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100 years
of reliable
solutions for
long-term success



Conception pluridisciplinaire de la tour Mohammed VI

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Hans Verbraken
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09 mars 2020



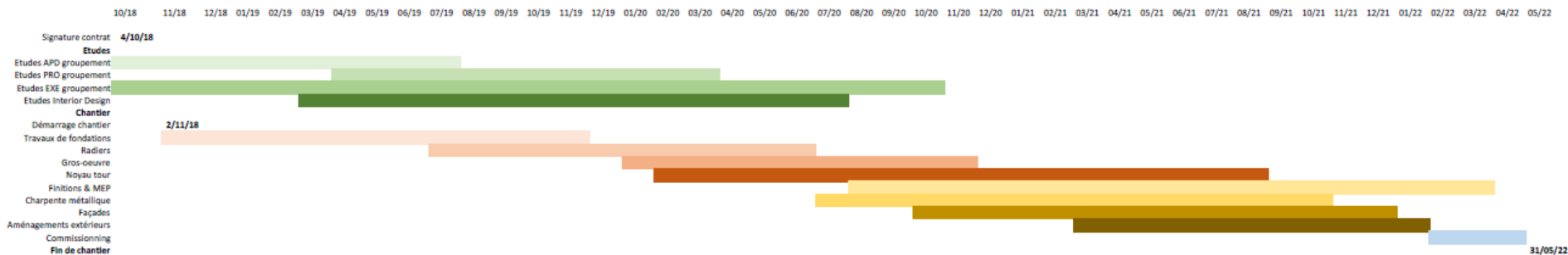
Programme

- Description architecturale
 - Organisation générale du design
 - Concept architectural
 - Particularités IGH
- Description du système de fondations
 - Conception des fondations profondes
 - Conditions de sol
 - Interaction sol-structure
- Description du système structurel
 - Conception de la structure
 - Comportement dynamique
 - Challenge client

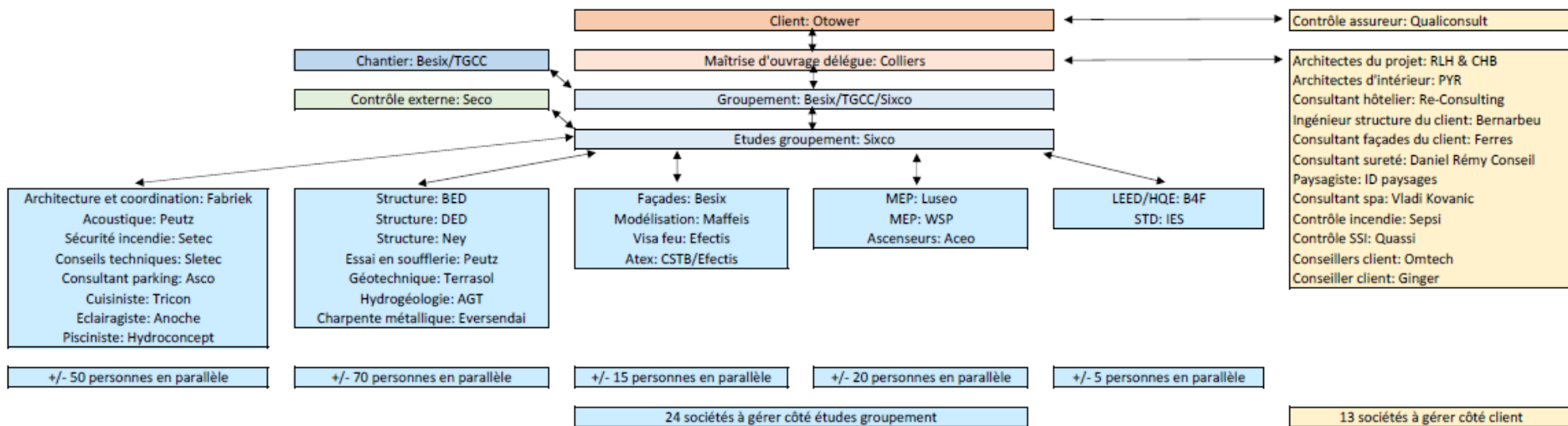
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Historique & planning projet

- Client: Président de la banque BMCE
- 4 octobre 2018: Signature
- Novembre 2018: Premier pieu de fondation
- 31 mai 2022: fin de chantier
- 36 mois de chantier



Organisation générale du design



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Localisation – Vallée du Bouregreg



Localisation – Vallée du Bouregreg



Rendu 3D



Description Projet

Etages techniques

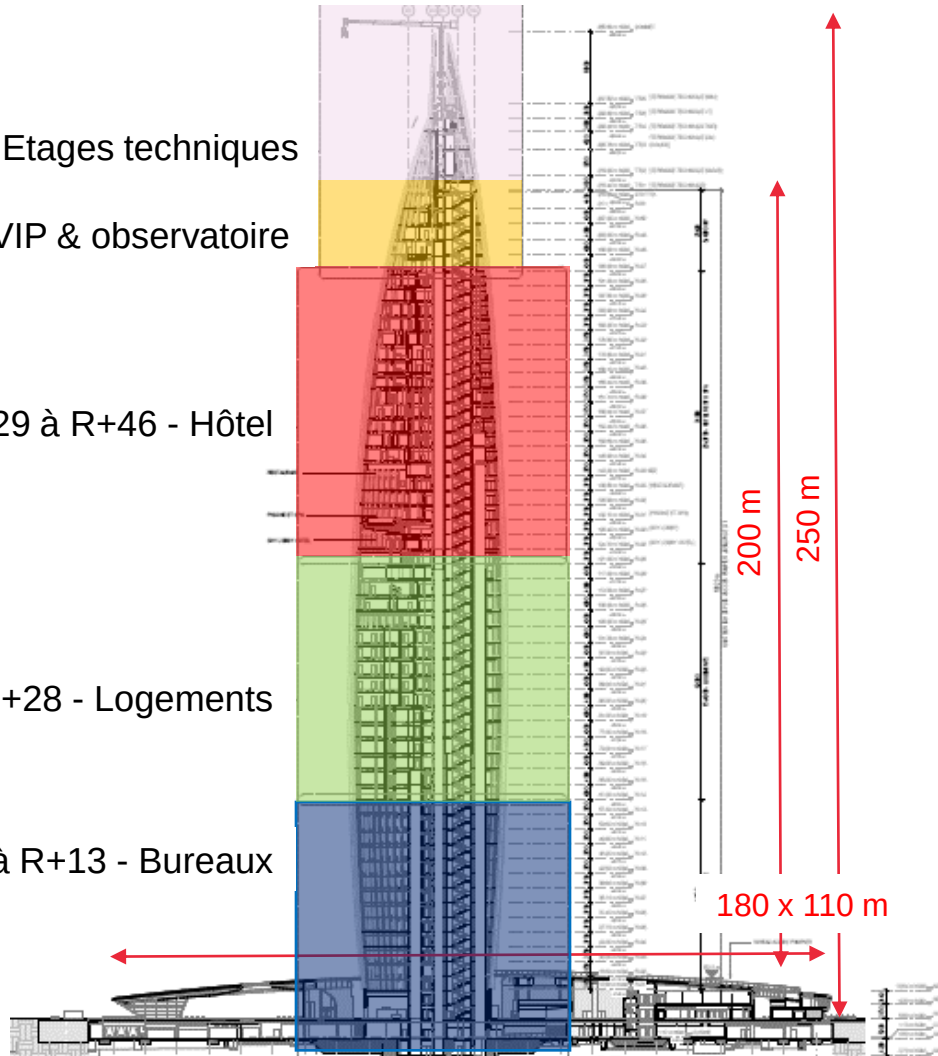
R+47 à R+51 – VIP & observatoire

- Classé “IGH” selon norme incendie
- LEED gold & HQE ‘très bon’
- Tour multi fonctionnelle
 - VIP/Observatoire
 - Hôtel
 - Logements
 - Bureaux

