations admissible in ultimate limit state for non-reinforced UHPFRC

Extract of NF P18-710



Strain *Stress* *Resultant*

Stress and strain distribution at ULS

Acceptable strain distributions

Bending with axial force : "Three pivots" limits known as tension controlled or compression controlled

Pivot F : limit lengthening $\varepsilon_{u,lim}$ of the UHPFRC on the most "tensioned" fiber of the section

Pivot B : limit shortening strain ε_{cud} of the UHPFRC on the most compressed fibre of the section

Pivot C : limit shortening strain ε_{c0d} of the UHPFRC under compression for the part due only to the axial force

Three resisting shear terms

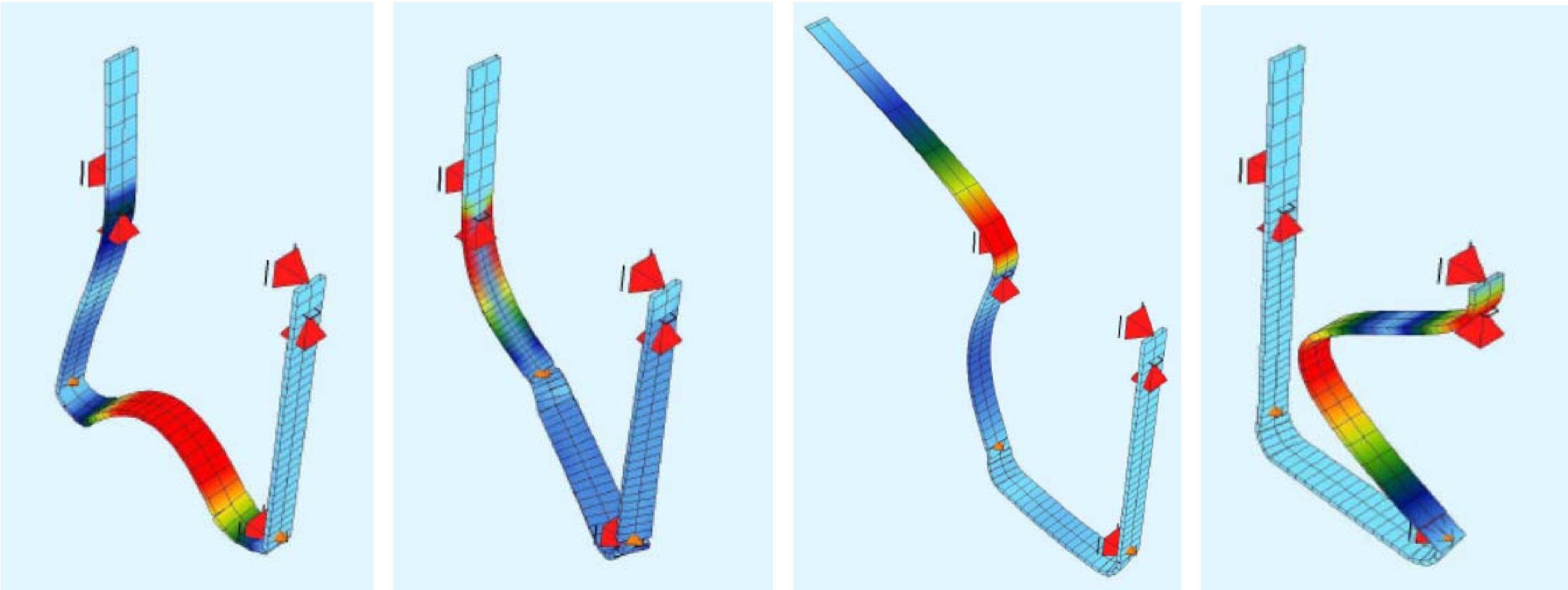
Resisting shear force

- UHPFRC contribution term
- Fiber contribution term
- Transverse reinforcement contribution term

Criteria of vibration analysis For each ribbon in Ductal FO

Natural frequency ≥ 7Hz

Response factor under harmonic load (0,2Q) ≤ 32

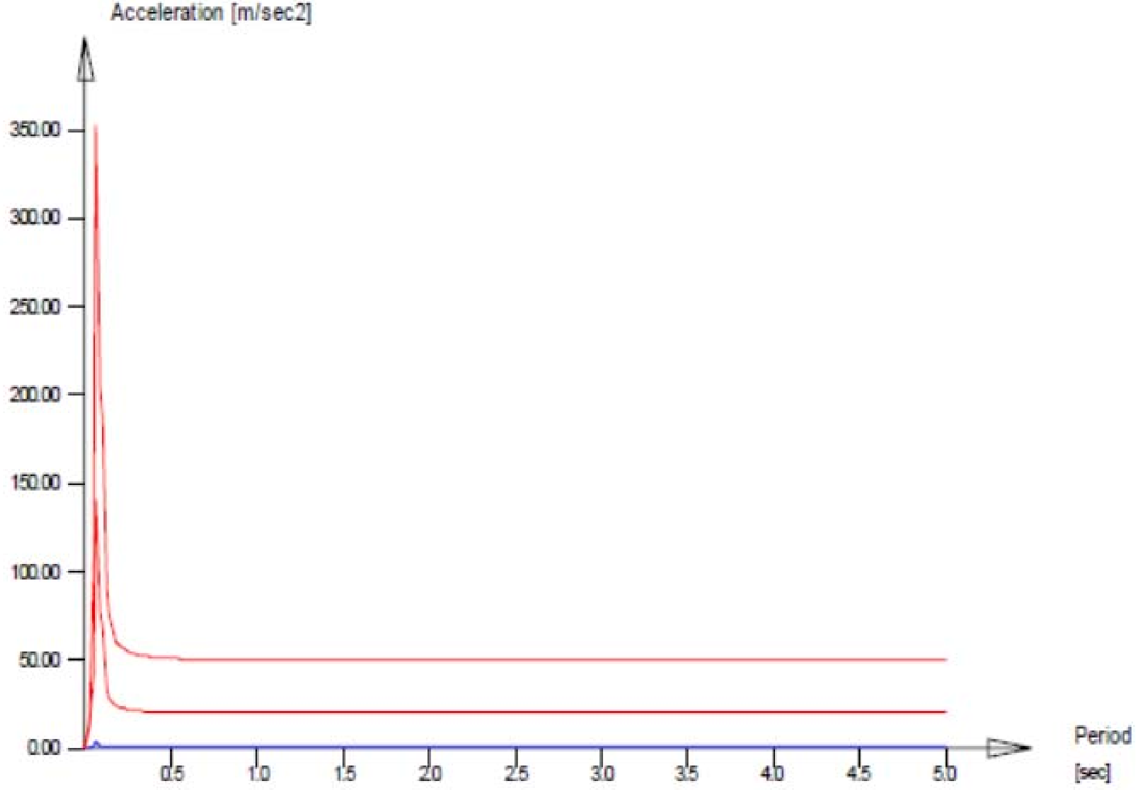


Calculation done with the software SOFISTIK AG

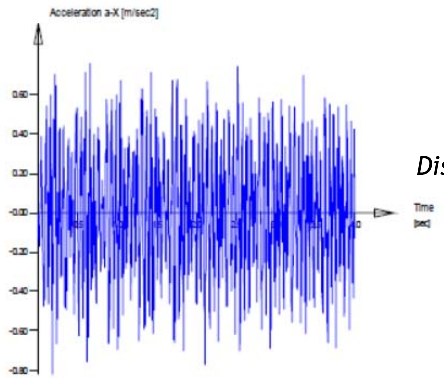
Criteria of vibration analysis For each ribbon in Ductal FO

Natural frequency ≥ 7Hz

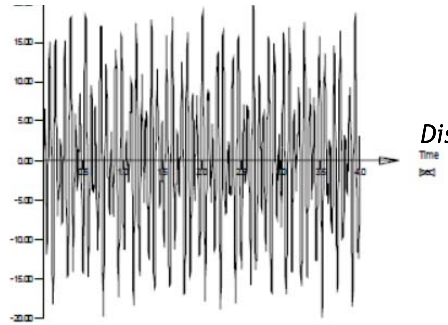
Response factor under harmonic load (0,2Q) ≤ 32



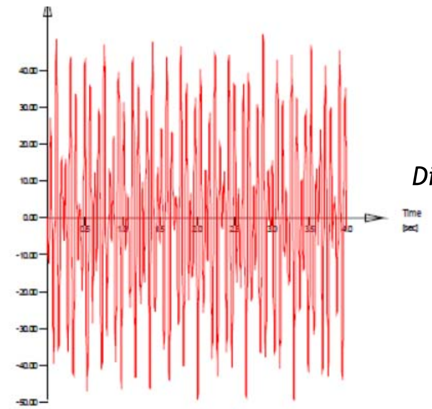
Response spectra under hormonic load (0,2Q and 10,84Hz)



Displacements in global X under harmonic load

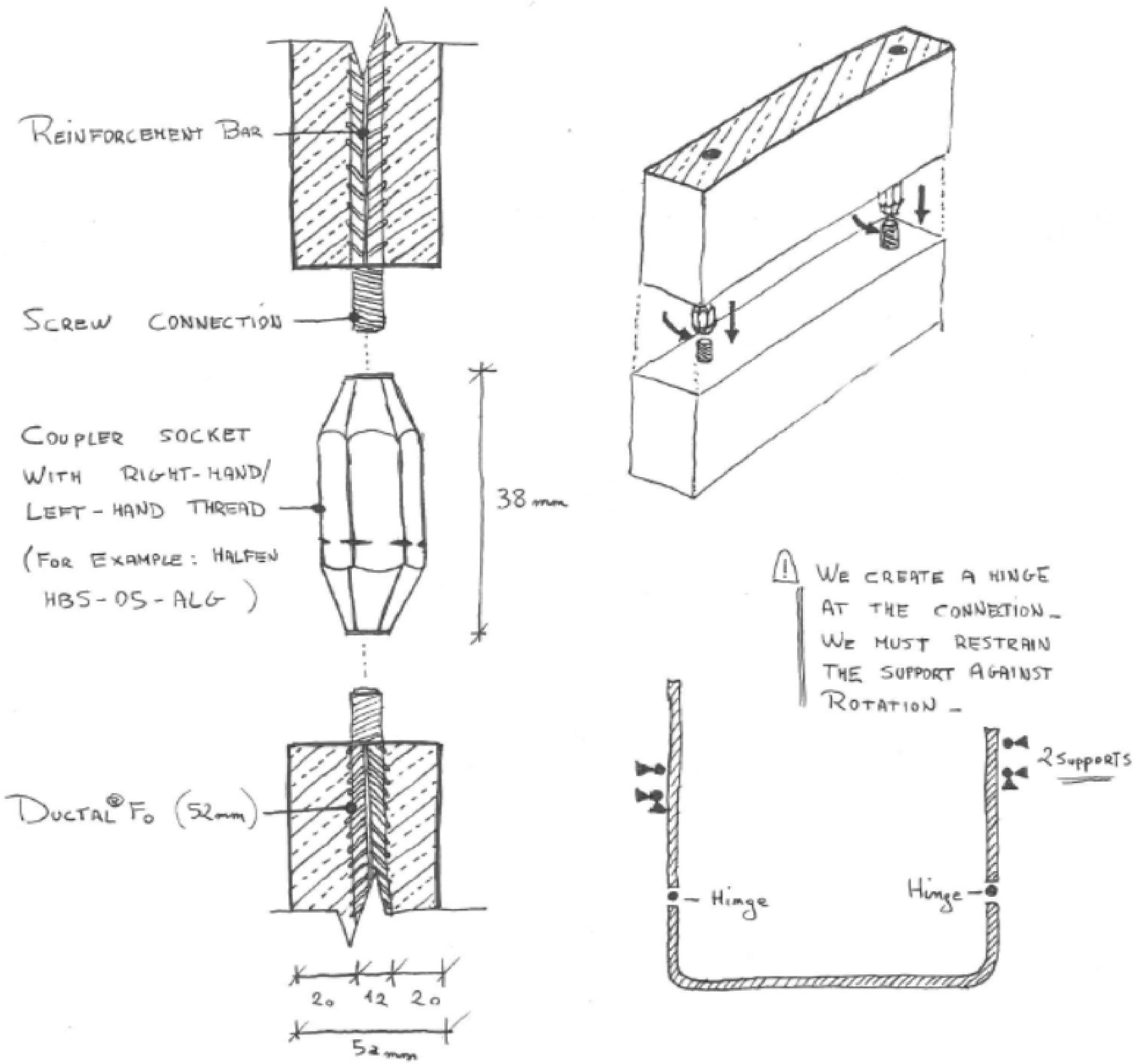


Displacements in global Y under harmonic load

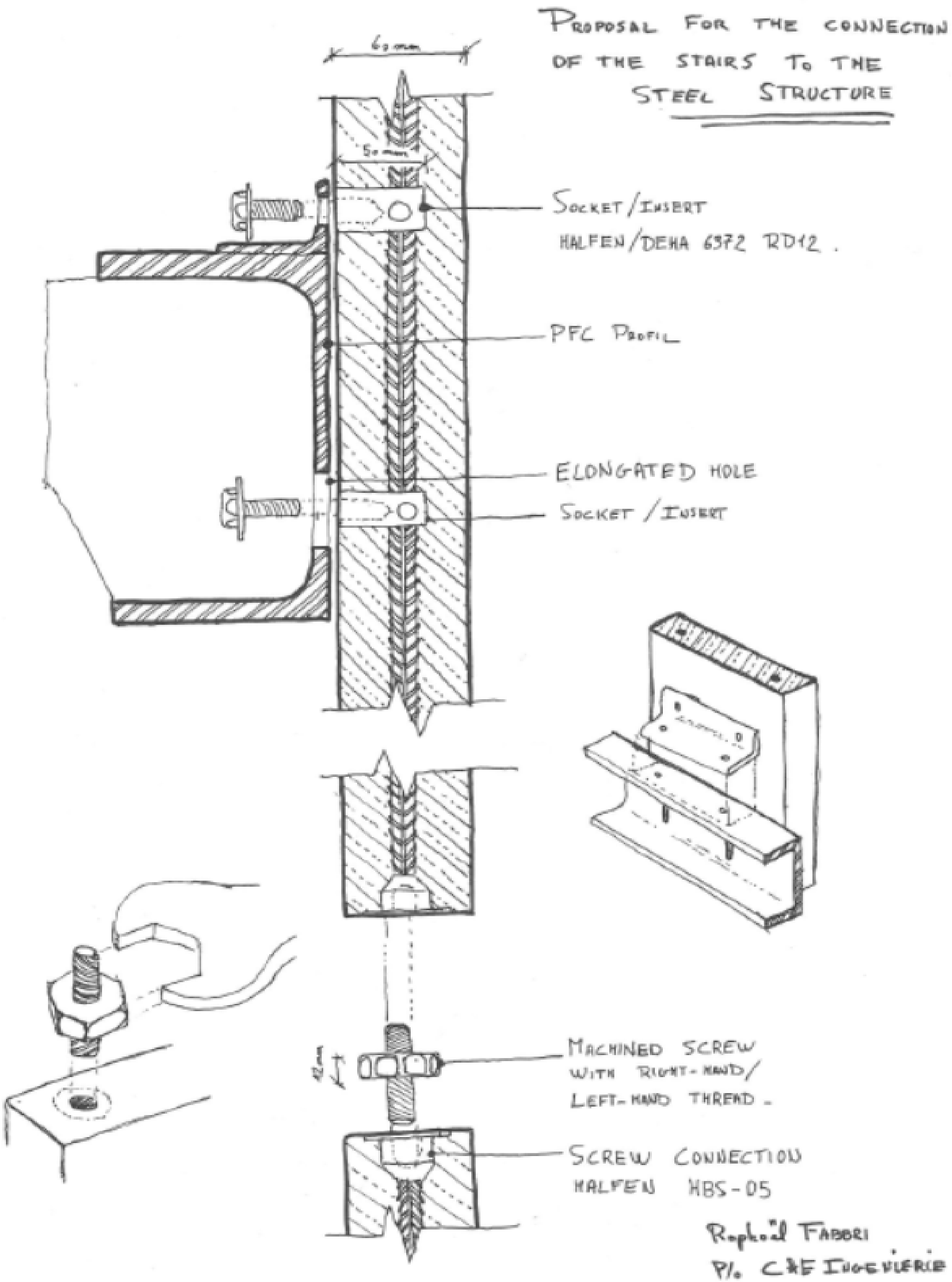


Displacements in global Z under harmonic load

Proposal for join between stair step and vertical ribbon



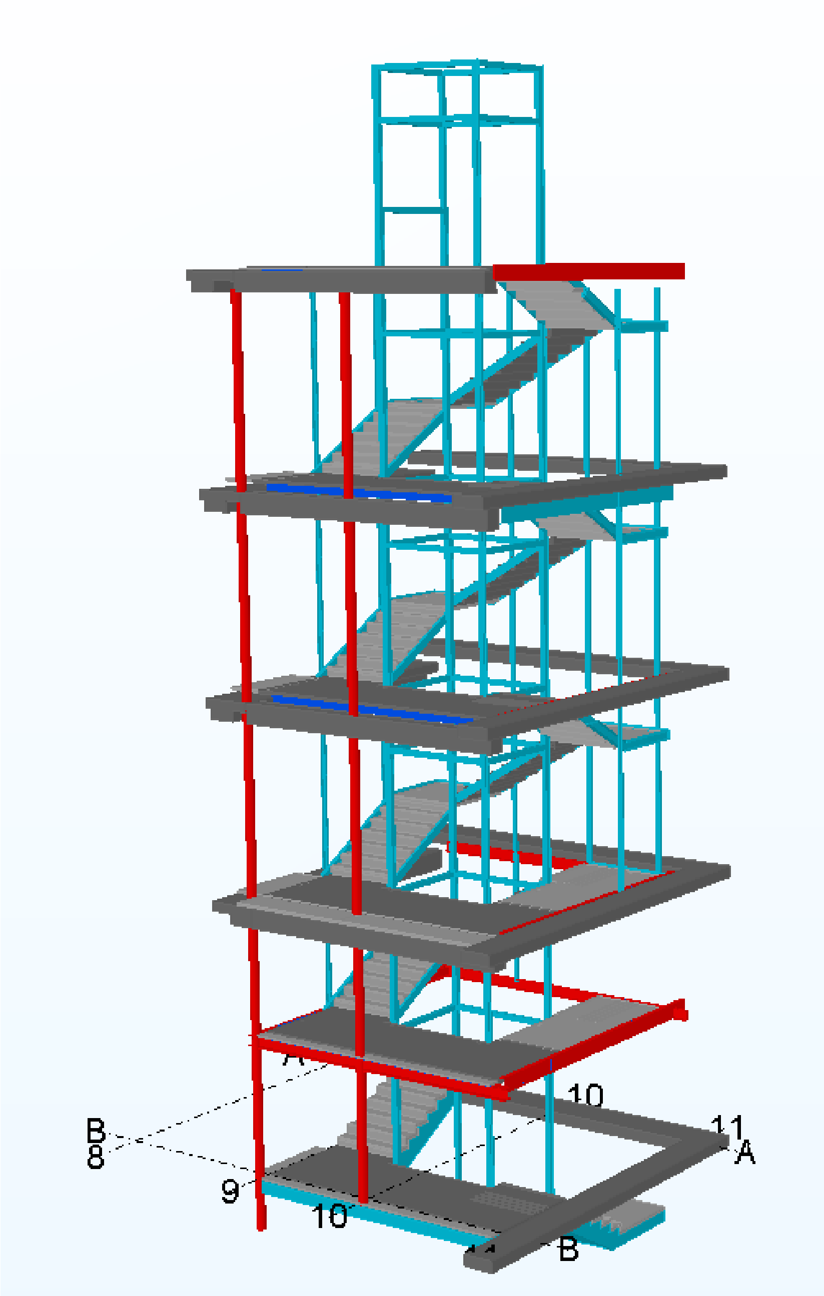
Construction process analysis

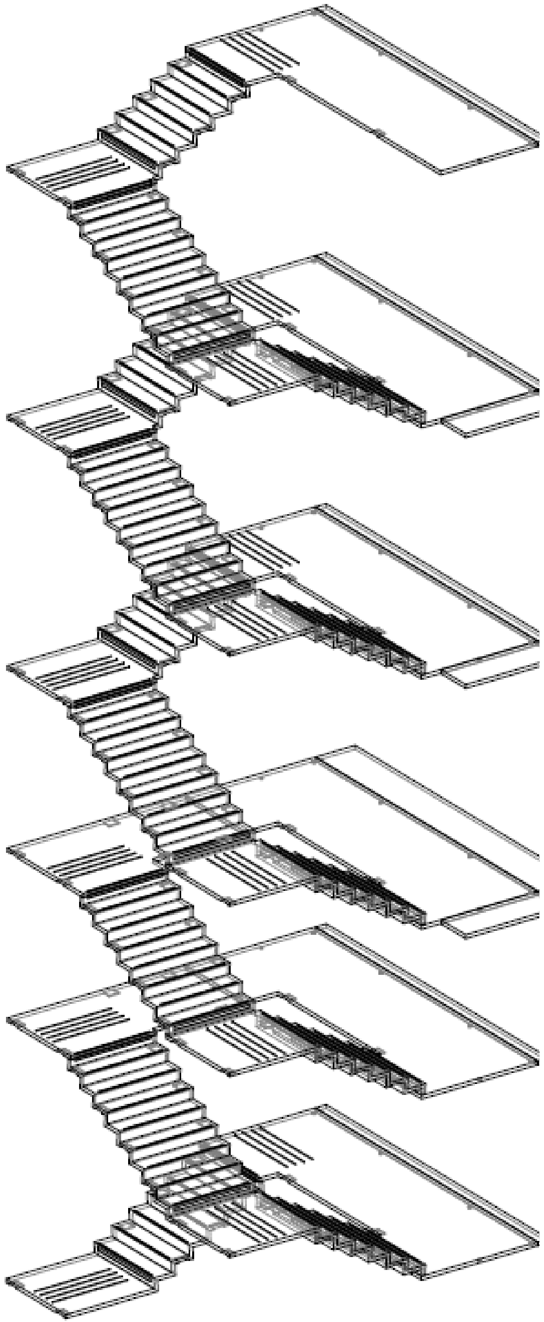


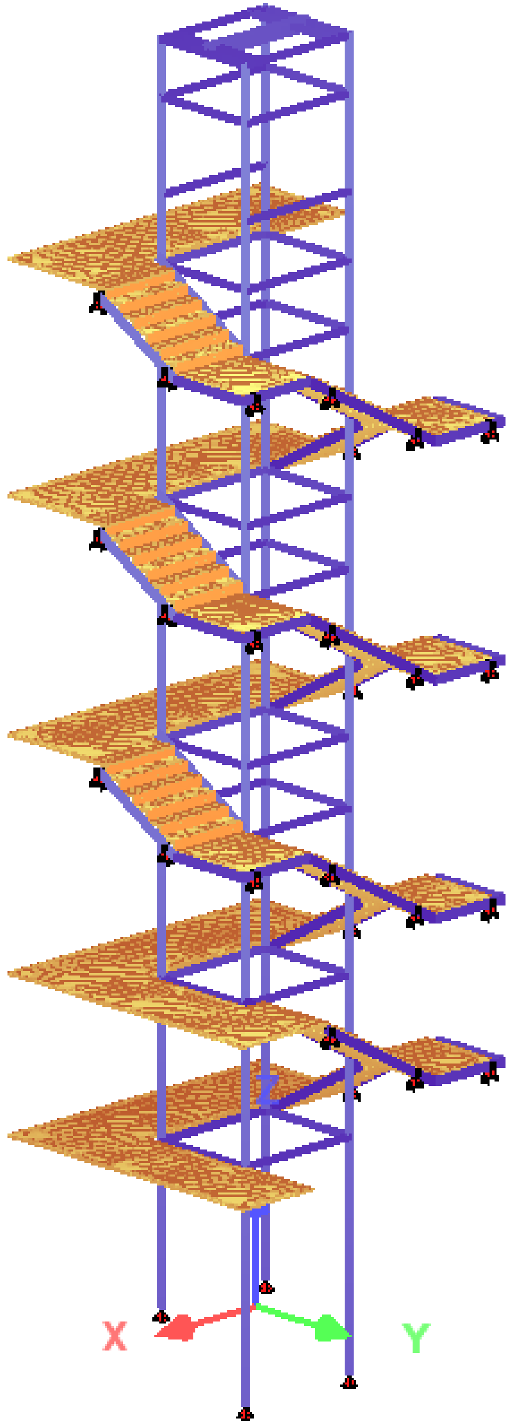
Proposal for the connexion of the stairs to the steel structure

Galeries Lafayette Foundation Public staircase / OMA Architect

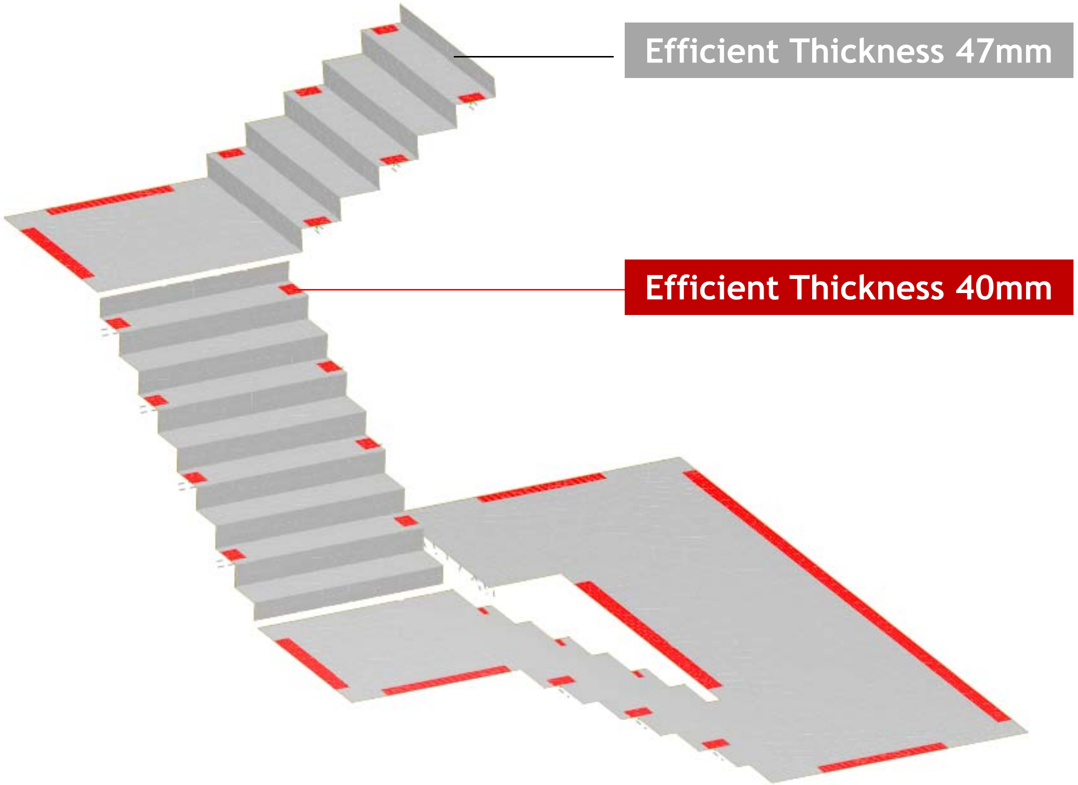
Localization : Paris Ist distrct_Galeries Lafayette Foundation / LBC+Jousselin prefabricaton
Building typology : Foundation
Quantity : 4 floors (22 elements)
Function : Public staircase
UHPFRC : Ductal® G2 FM STT


B
8
9
10
10
11
A
B

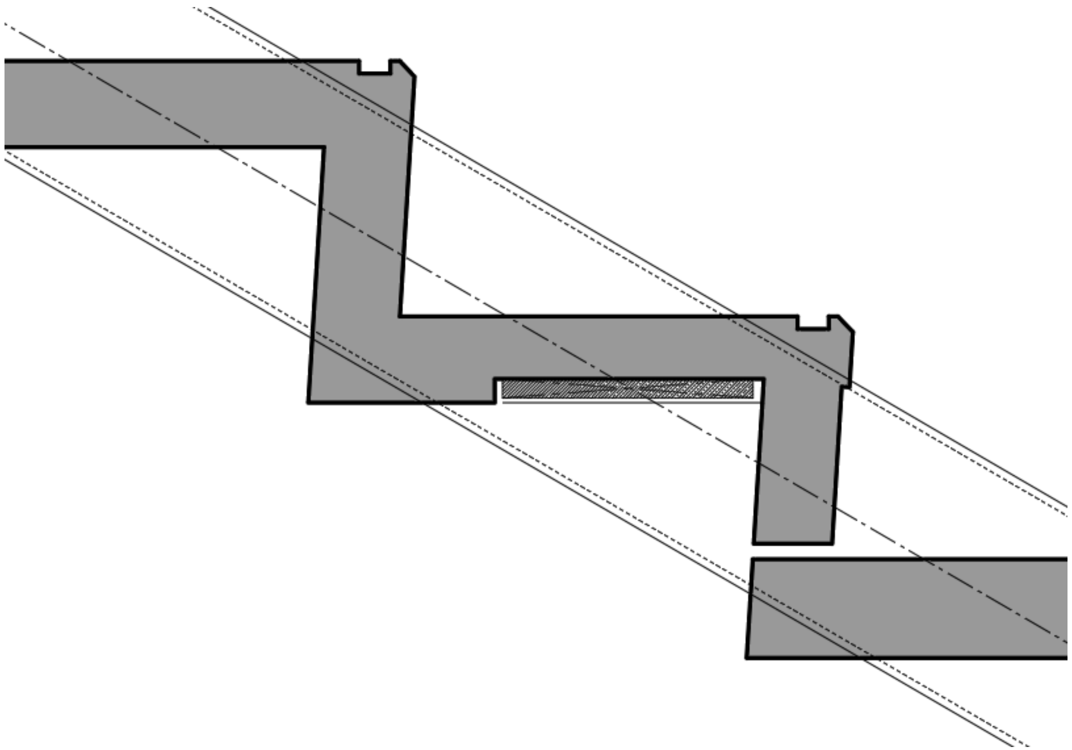



X
Y

Design hypothesis _ Geometry



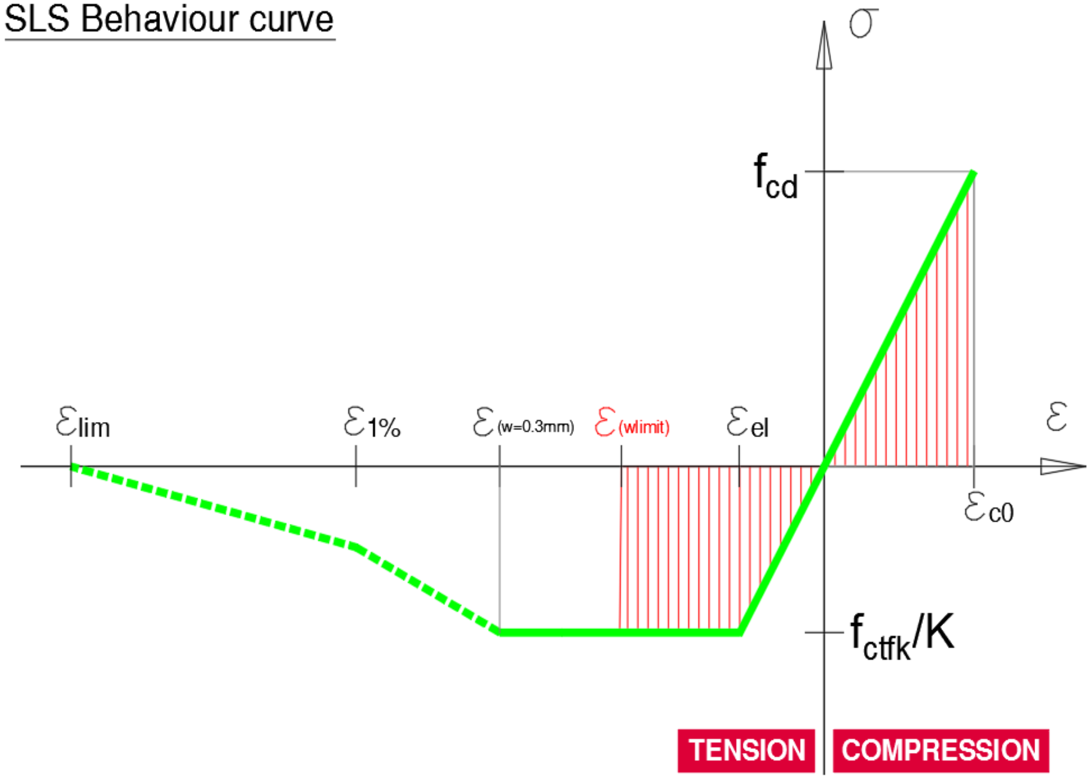
Thickness of the stairs



Sectional view of the stairs

Structural Analysis_ SLS

SLS Behaviour curve



Stress limitation

Non-reinforced Ductal FO

- Compressive stress ≤ 0.6 fck
- Tensile stress ≤ fctfk/K

Crack control - Limitation of plastic behaviour

Table 7.201 — Recommended values of w_{max} (mm)

Exposure class	Members in reinforced UHPFRC and members in prestressed UHPFRC with unbonded tendons	Members in prestressed UHPFRC with bonded tendons	Members in non-reinforced and non-prestressed UHPFRC	
	Quasi-permanent load combination	Frequent load combination	Characteristic load combination	Frequent load combination
X0, XC1	0.3	0.2	0.3	0.3
XC2, XC3, XC4	0.2	0.1	0.2	0.1
XD1, XD2, XD3 XS1, XS2, XS3	0.1	Tensile limitation to 2/3.min($f_{ctm,el}$, f_{ctfm}/K_{global})	0.1	0.05

Extract of NF P18-710[2.2]