R+29 à R+46 - Hôtel

R+14 à R+28 - Logements

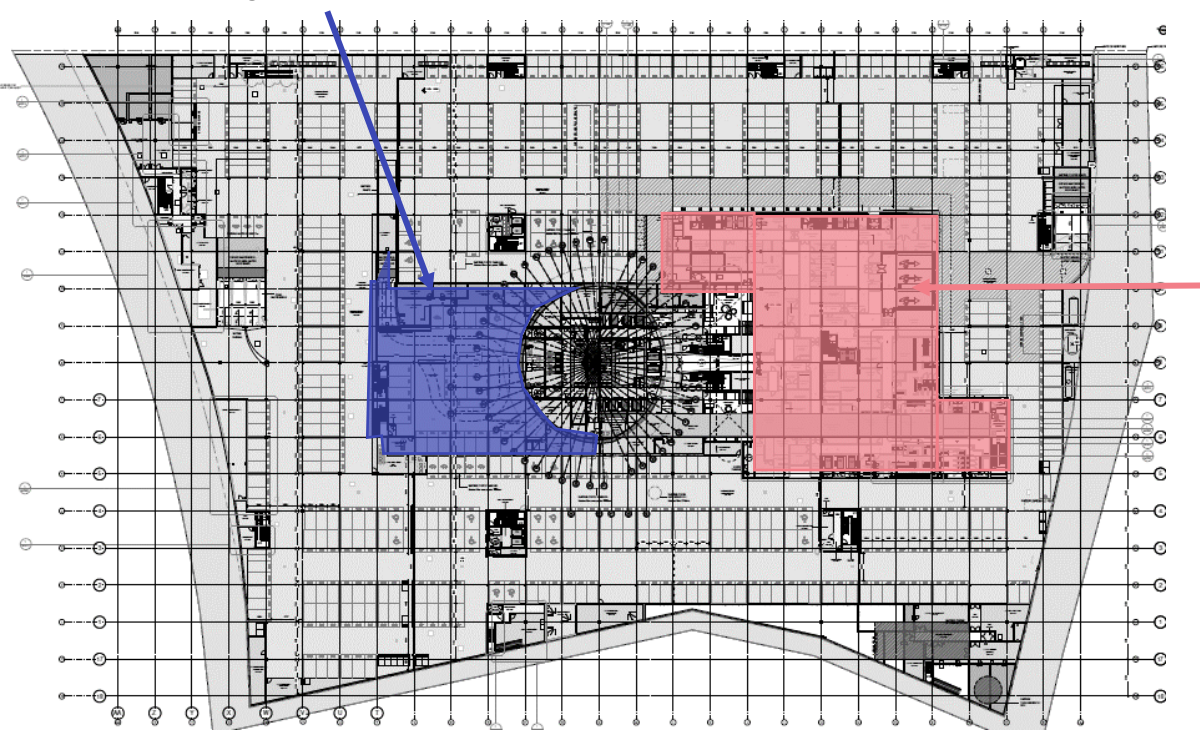
R+1 à R+13 - Bureaux



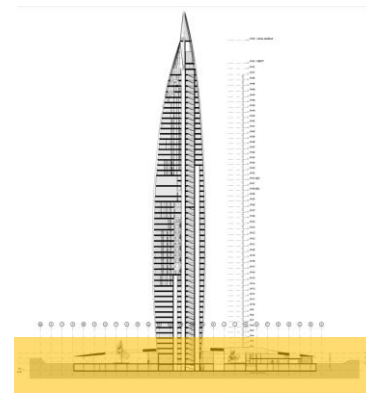
SS1



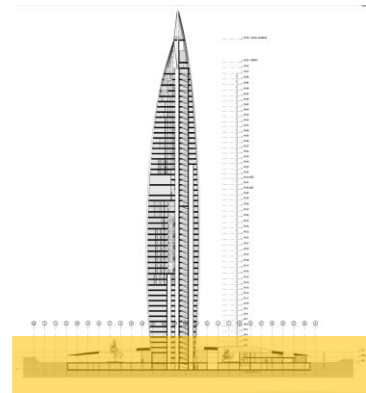
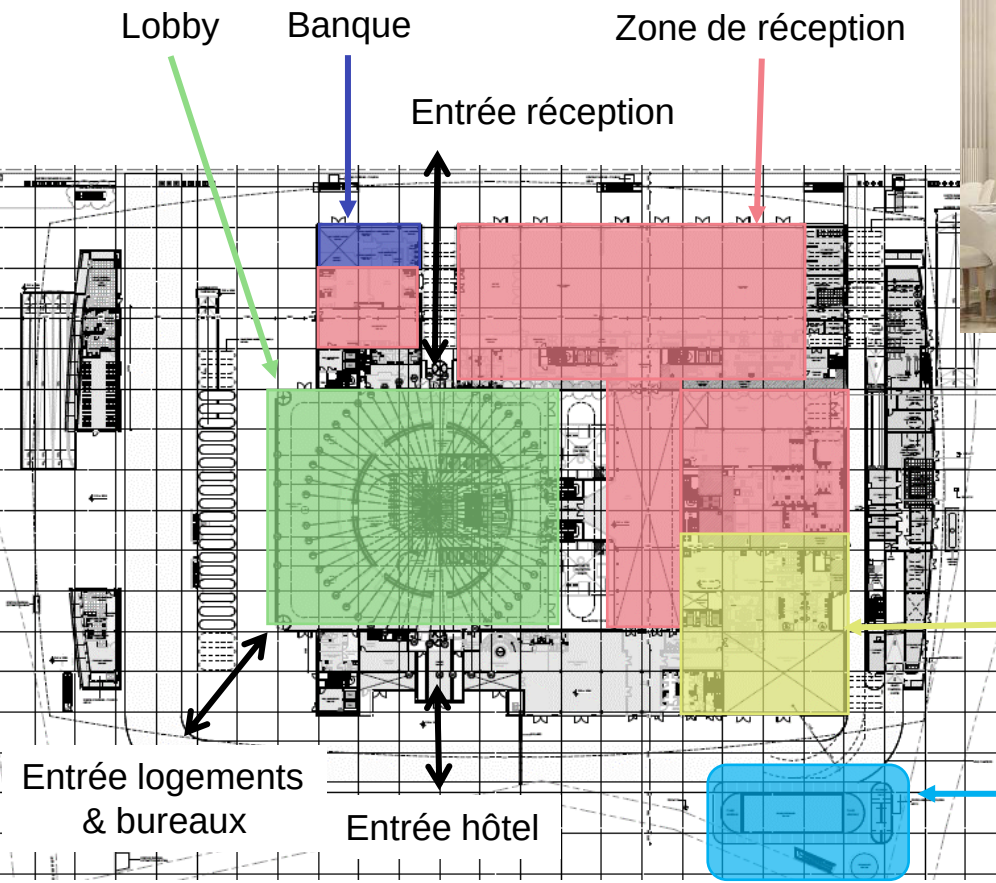
Parking VIP