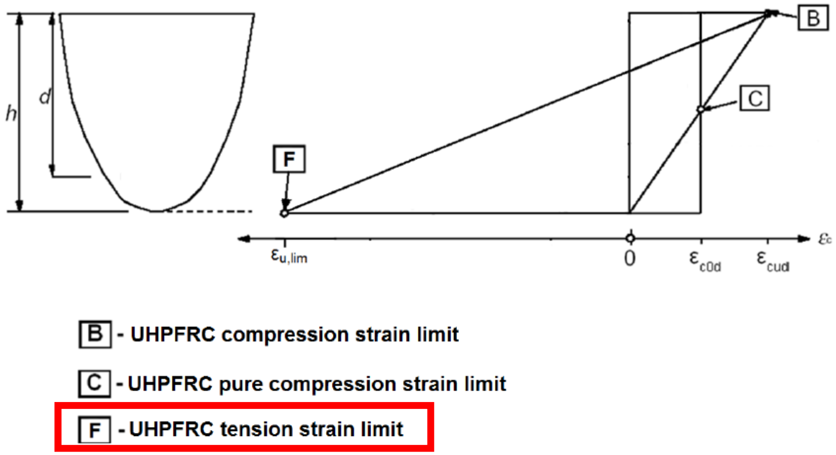
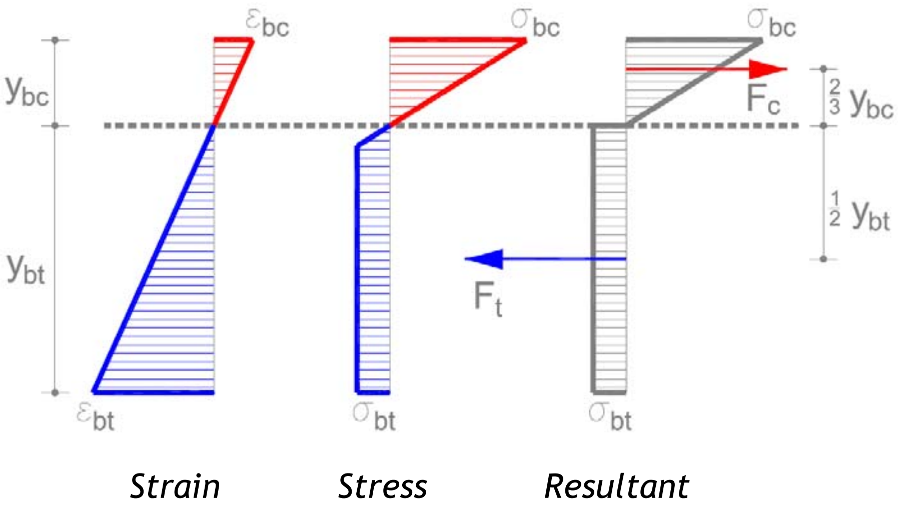


Figure 6.201 — Diagram of relative deformations admissible in ultimate limit state for non-reinforced UHPFRC

Extract of NF P18-710



Stress and strain distribution at ULS

Acceptable strain distributions

Bending with axial force : 3 pivot limits

Pivot F : limit lengthening $\varepsilon_{u,lim}$ of the UHPFRC on the most tensioned fiber of the section

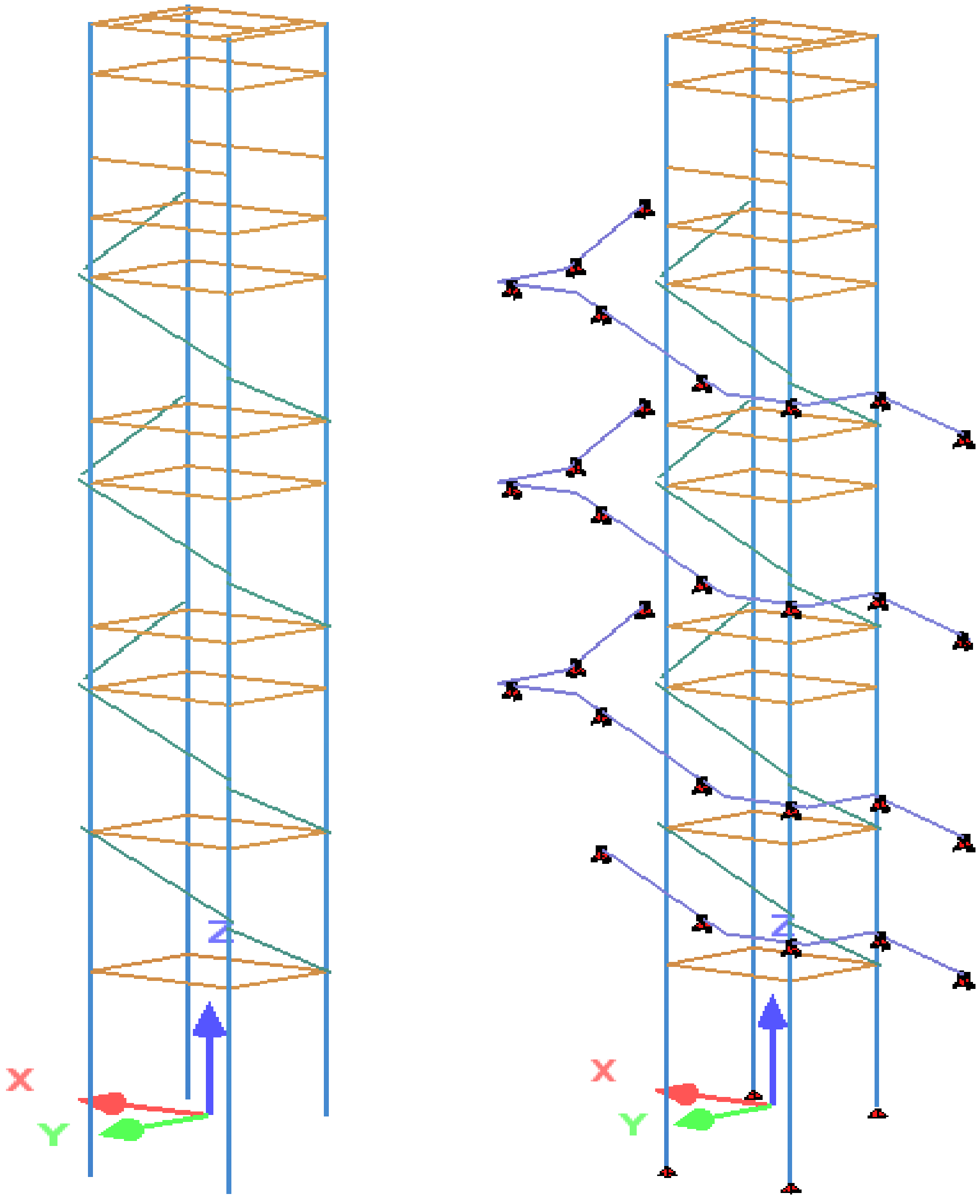
Pivot B : limit shortening strain ε_{cud} of the UHPFRC on the most compressed fibre of the section

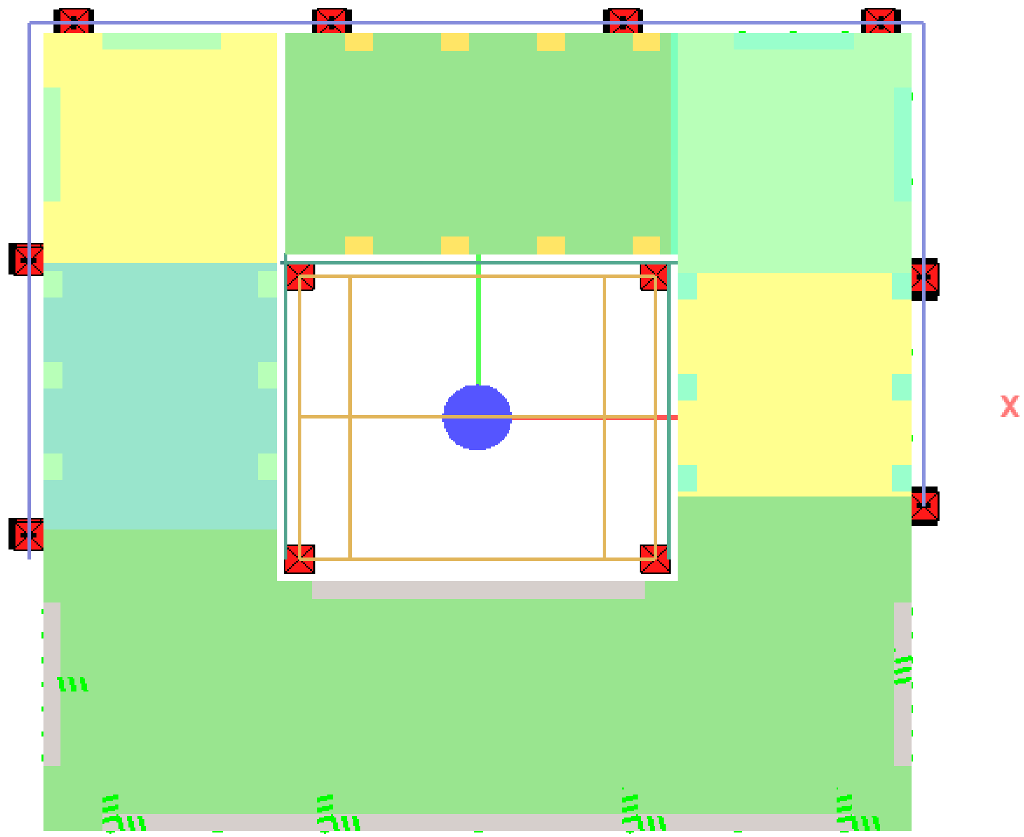
Pivot C : limit shortening strain ε_{c0d} of the UHPFRC under compression for the part due only to the axial force

Three resisting shear terms

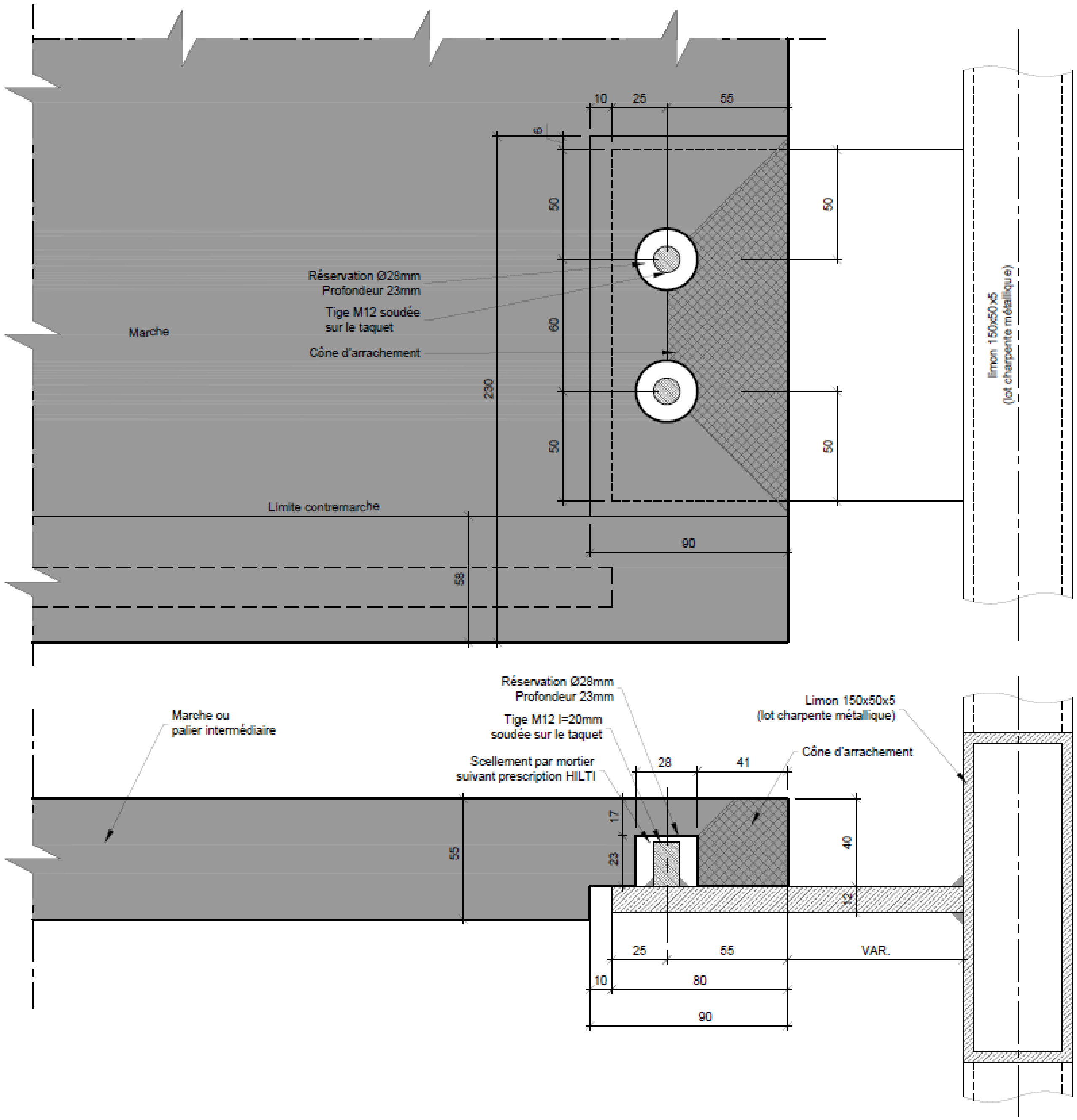
Resisting shear force

- UHPFRC contribution term
- Fiber contribution term
- Transverse reinforcement contribution term



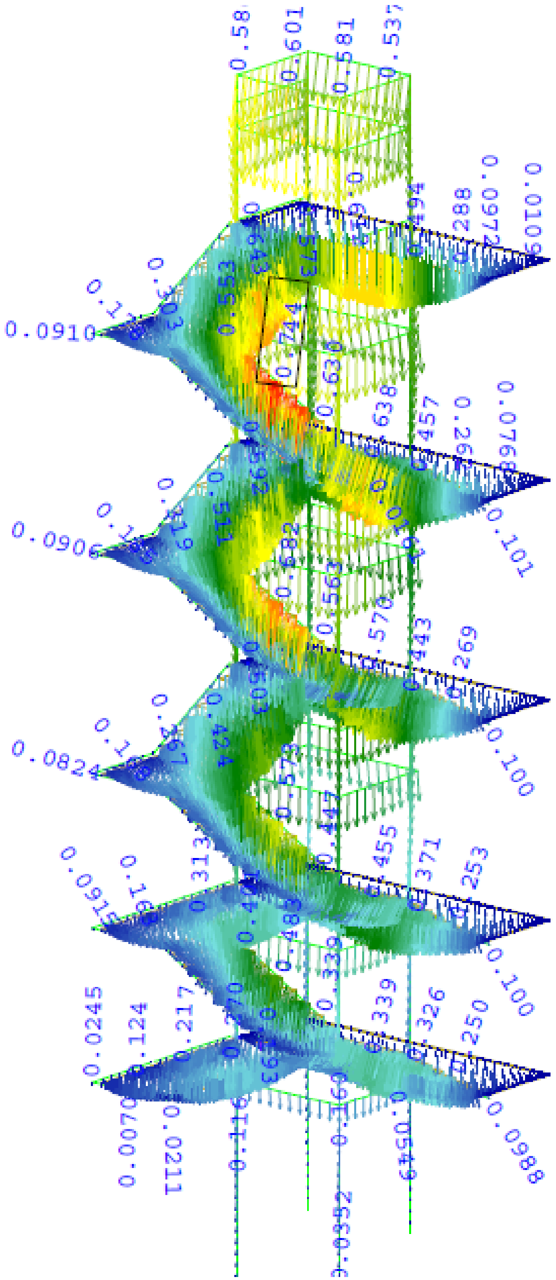


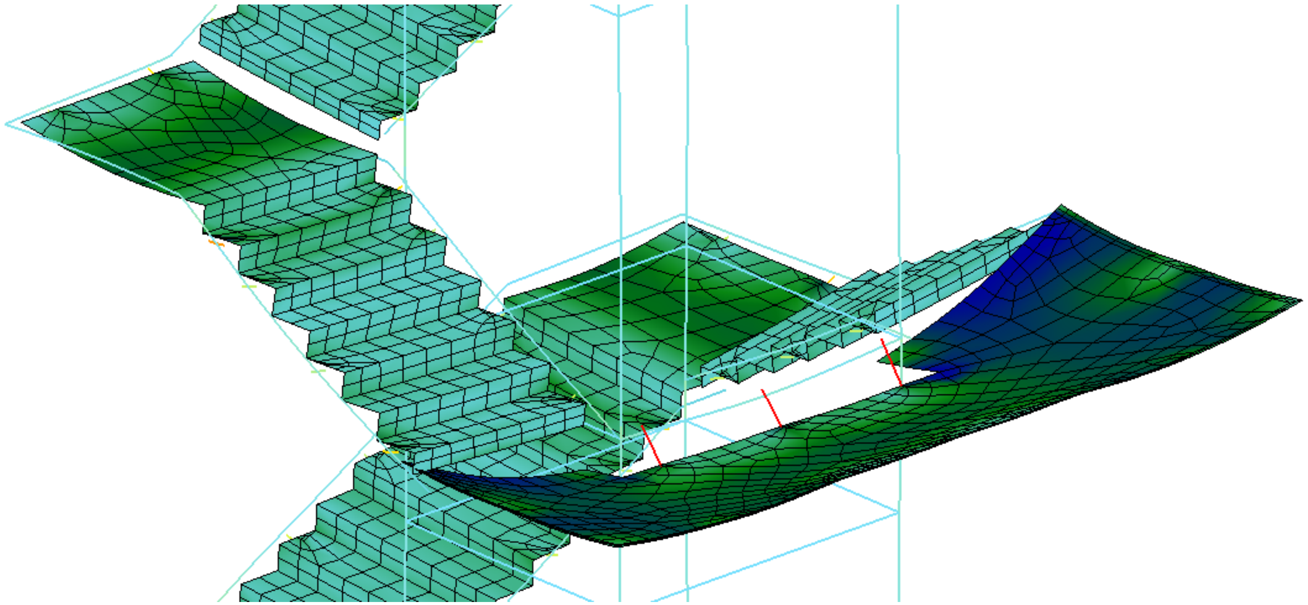
Horizontal stability



Vérification de la cône d'arrachement
Verification of cone of tearing

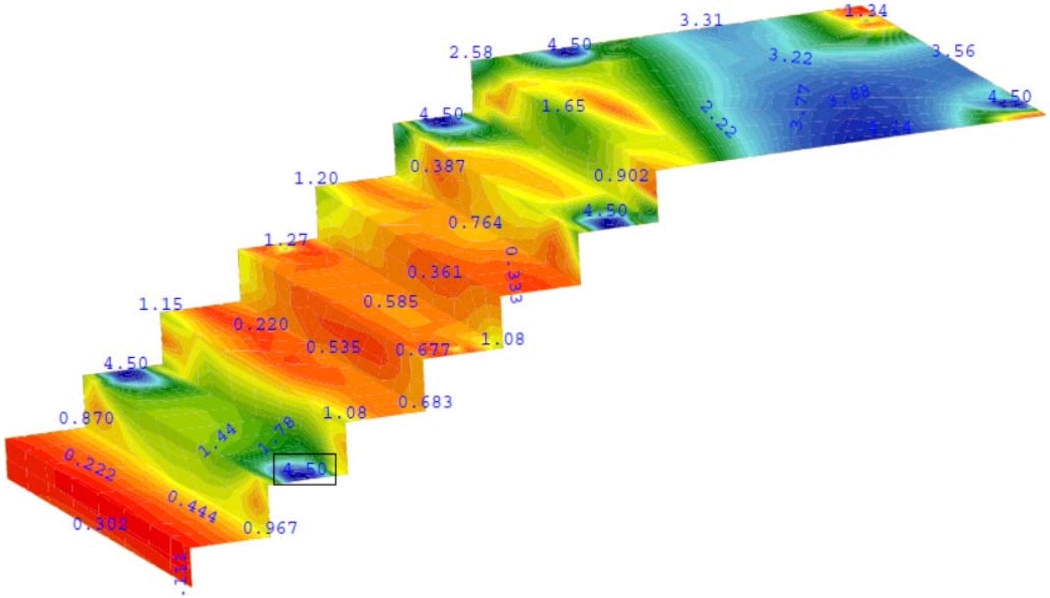
A. Interactions between metal frame and Ductal element