Livraison et cuisine



RDC

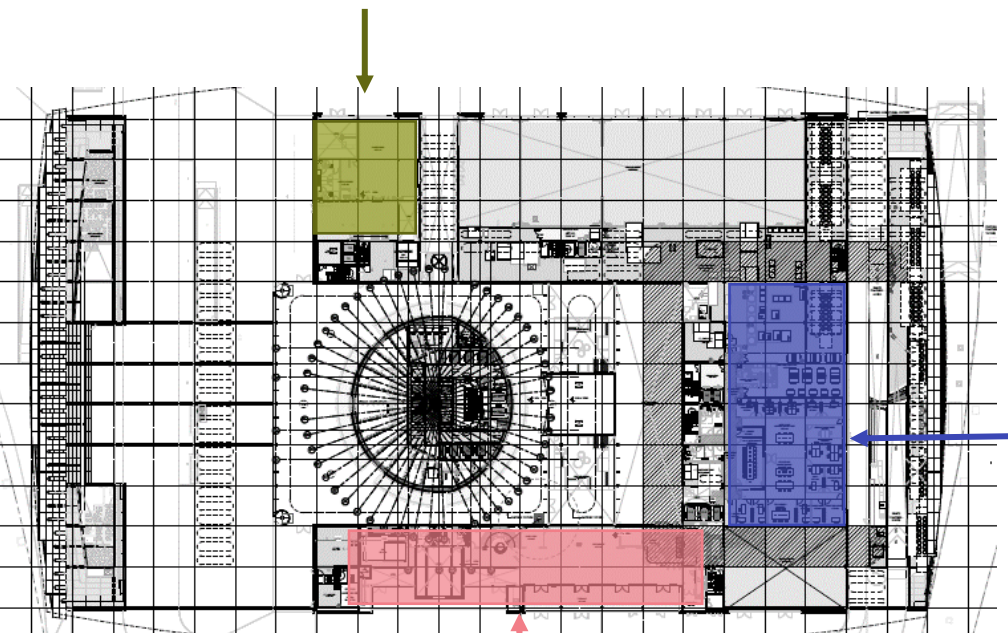


Restaurant familial

Piscines extérieures

R+1

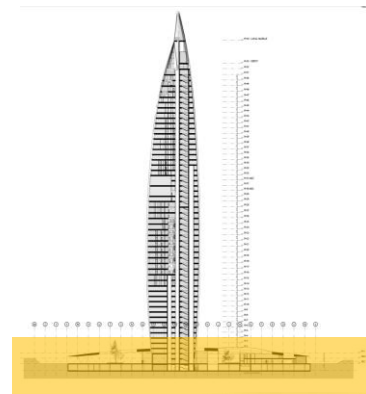
Salles de réunion



Restaurant et bar



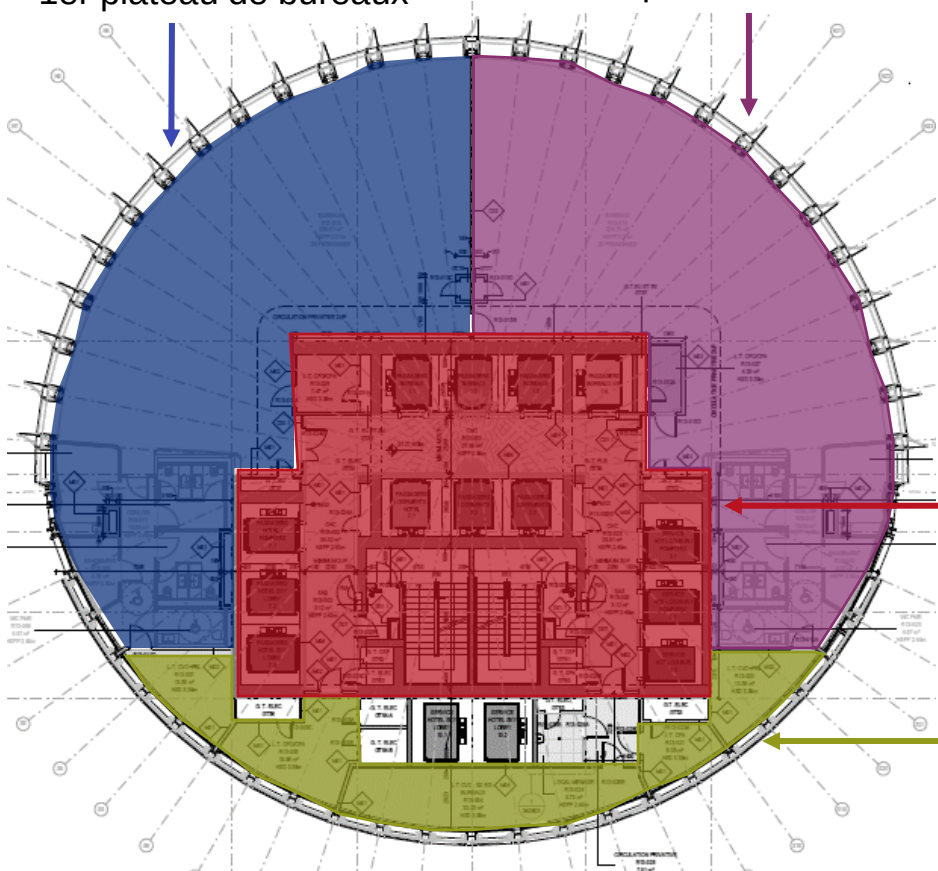
Administration hôtel



Bureaux de la tour

1er plateau de bureaux

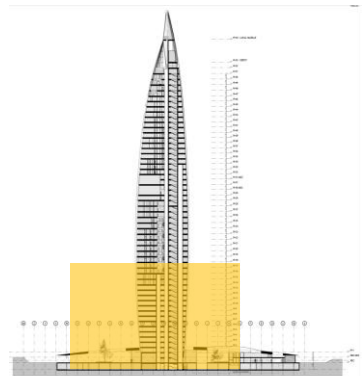
2ème plateau de bureaux



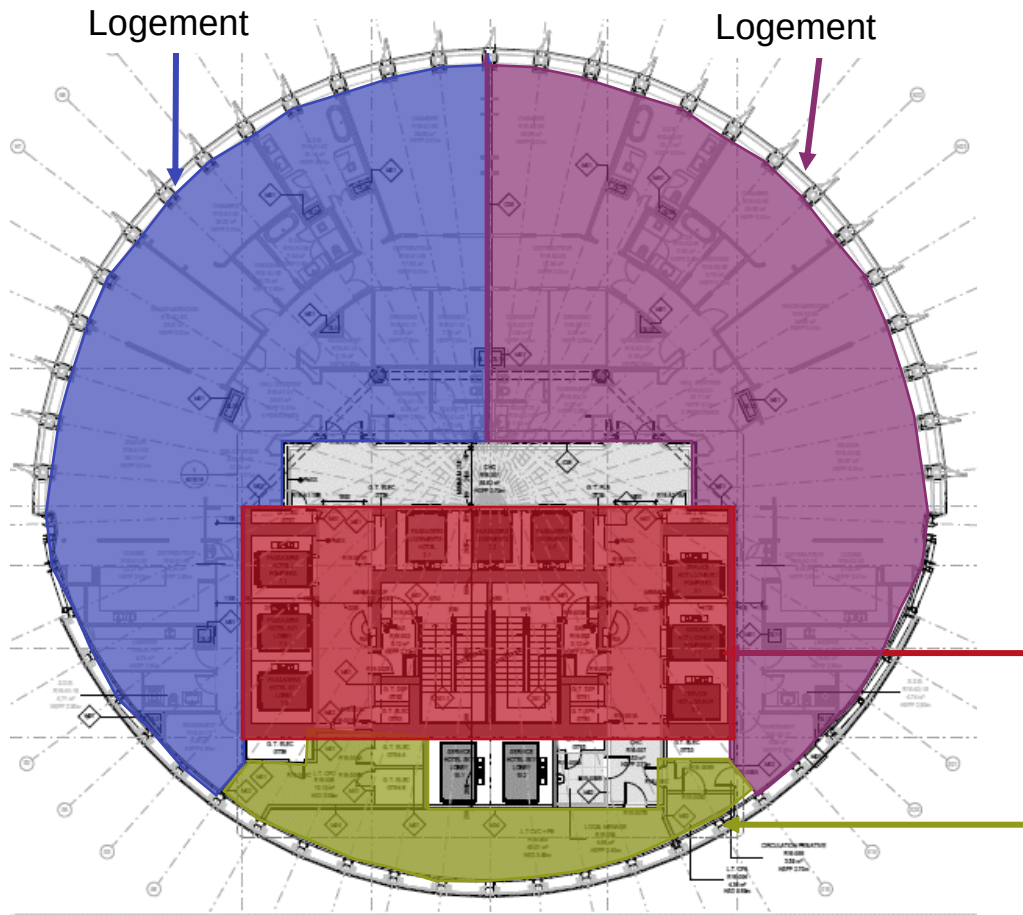
- Pas d'étage de locaux techniques

Noyau décentré

LT au sud



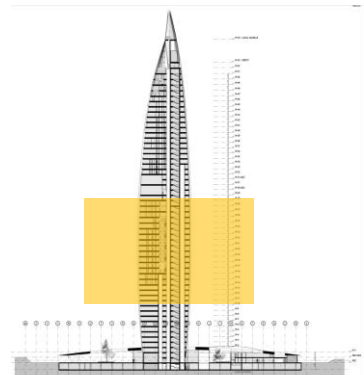
Appartements



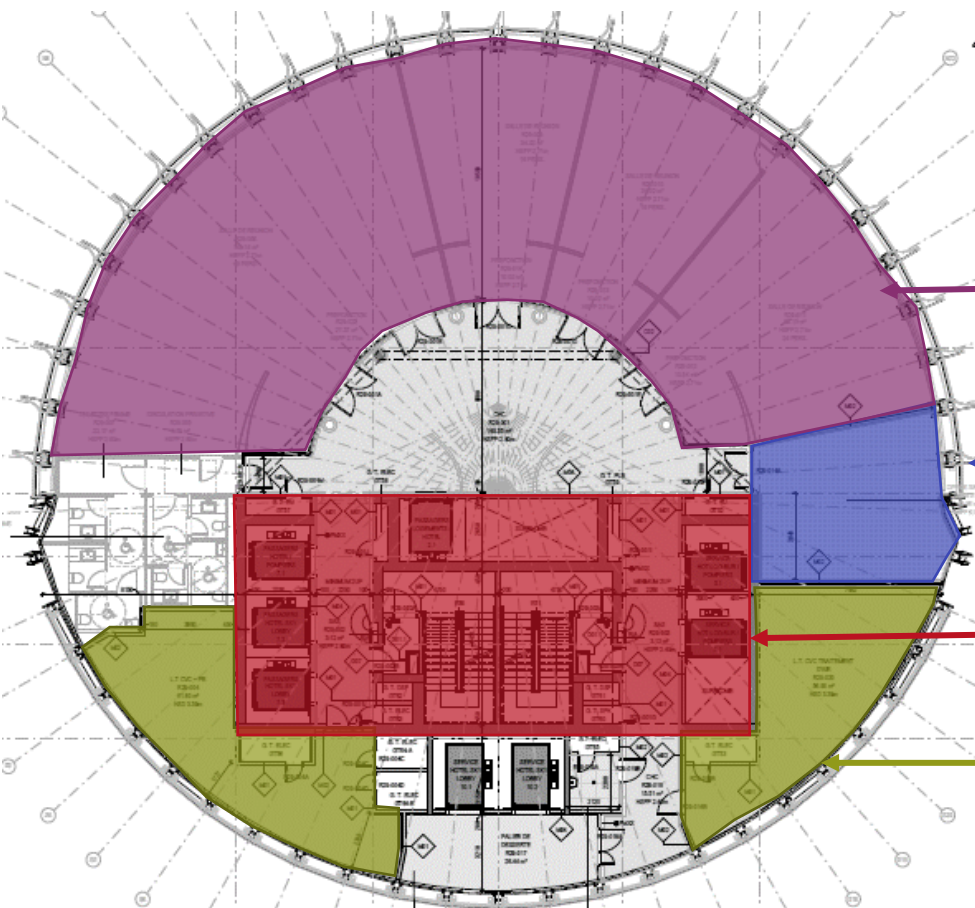
- Total de 30 logements
- Surface moyenne: +/- 300m²
- 1 duplex de 1400m²

Noyau décentré

LT au sud



Hôtel – Salles de réunion

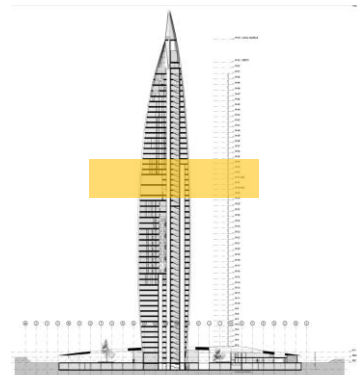
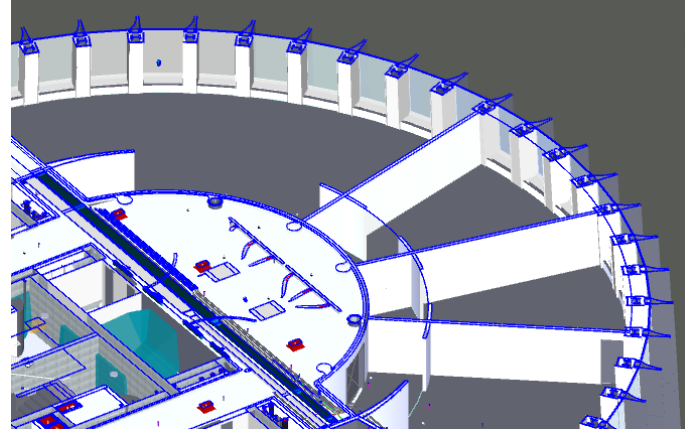