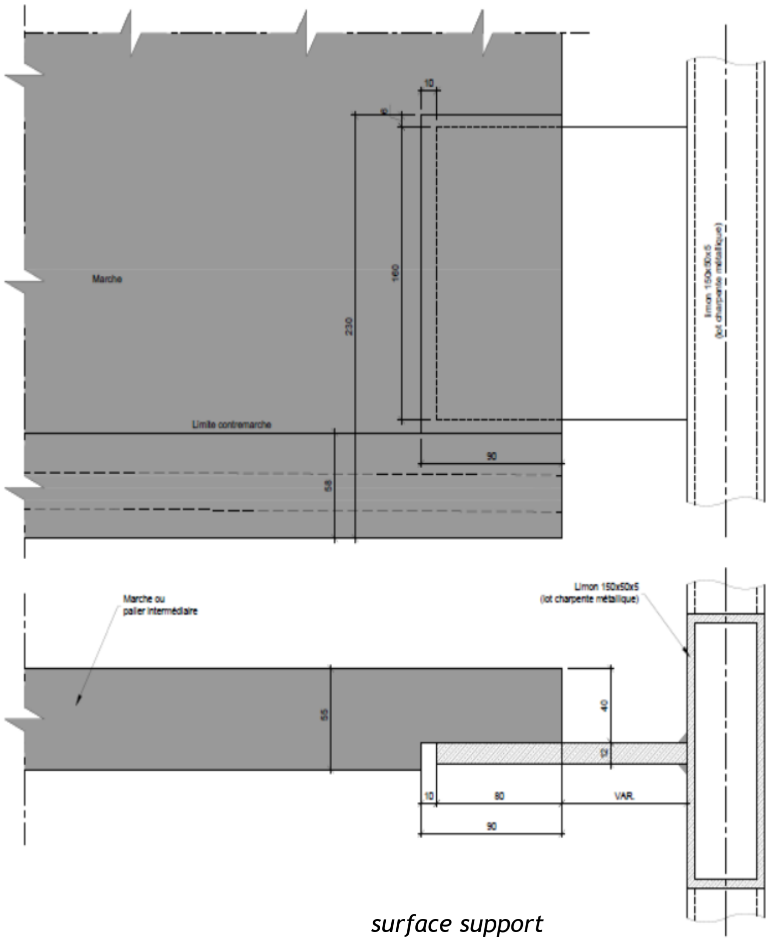


The displacement of the metal frame has a signficant impact on the behavoir of the elements in Ductal, so it's the key point to have a global modelling to take into account the interactions between the metal frame and Ductal element.

B. Redistribution of peak stress



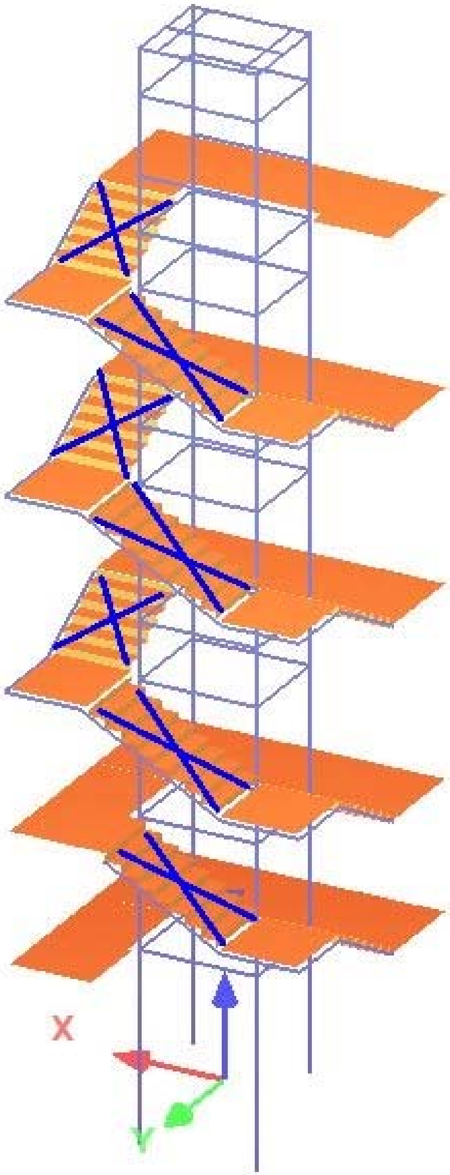
Peak stress at the supports

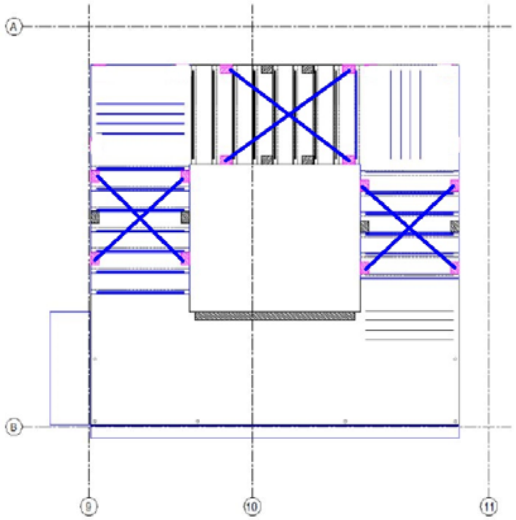


surface support

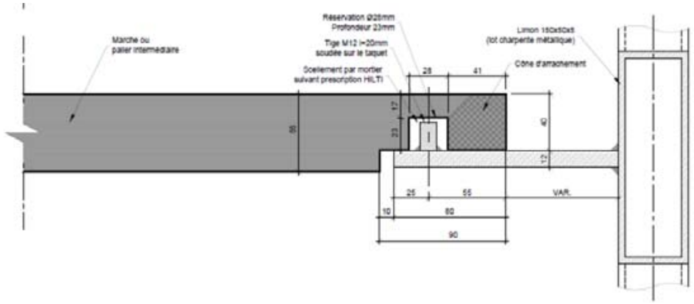
The peak stress occurs at the supports. In the modelling, the punctual support points should be avoided. Il could be replaced by a surface support to have enough area for the redistribution of the peak stress.

C. Optimization of horizontal clamping

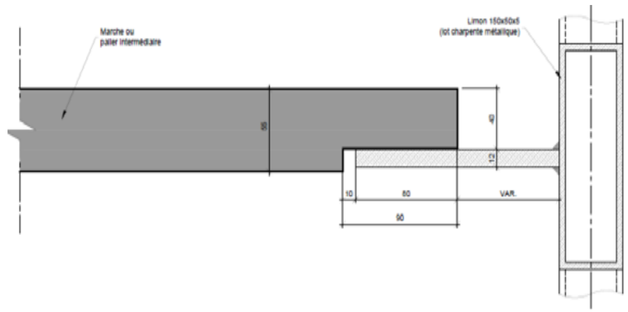




Bracing system



First type of support
Horizontal clamping and vertical support



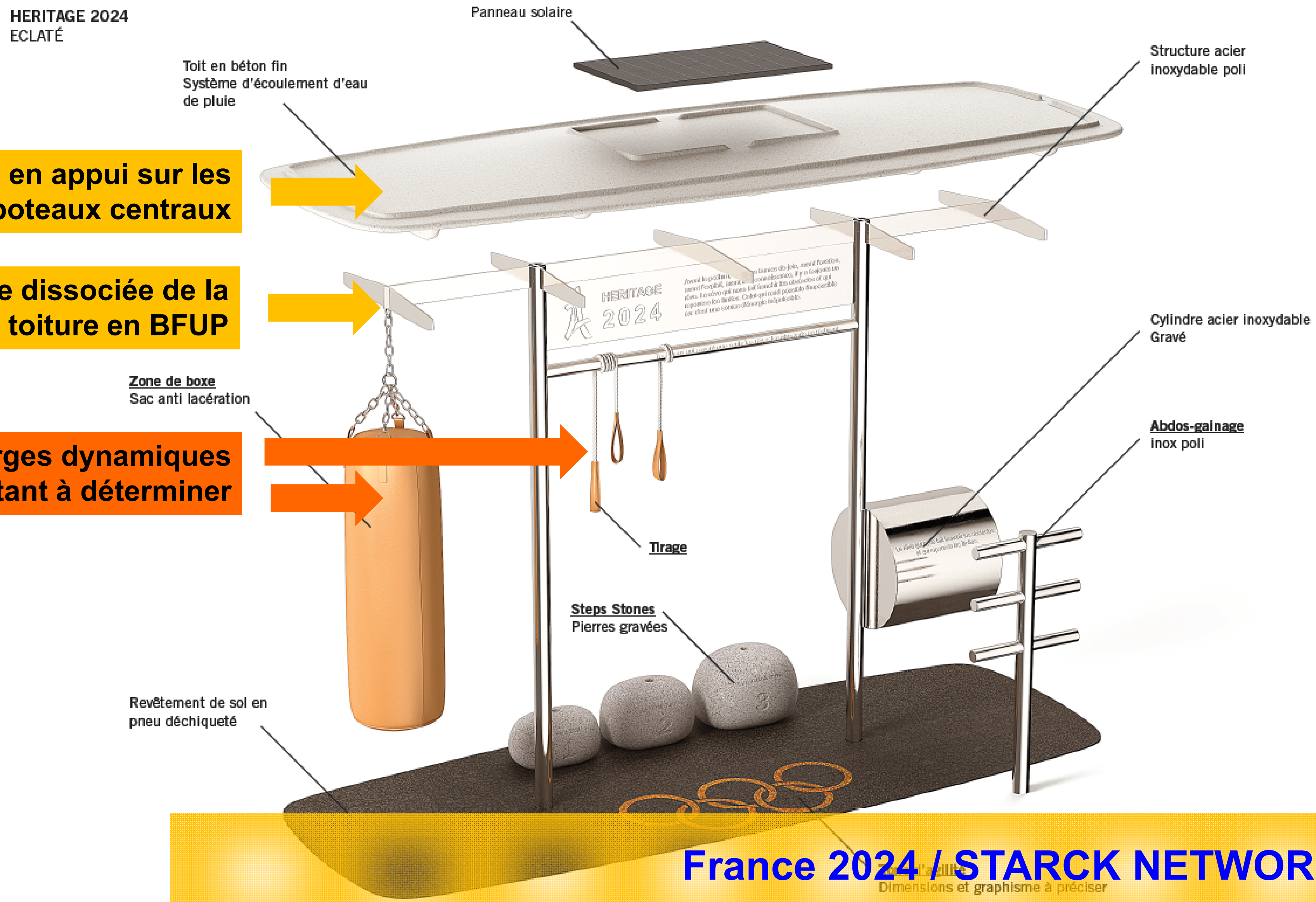
Second type of support
Vertical support only

Every piece of stair play a role of bracing system, to make it efficient and to transfer the lateral force easier, 2 ranges of horizontal clamping is made for each piece.

Toiture en appui sur les poteaux centraux

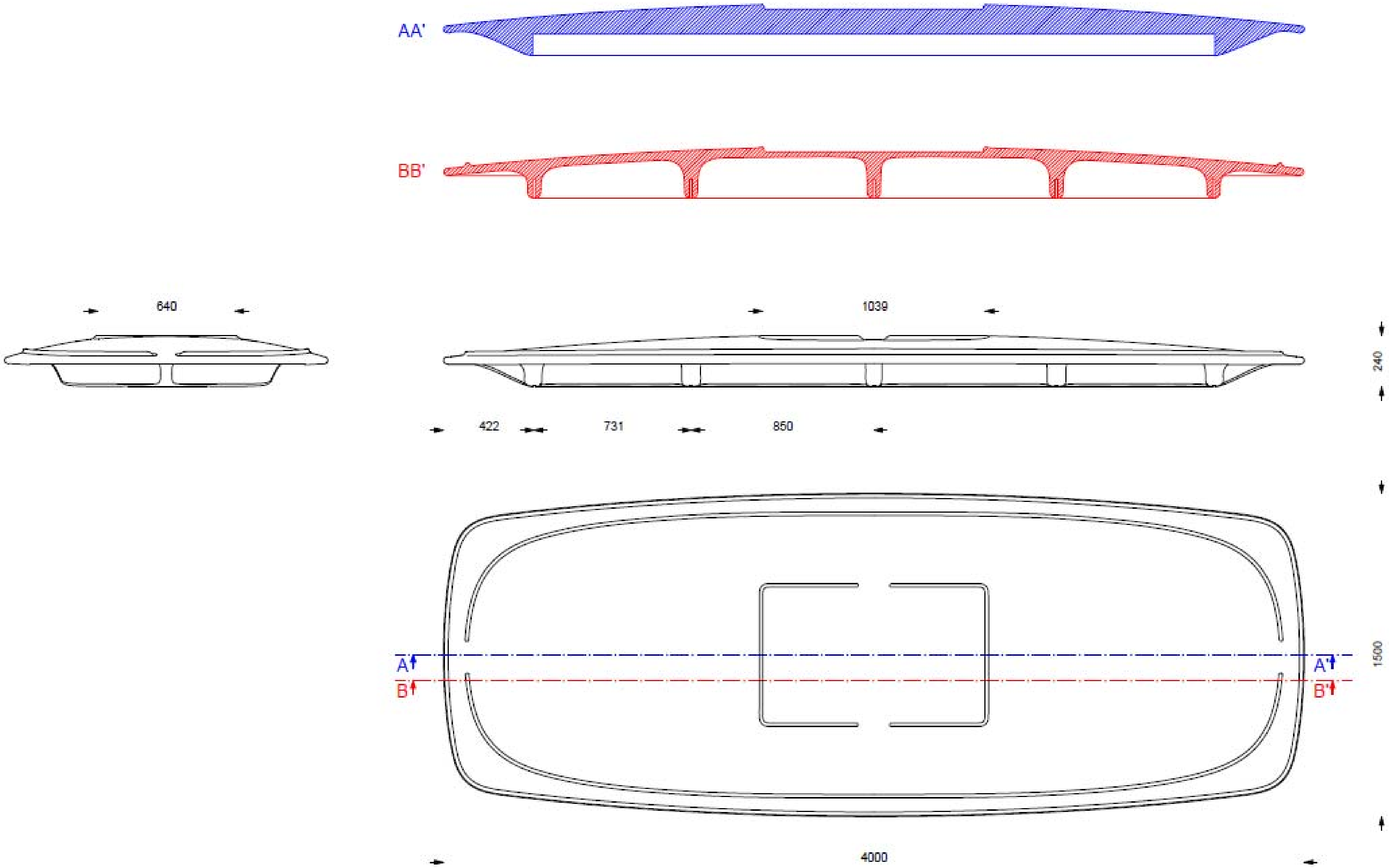
Structure dissociée de la toiture en BFUP