Salles de réunion

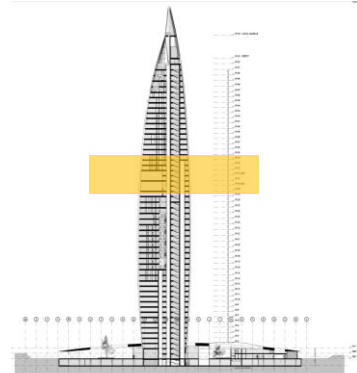
Cuisine d'envoi

Noyau décentré

LT au sud



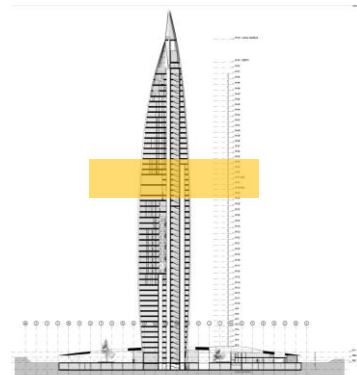
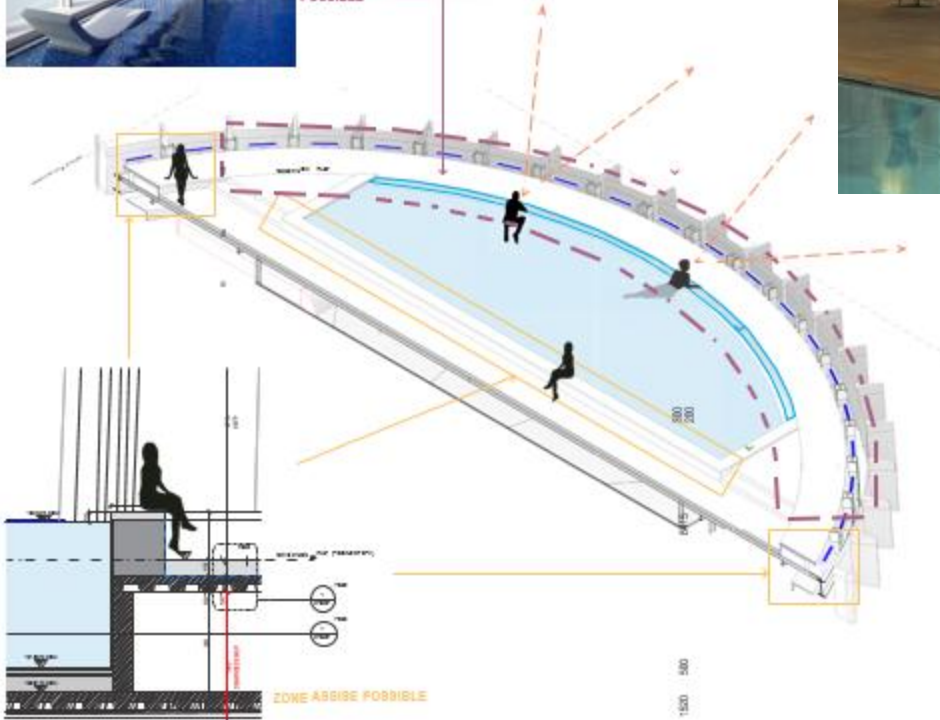
Hôtel – Sky lobby



Hôtel – Piscine



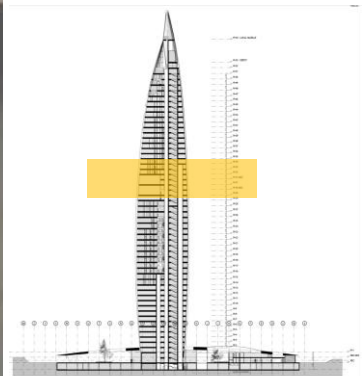
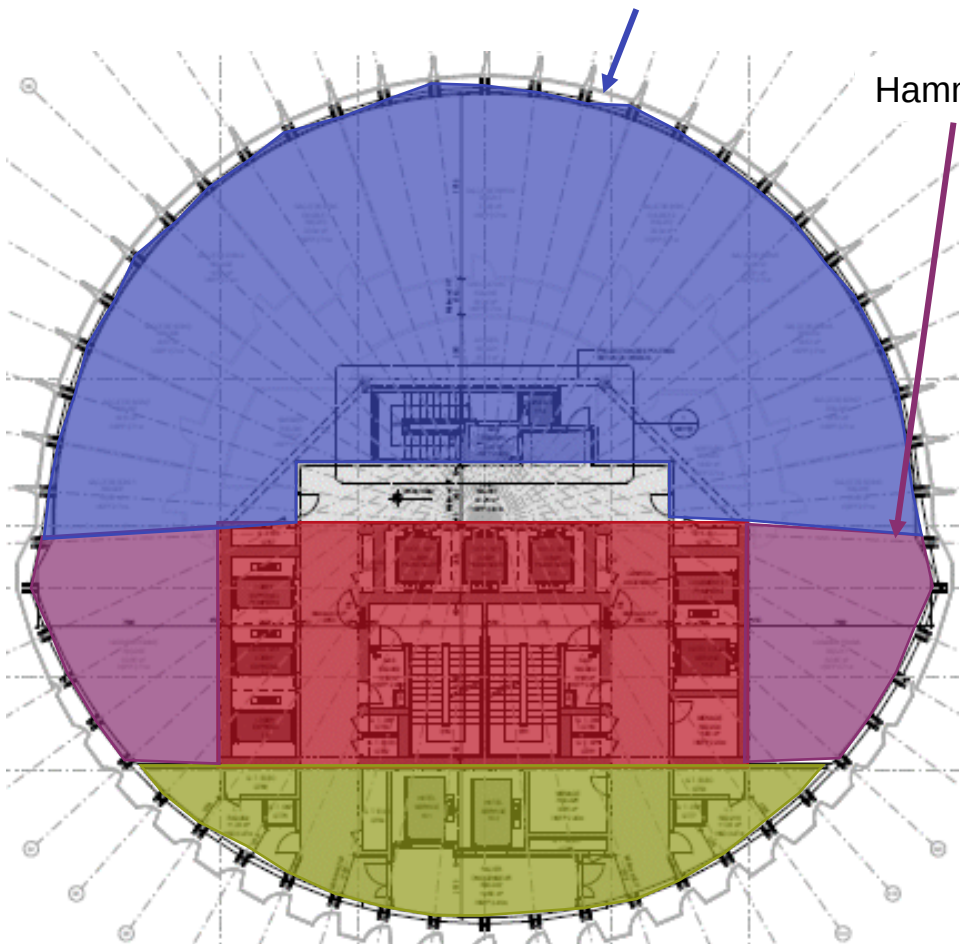
ZONE CHAISE LONGUE
POSSIBLE