Charges dynamiques restant à déterminer



France 2024 / STARCK NETWORK Designer

GEOMETRIE ET MATERIAU

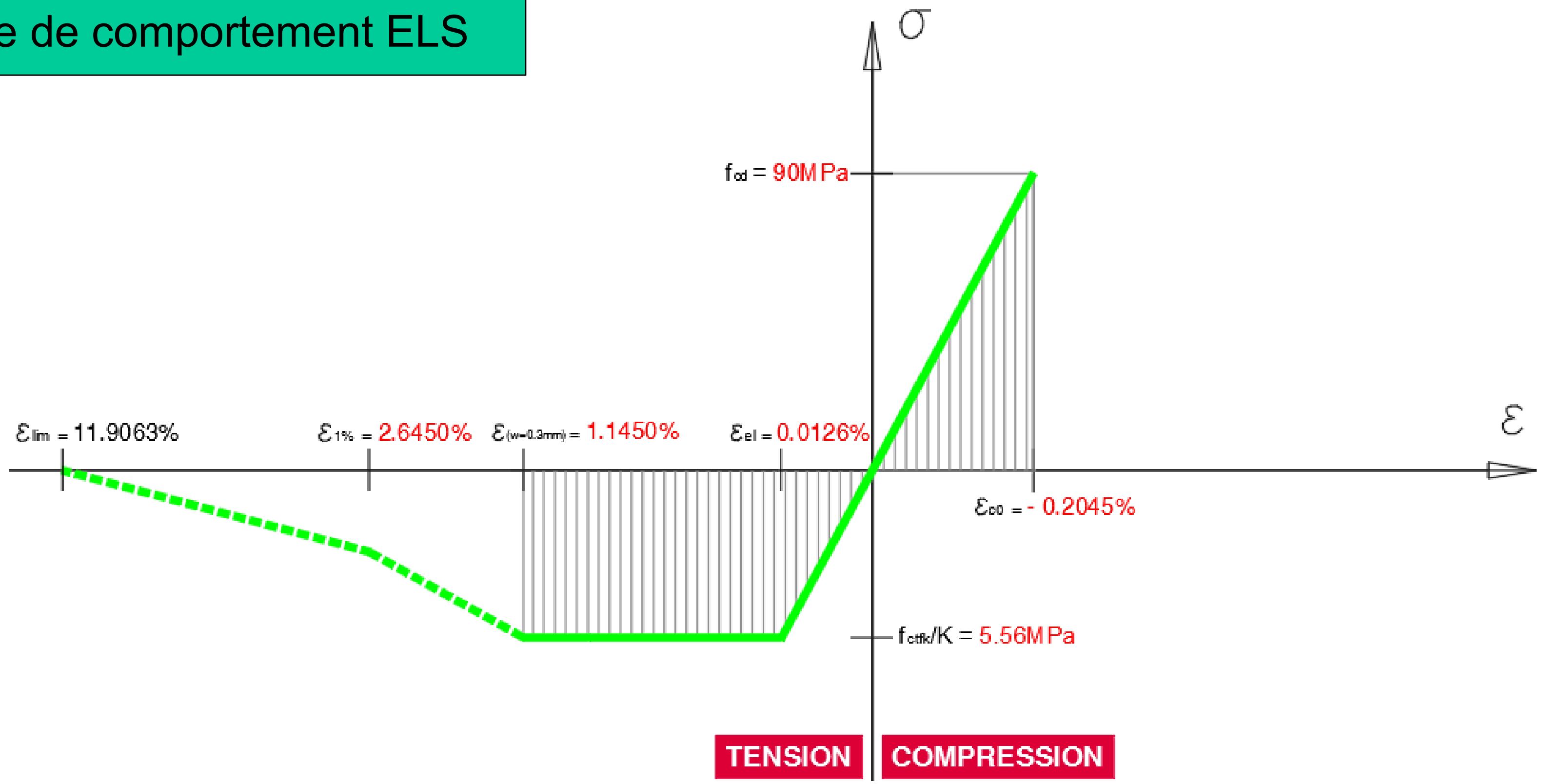


GEOMETRIE ET MATERIAU

CARTE D'IDENTITE MATERIAU

SMART[UP] [STRUCTURE] Gris 2,5% FM

Courbe de comportement ELS

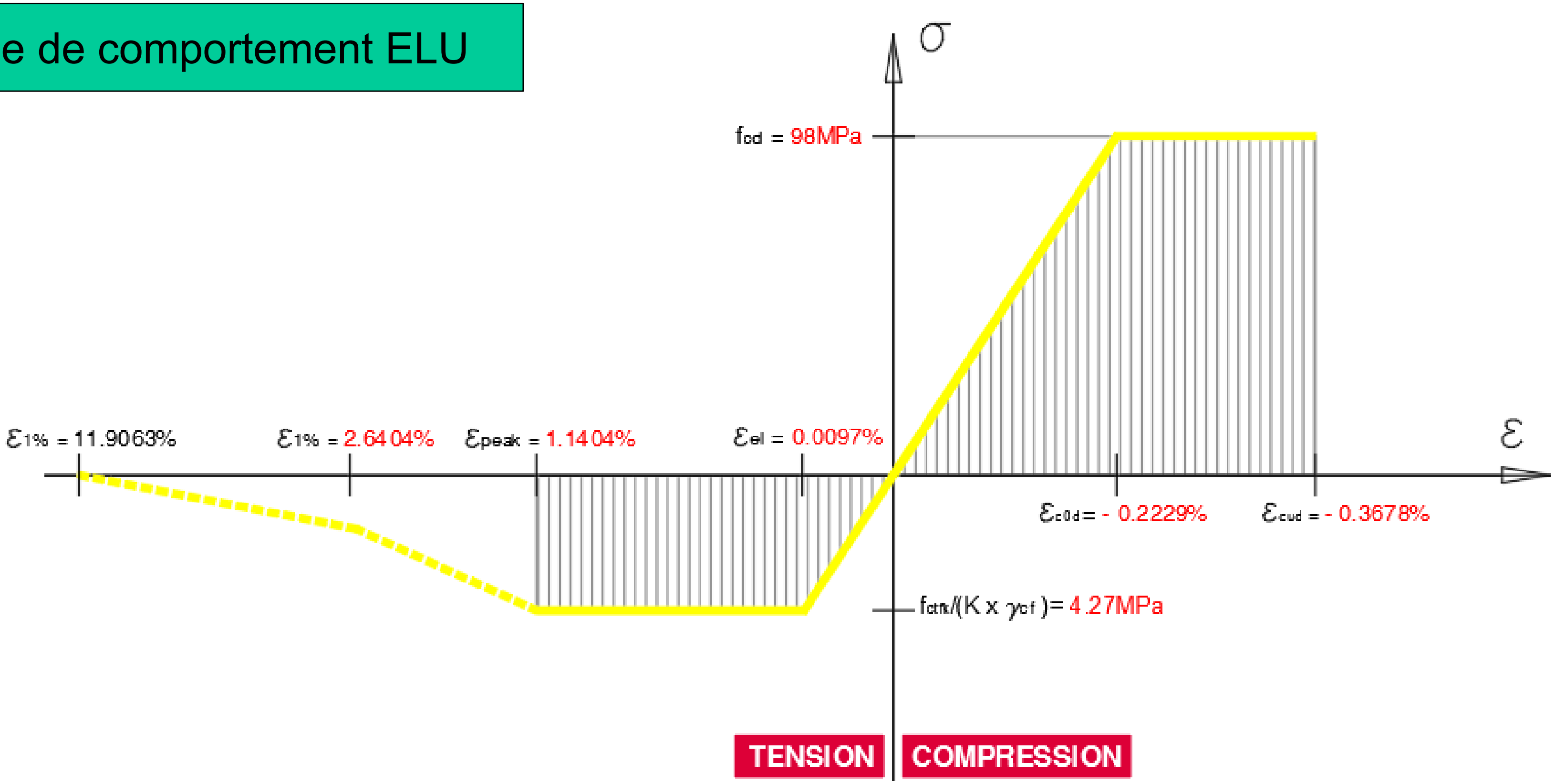


GEOMETRIE ET MATERIAU

CARTE D'IDENTITE MATERIAU

SMART[UP] [STRUCTURE] Gris 2,5% FM

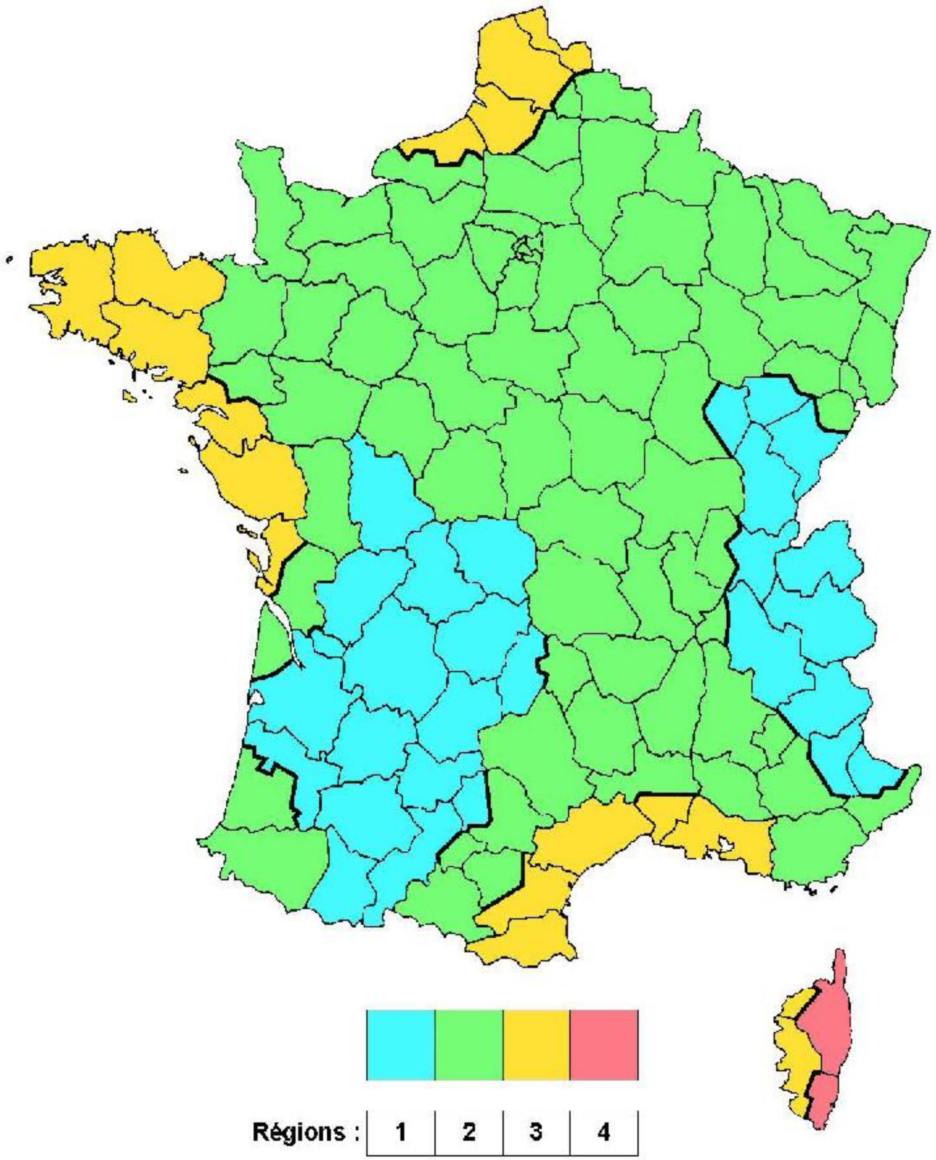
Courbe de comportement ELU



Actions du vent

Pression dynamique de pointe q_p **(à confirmer)**

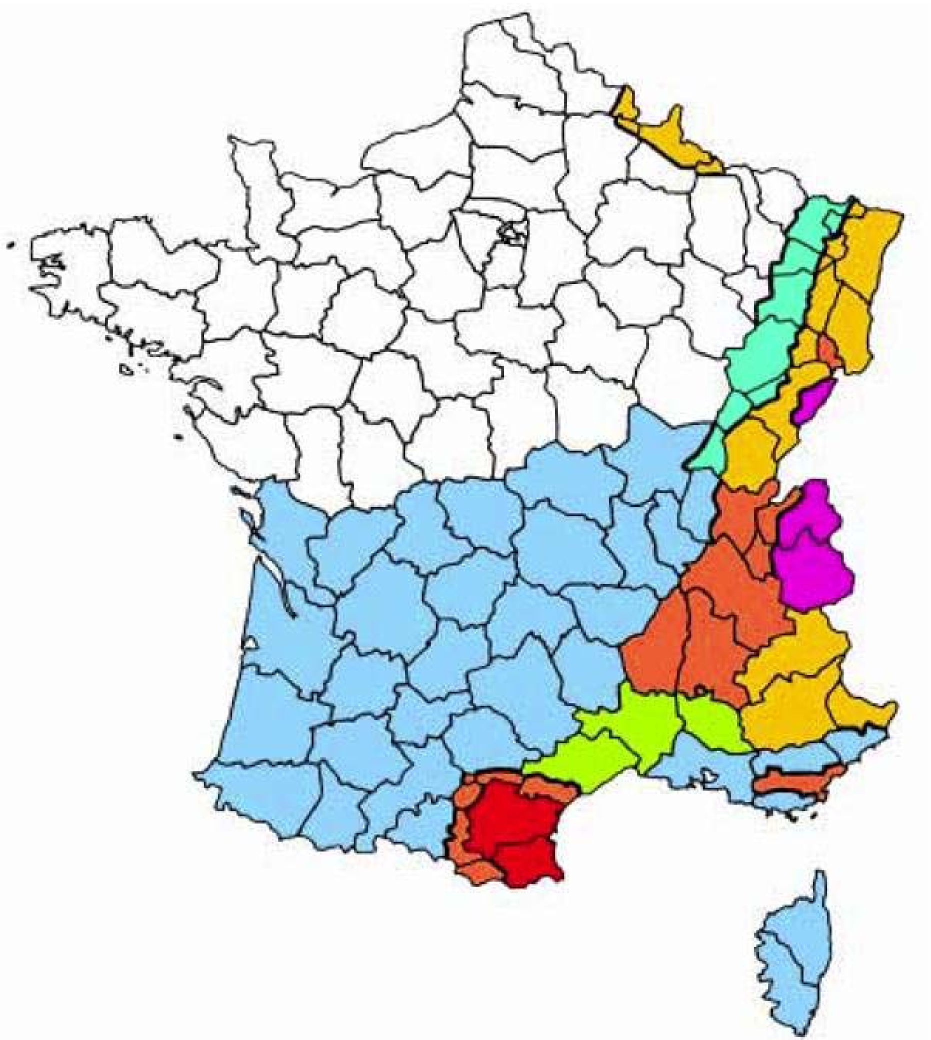
	Cas 1	Cas 2	Cas 3	Cas 4	Cas 5	Cas 6
Zone du vent	1	2	3	4	Réunion	2
Vitesse de référence [m/s]	22	24	26	28	32	24
Vitesse de référence [km/h]	79.2	86.4	93.6	100.8	115.2	86.4
Catégorie de rugosité du terrain	0	0	0	0	0	II
Hauteur du projet [m]	3.5	3.5	3.5	3.5	3.5	3.5
Pression dynamique de pointe q_p [Pa]	688	819	961	1115	1456	607



Catétorie de terrain	
0	Mer ou zone côtière exposée aux ventes de mer, lacs et plans d'eau parcourus par le vent sur une distance d'au moins 5km
II	Rase campagne, avec ou non quelques obstacles isolés(arbres, bâtiments etc.) séparés les uns des autres de plus de 40 fois leur hauteur
IIIa	Campagne avec des haies; vignobles; bocage; habitat dispersé
IIIb	Zones urbanisées ou industrielles; bocage dense; vergers
IV	Zones urbaines dont au moins 15% de la surface sont recouvers de bâtiments dont la hauteur moyenne est supérieure à 15m; forêts

La pression dynamique de pointe qp retenu pour cette étude de faisabilité est de **961Pa** (0.916kN/m²), **elle est indicative du niveau du pression à prendre en compte**

CHARGEMENT



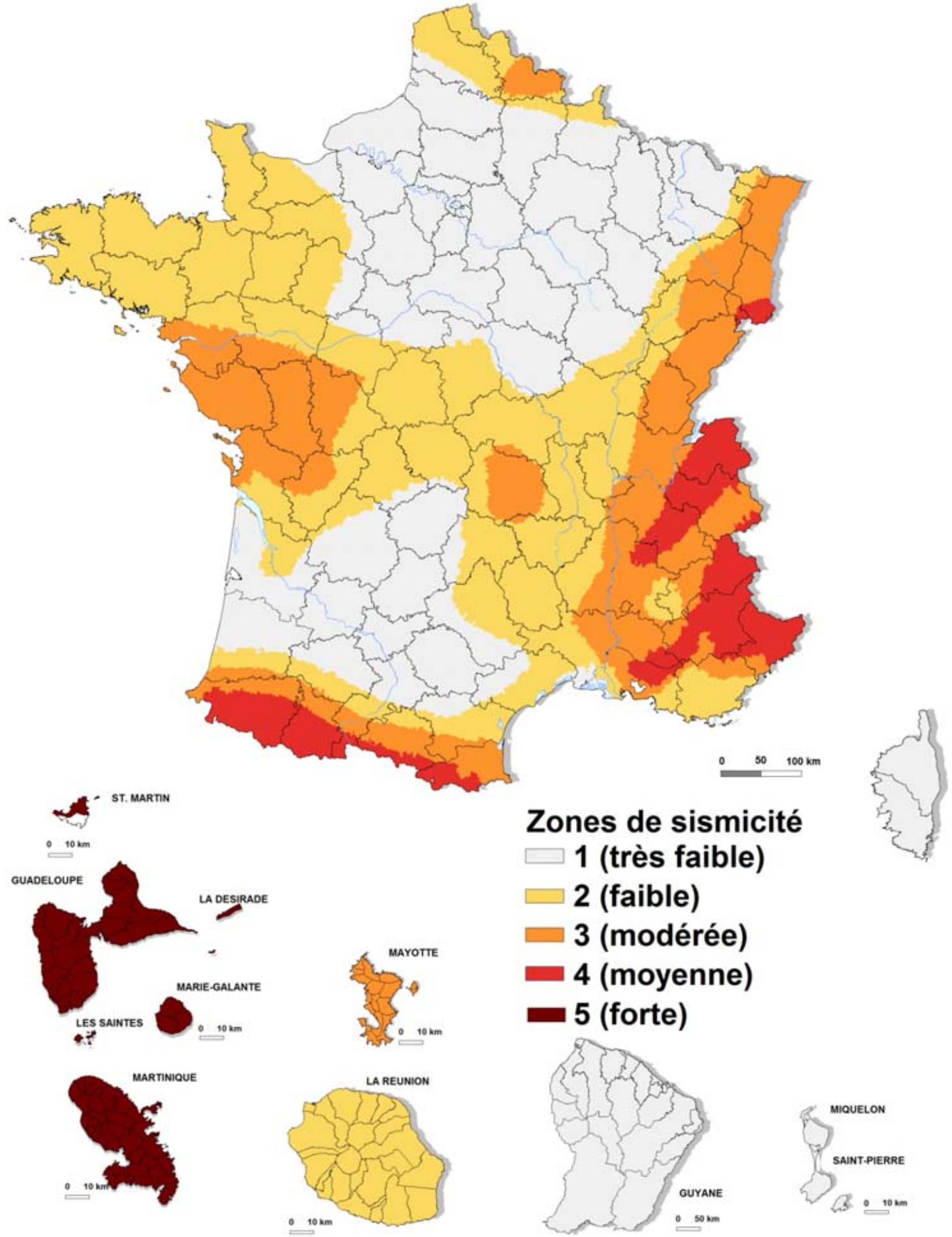
Régions	A1	A2	B1	B2	C1	C2	D	E
Valeur caractéristique (S_k en kN/m2) de la charge de neige sur le sol à une altitude inférieure à 200m	0.45	0.45	0.55	0.55	0.65	0.65	0.9	1.4
Valeur de calcul S_{Ad} de la charge exceptionnelle de neige sur le sol	-	1	1	1.35	-	1.35	1.8	-

Charges de neige

Sans prendre en compte des charges exceptionnelles de neige

	Cas 1	Cas 2	Cas 3	Cas 4	Cas 5	Cas 6	Cas 7	Cas 8
Régions	A1	A2	B1	B2	C1	C2	D	E
Valeur caractéristique (S_k en kN/m2)	0.45	0.45	0.55	0.55	0.65	0.65	0.9	1.4
Coefficient de forme μ_1(Toiture à un seul	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Coefficient d'exposition C_e	1	1	1	1	1	1	1	1
Coefficient thermique C_t	1	1	1	1	1	1	1	1
Charge de neige (kN/m²)	0.36	0.36	0.44	0.44	0.52	0.52	0.72	1.12

Le cas le plus défavorable est de **1.12kN/m²** dans les zones E.