Hôtel – Spa

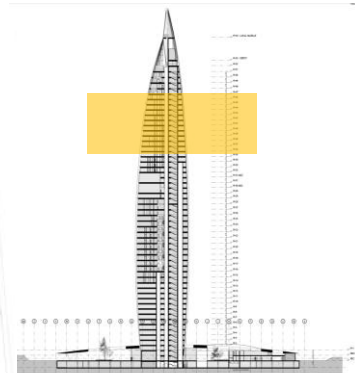
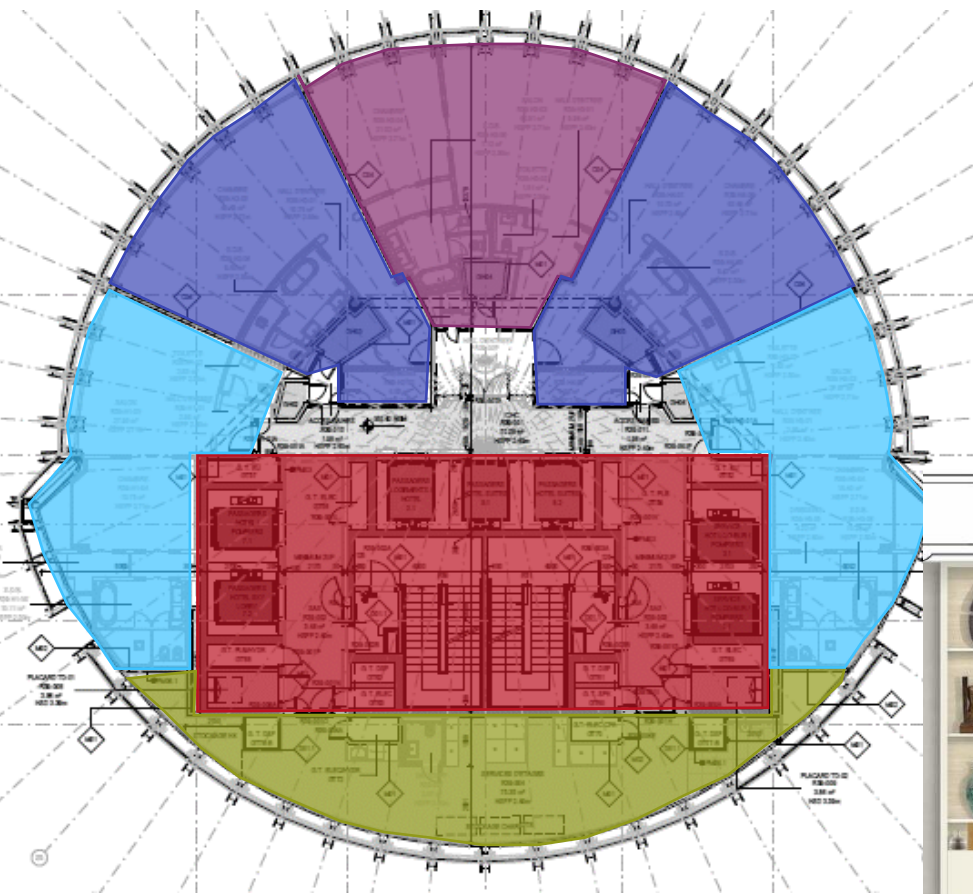
Salles de soin, massage

Hammam



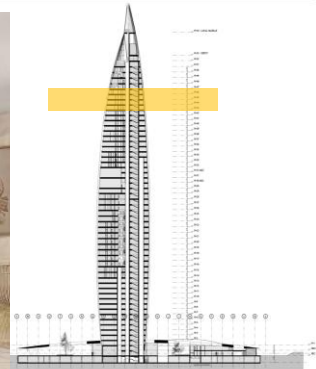
Hôtel

- Total de 55 chambres
- Surfaces allant de 40 à 230m²

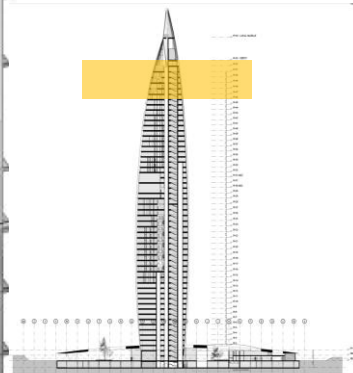
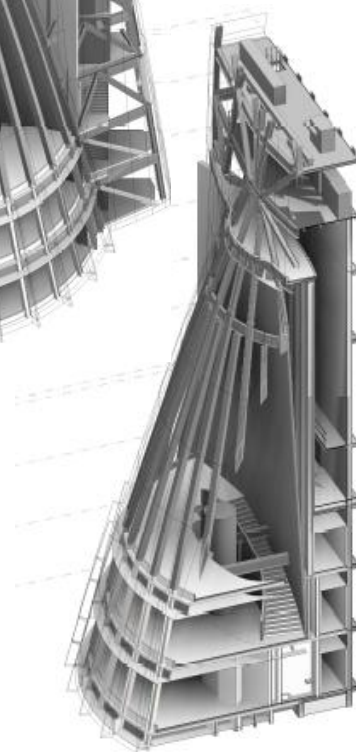
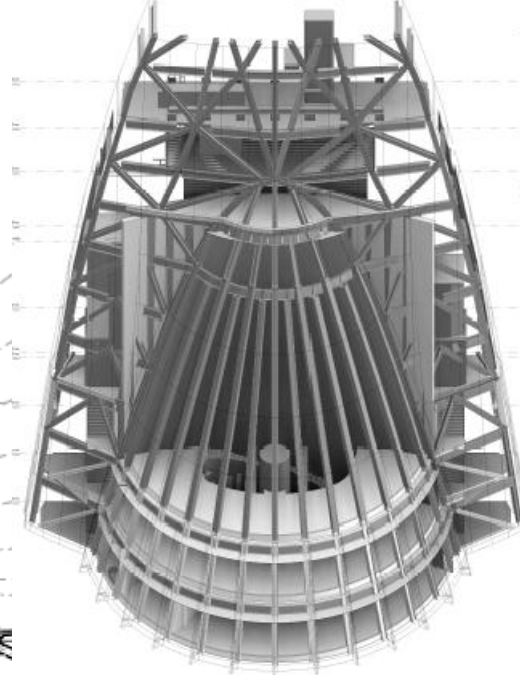
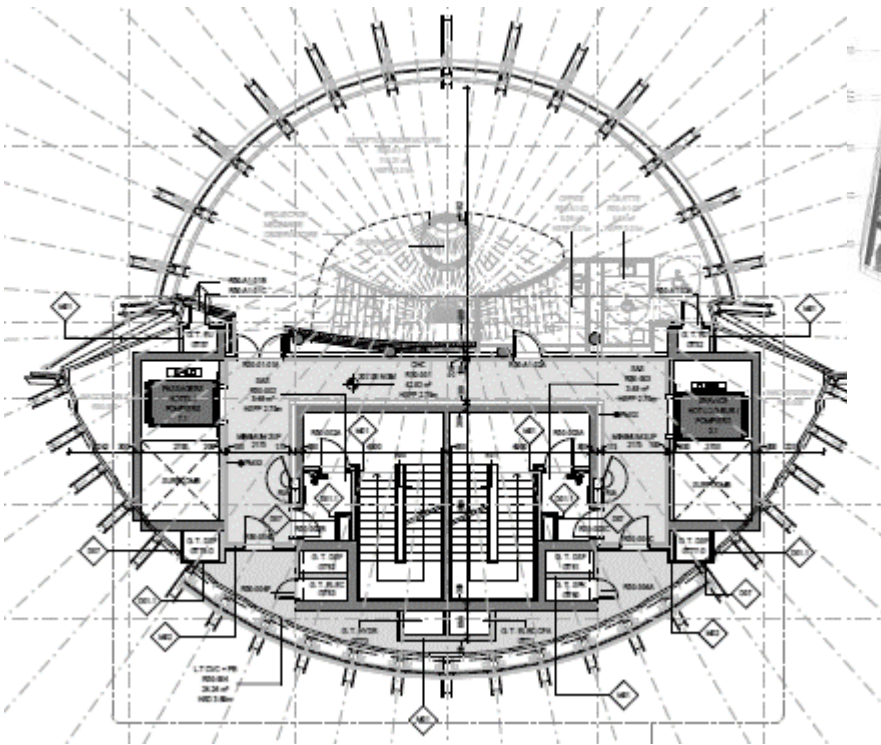