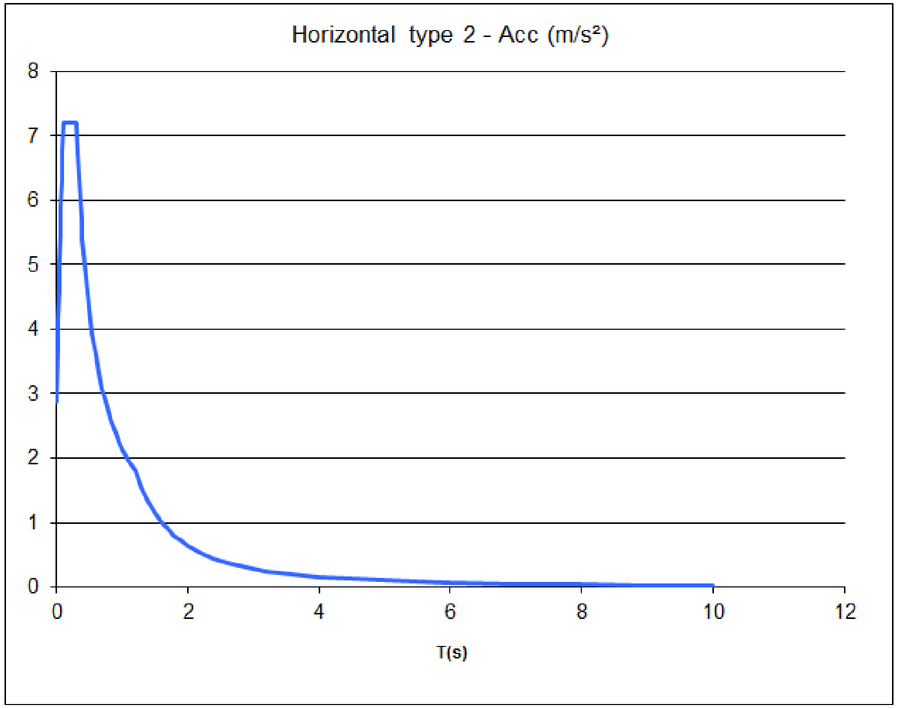
Actions sismiques

Zone de sismicité : ZONE 4

Type de sol: D

Catégorie d'importance: II

Rapport Sd(T1)/g **0.73** = 7.2m/s² / 9.8m/s²

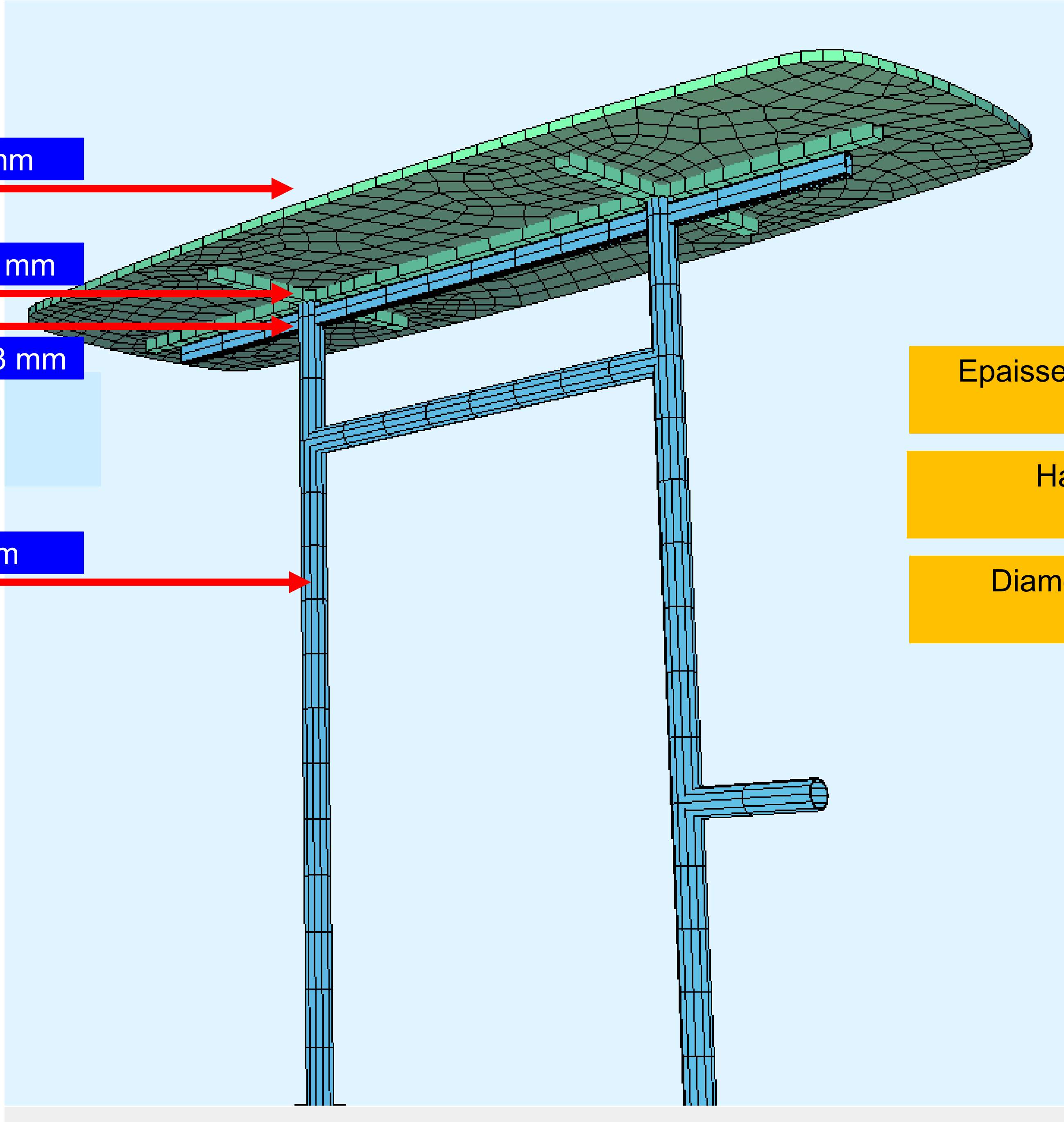


Epaisseur courante : 35 mm

Nervure BFUP : 60x90X5 mm

Nervure ACIER : 80x40X3 mm

Tube creux : D101,6x5 mm

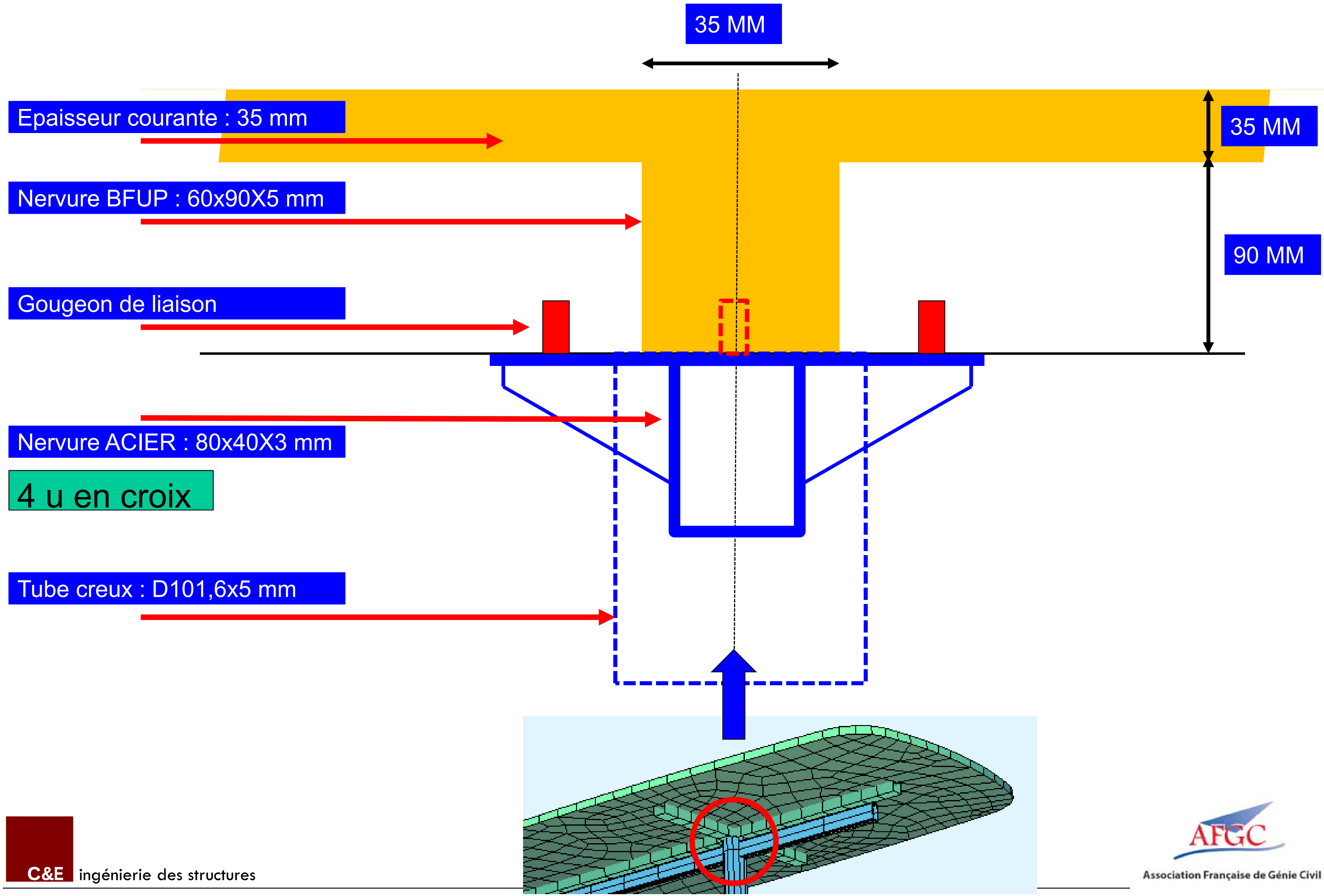


Epaisseur plaque de toiture en BFUP : 35 mm

Hauteur du raidisseur en BFUP : 60x90 mm

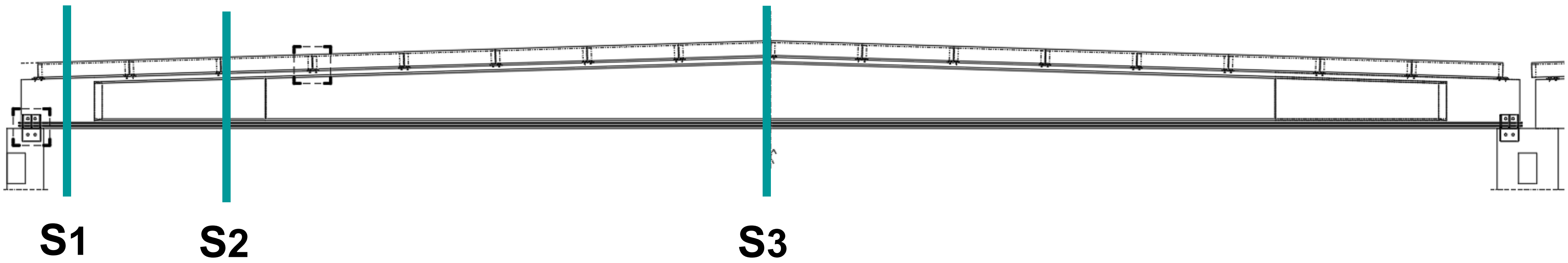
Diamètre des tubes en acier INOX : 101,6mm x 5

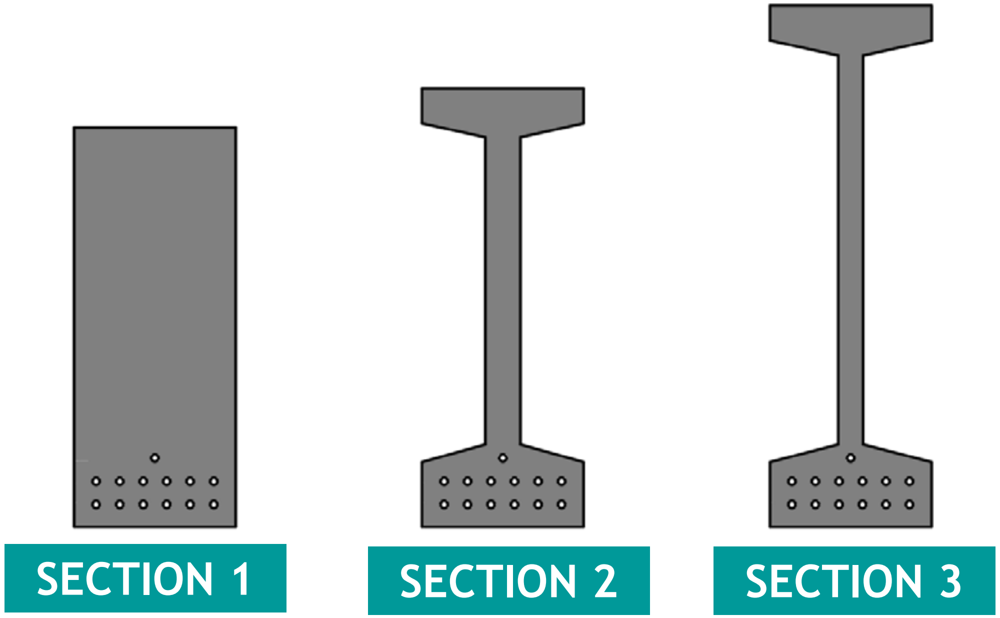
ENCASTREMENT SUR LES NERVURES



Localization : China
Building typology : Pre stressed beam
Quantity : 25 m long
Function : Structure supporting a Roof
UHPFRC : Ductal® FM STT

Design hypothesis _ Geometry



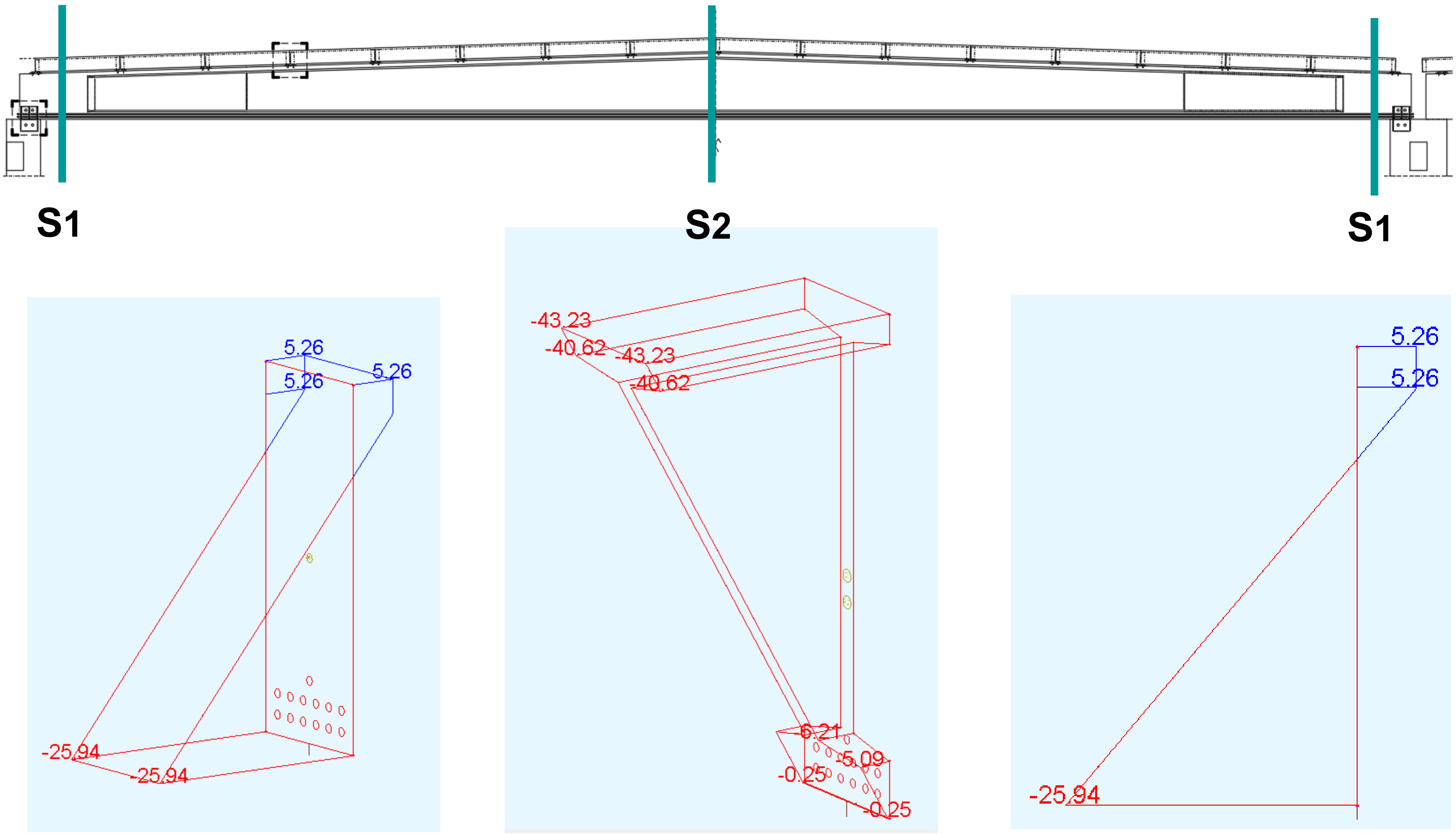


PARTICULARITIES OF BEAM

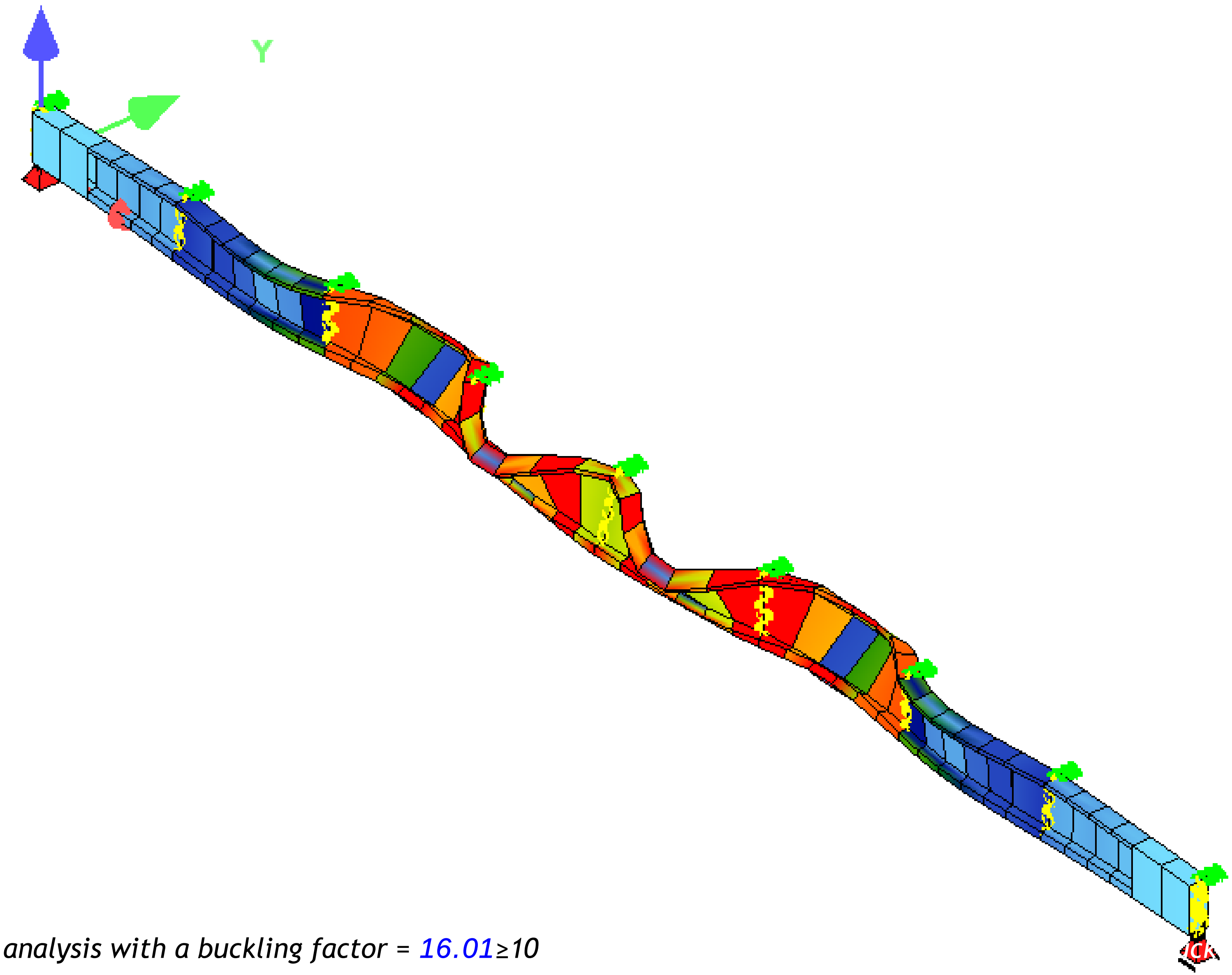
Span	24.54m
Maximum height	1.1731m
Minimum height	0.805m
Slope	3%
Width of the upper and lower flange	0.324m
Thickness of the upper flange	0.07m
Thickness of the lower flange	0.13m
Thickness of the web	0.05m
Height of the variable part of flange	0.03m
Pre-tensionned tendon (Diameter)	15.2mm
Number of pre-tensionned tendon	13 units

Statically determinate beam
support conditions :
axial blocking at one end of the beam
axial slippery at the other end