VIP

- 2 appartements VIP
- De 175 & 400m²



Observatoire



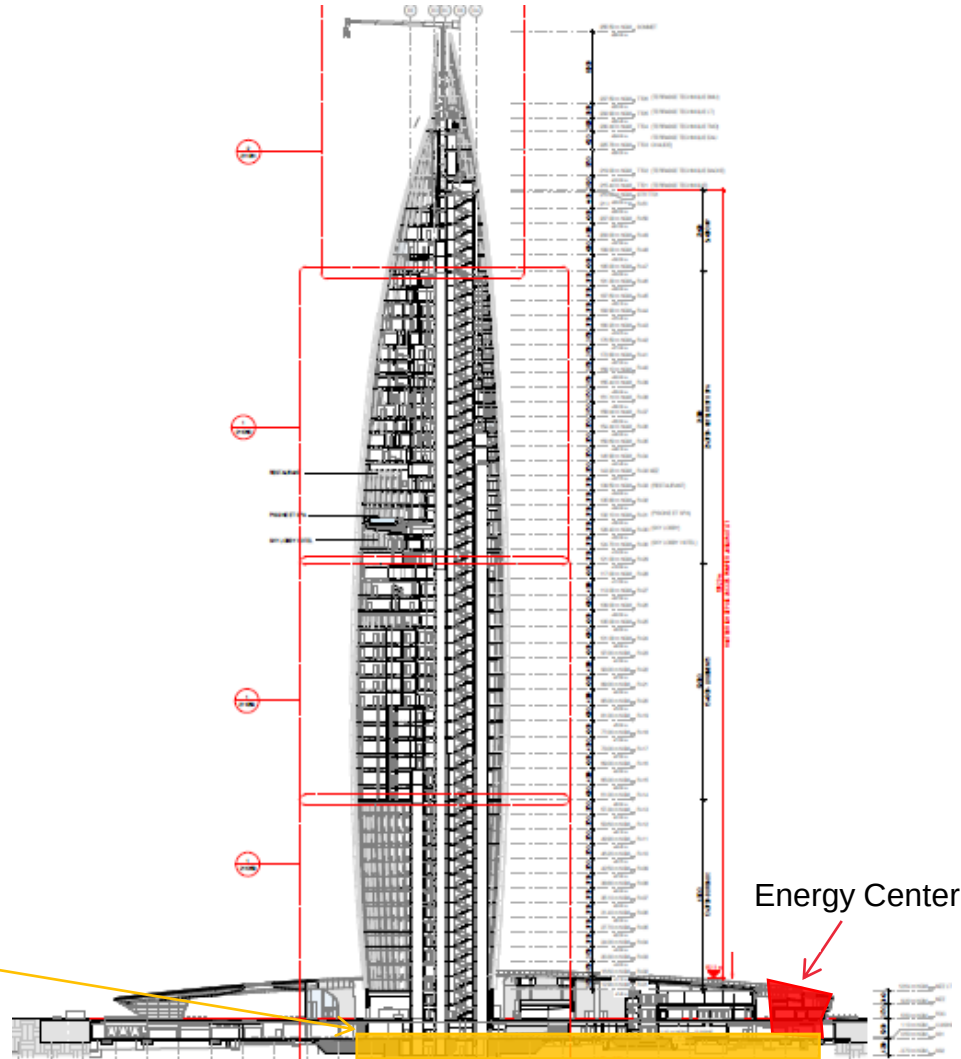
- Description architecturale
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Particularités IGH

- Energy center

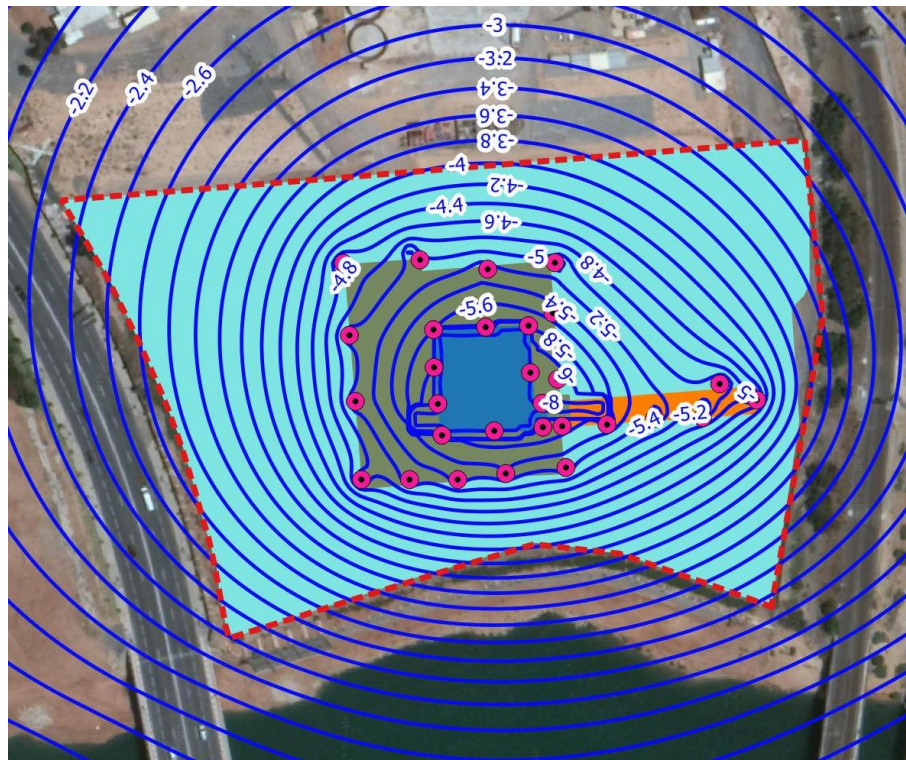
- Alimentation tour via Energy Center et passage via tunnel technique