Structural analysis_ SLS_Stress limitation

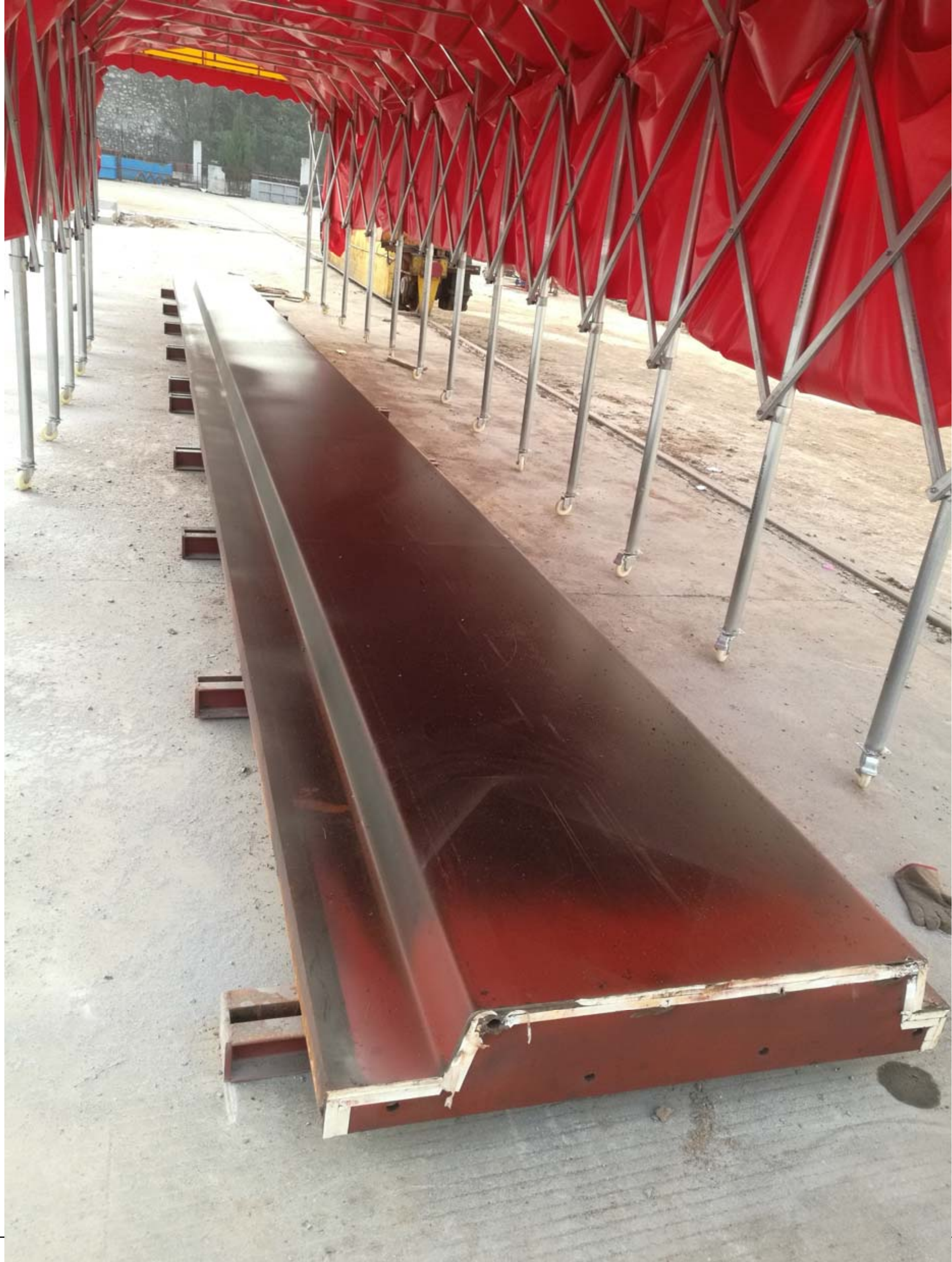


Characteristic combination : Stress distribution at mi-span and at the end



First mode of buckling analysis with a buckling factor = 16.01≥10

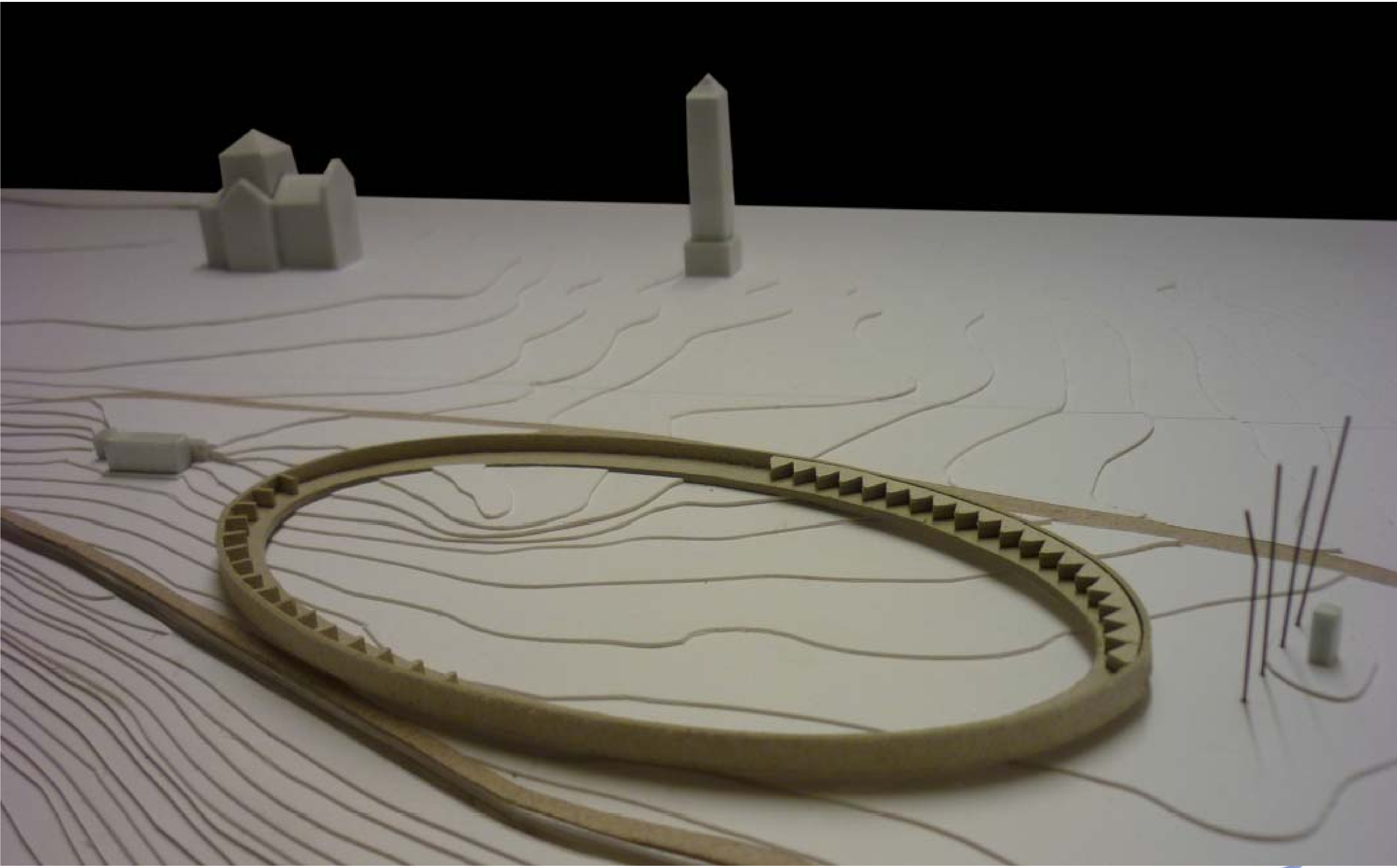
19.96

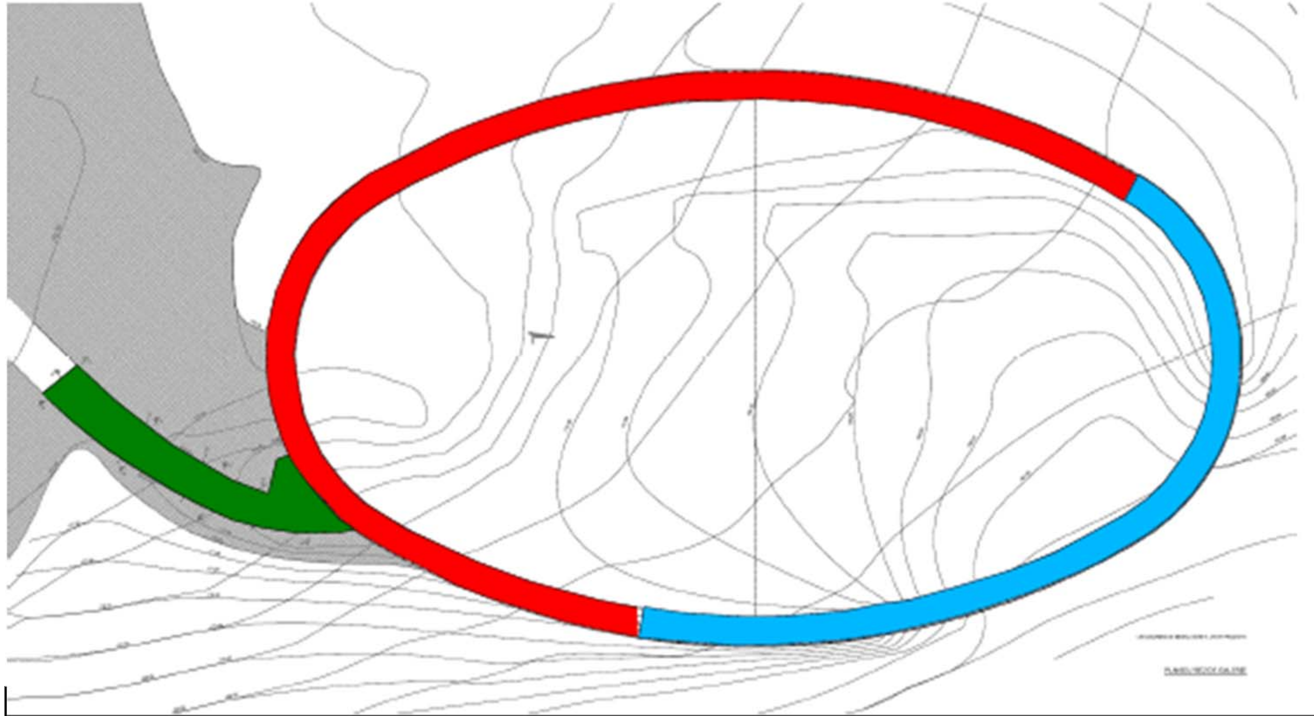


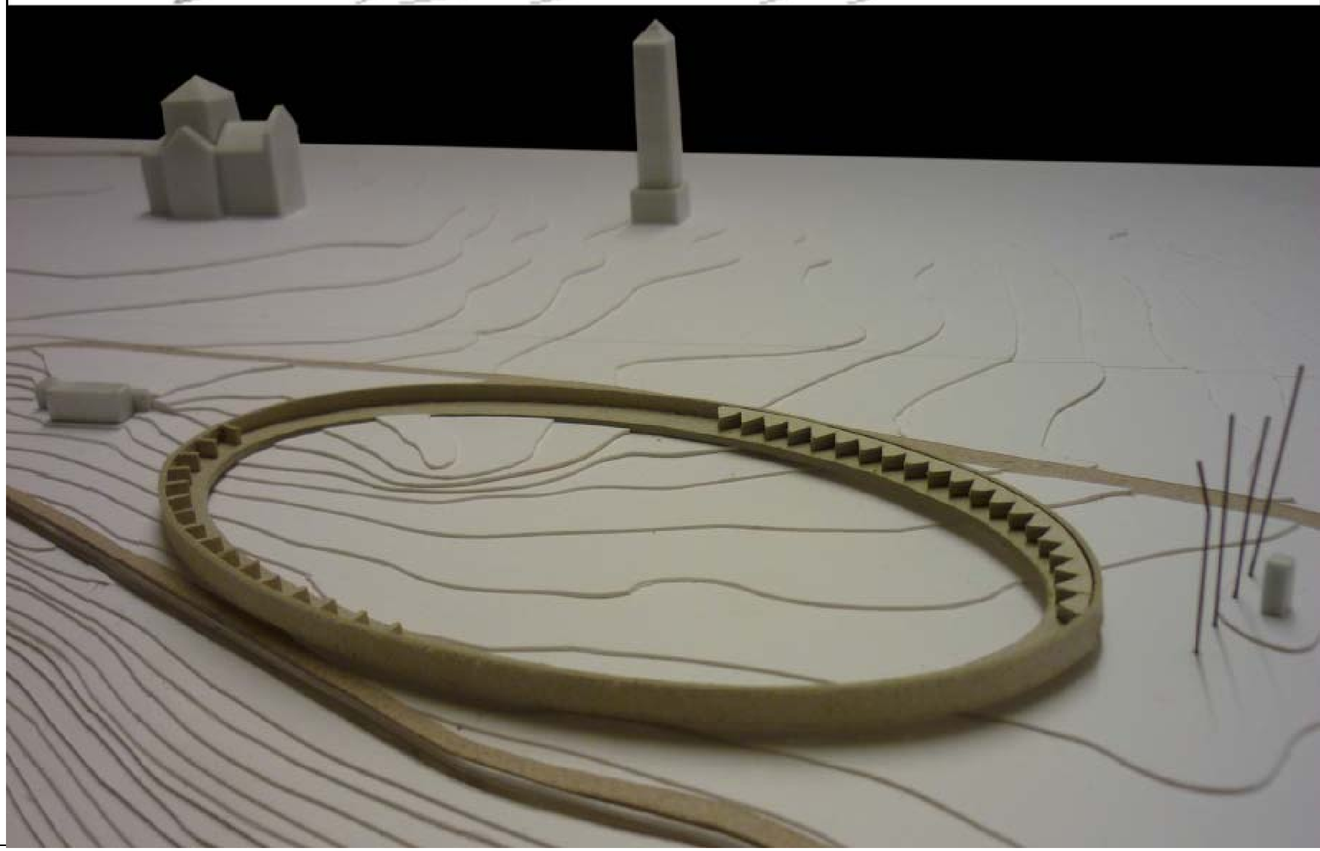
Testing until the beam is broken

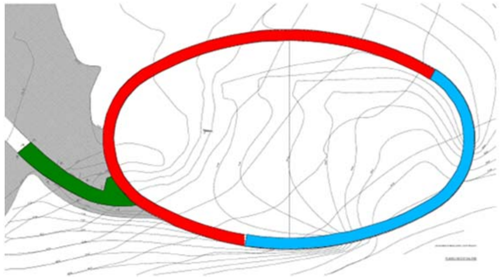
Arras First world war memorial, France / AAPP Architect

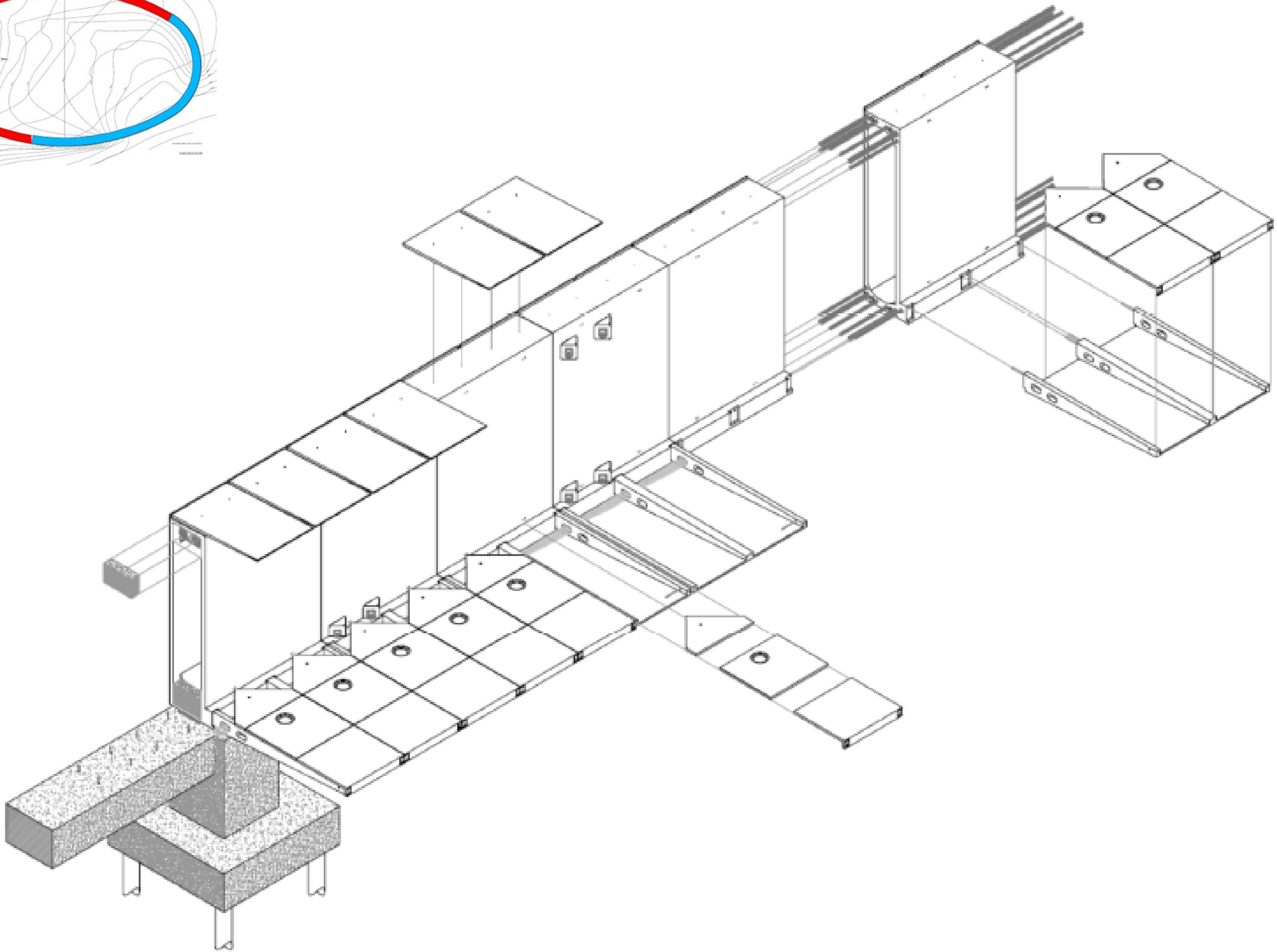
Localization : Arras France, Eiffage Prefabricator
Building typology : Memorial
Quantity : 320 ml
Function : Structure supporting a footbridge
UHPFRC : BSI

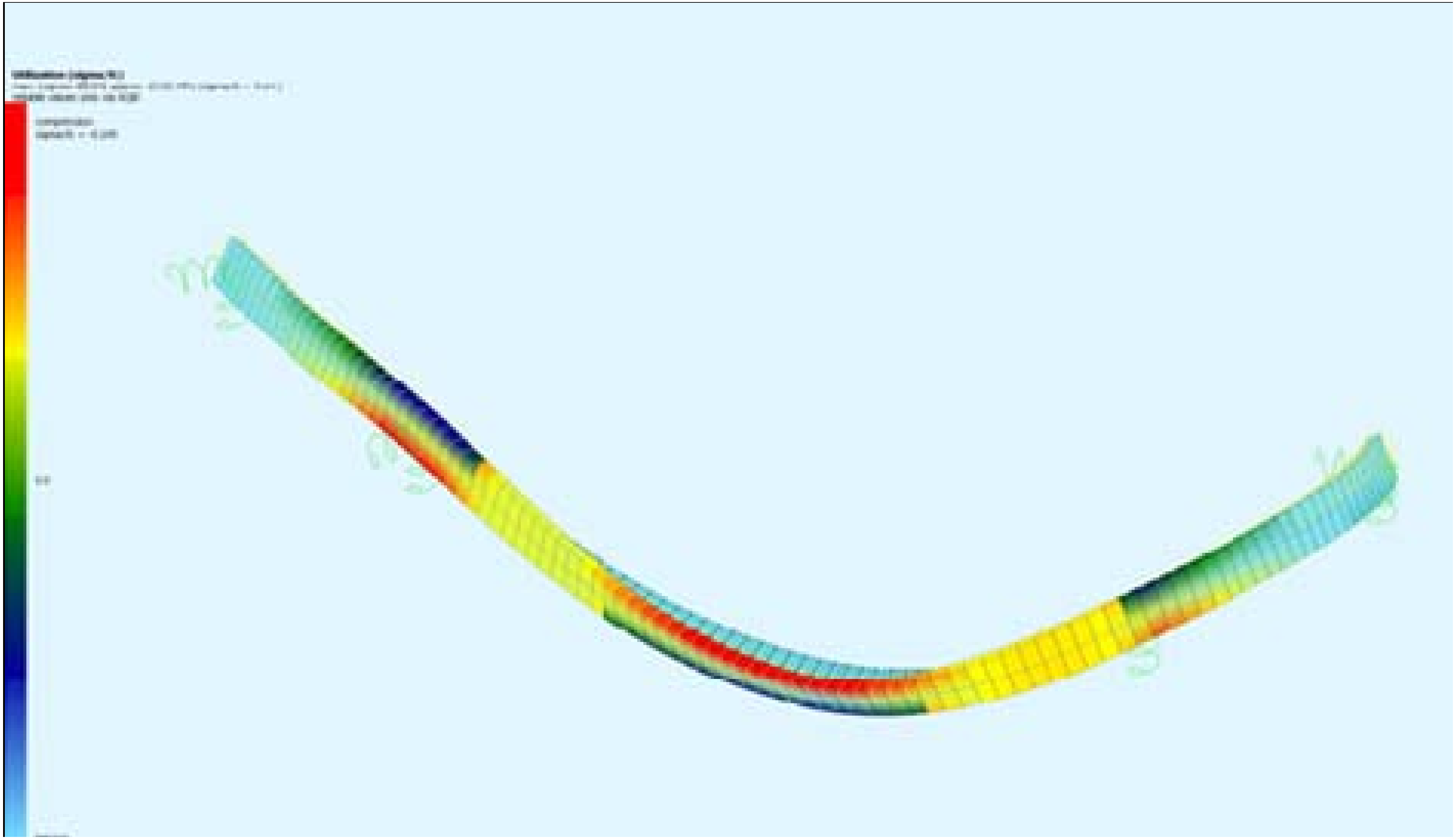


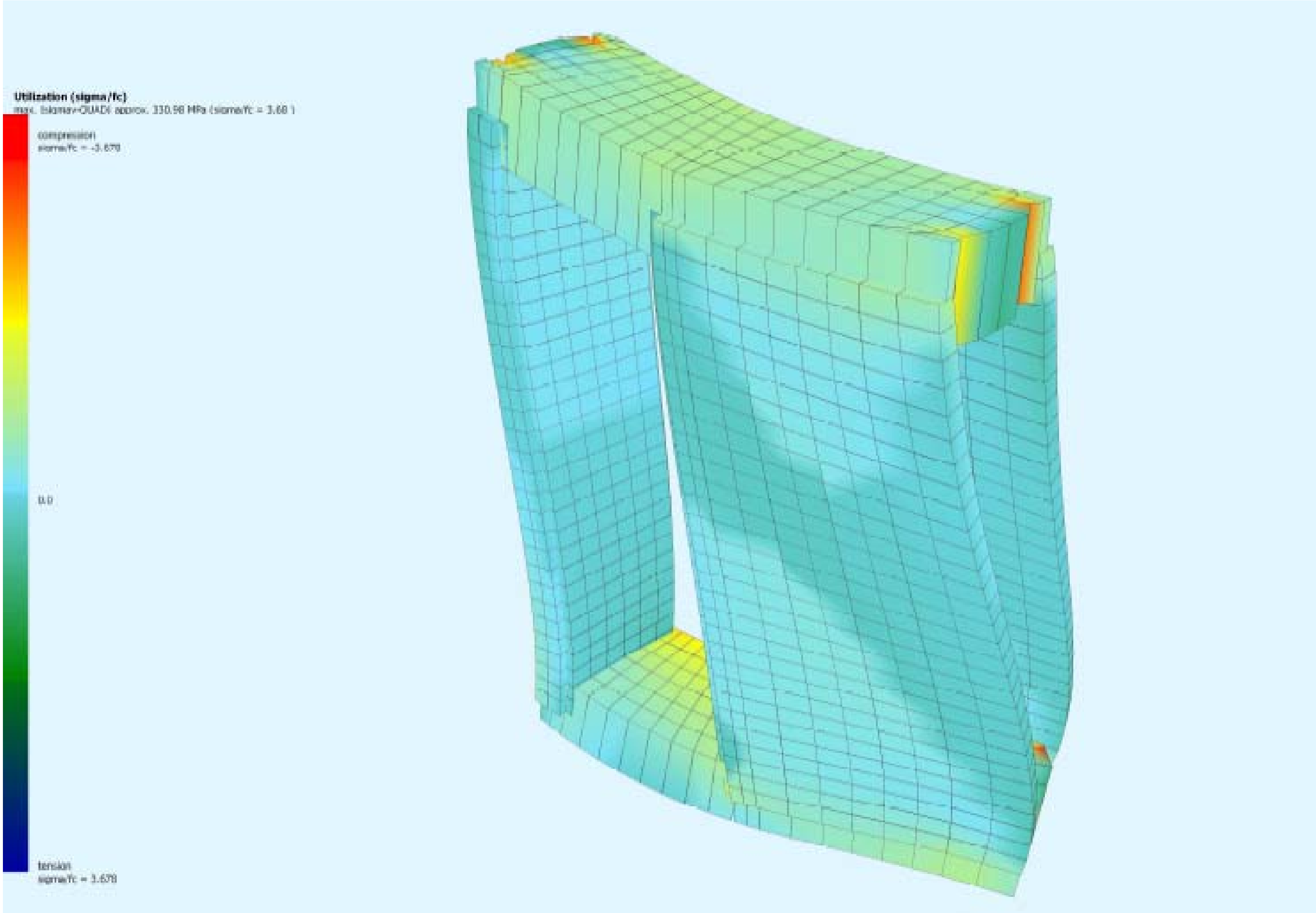












Calculation done with the software SOFISTIK AG

1- Matériau, quelques repères

2- Conception, quelques règles

3- Etude de cas

4- Synthese

1- Choix du matériau
2- Stratégie géométrique
3- Schéma schématique / Position et nature des appuis
4- Risques de conception / Courbes de comportement / fissure
5- Stratégie de processus de construction / retrait
6- Calcul préliminaire / scénario
7- Synthèse

1- Matériau

Fibres organiques ou métalliques

Pour le béton de fibres métalliques choix de la loi de comportement en traction en fonction du volume de fibres

La courbe de comportement du matériau est différente selon l'analyse menée (contrainte ou déformation) et dépend du choix du matériau (FO ou FM) et de l'épaisseur de l'élément

2 - Épaisseur de l'élément

Une attention particulière doit être accordée à la classification de l'élément par rapport à son épaisseur. Un élément est considéré comme mince si son épaisseur est inférieure à 3 fois la longueur des fibres. Certaines propriétés telles que la résistance en traction ou l'analyse de la fissuration vont changer.

3- Intégration du ferraillage

BUHP FO: possible mais pas conventionnel

BUHP FM: possible

Ductal FM + FO: la combinaison des renforts et des fibres dans le calcul ne se fait que dans l'analyse post-élastique. Dans le cas d'éléments minces, l'élongation des fibres ne peut pas dépasser 50% de la valeur maximale donnée.

4- Analyse du cisaillement

BUHP FO: l'analyse ne tient compte que de la capacité de résistance des fibres

BUHP FM: l'analyse considère les fibres, la section et le ferraillage

BUHP FM + FO: les mêmes fibres d'une section ne peuvent pas être utilisées simultanément pour l'analyse de la contrainte de flexion et l'analyse de la contrainte de cisaillement.

5- Ancrages et support

Les ancrages peuvent affecter l'épaisseur globale de l'élément.

6- Analyse de la fissuration

L'analyse de la fissuration est la base du calcul post-élastique. Pour chaque projet la valeur maximum donnée par le référentiel de calcul doit être discutée selon le contexte du projet, le site, le client, la conception d'ensemble.