Connexion Energy
Center et tour via tunnel
technique



Particularités IGH

Galerie technique

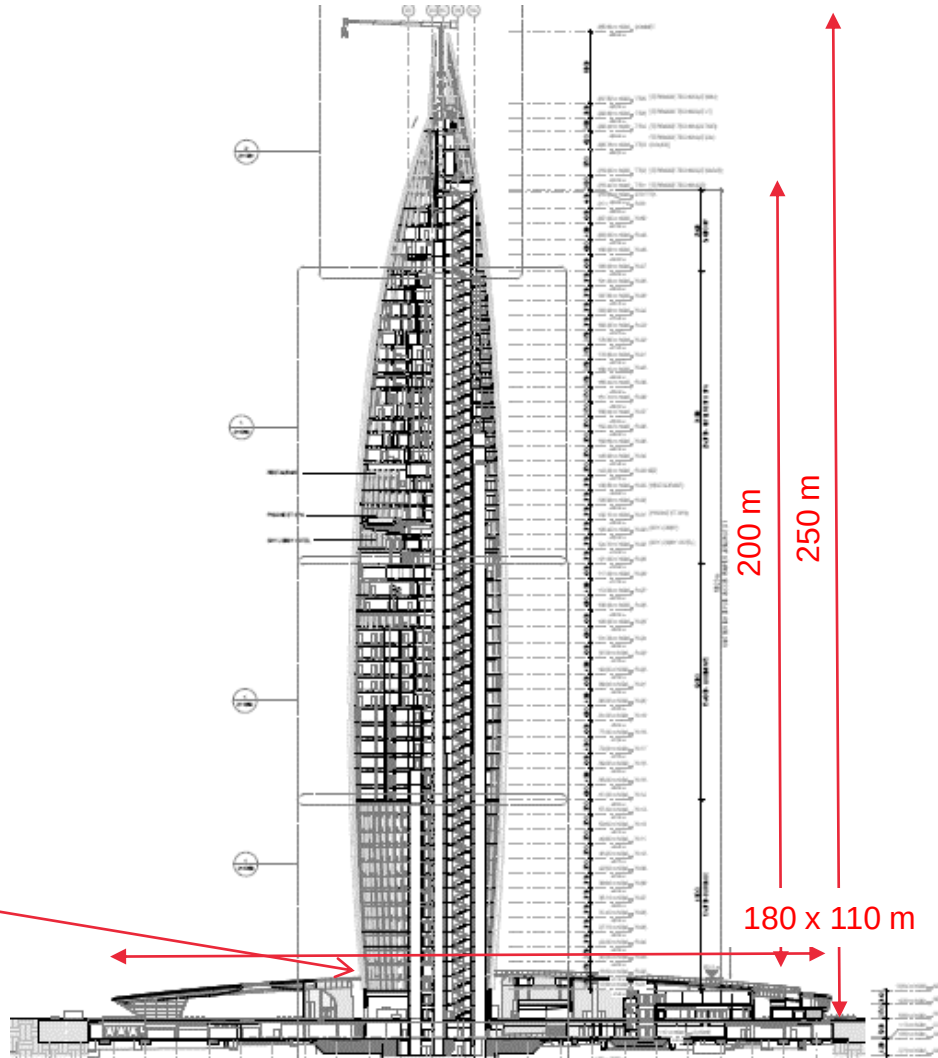


Particularités IGH

- Réduction hauteur tour

- Accès pompiers via toiture du socle pour réduction hauteur et classement Immeuble de Grande Hauteur

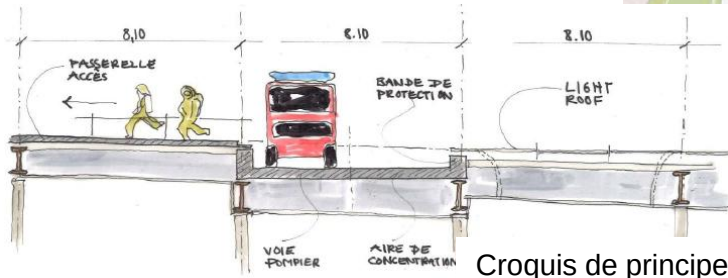
Accès pompiers via R+2



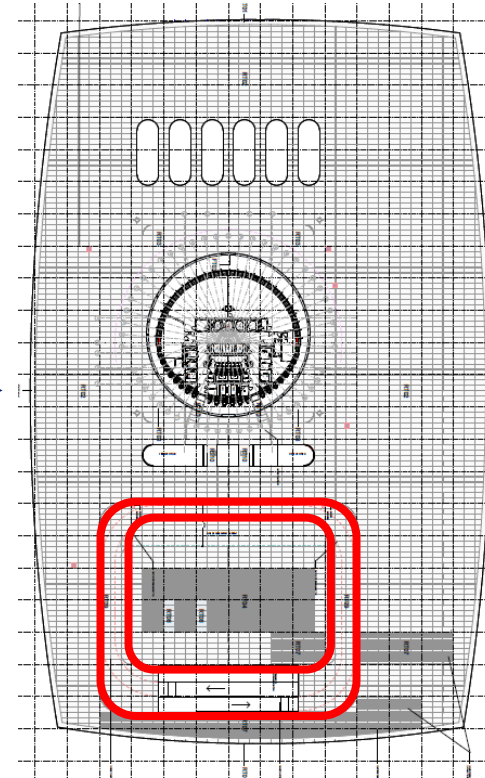
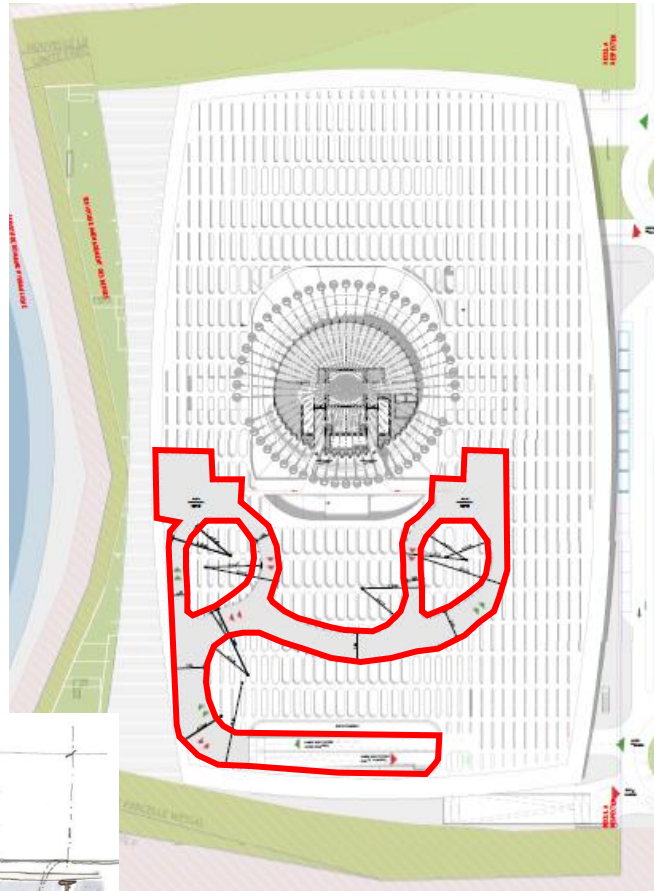
Particularités IGH

- Réduction hauteur tour

- Optimisation du parcours pompiers en toiture entre APS & APD → parcours clair sans manoeuvre



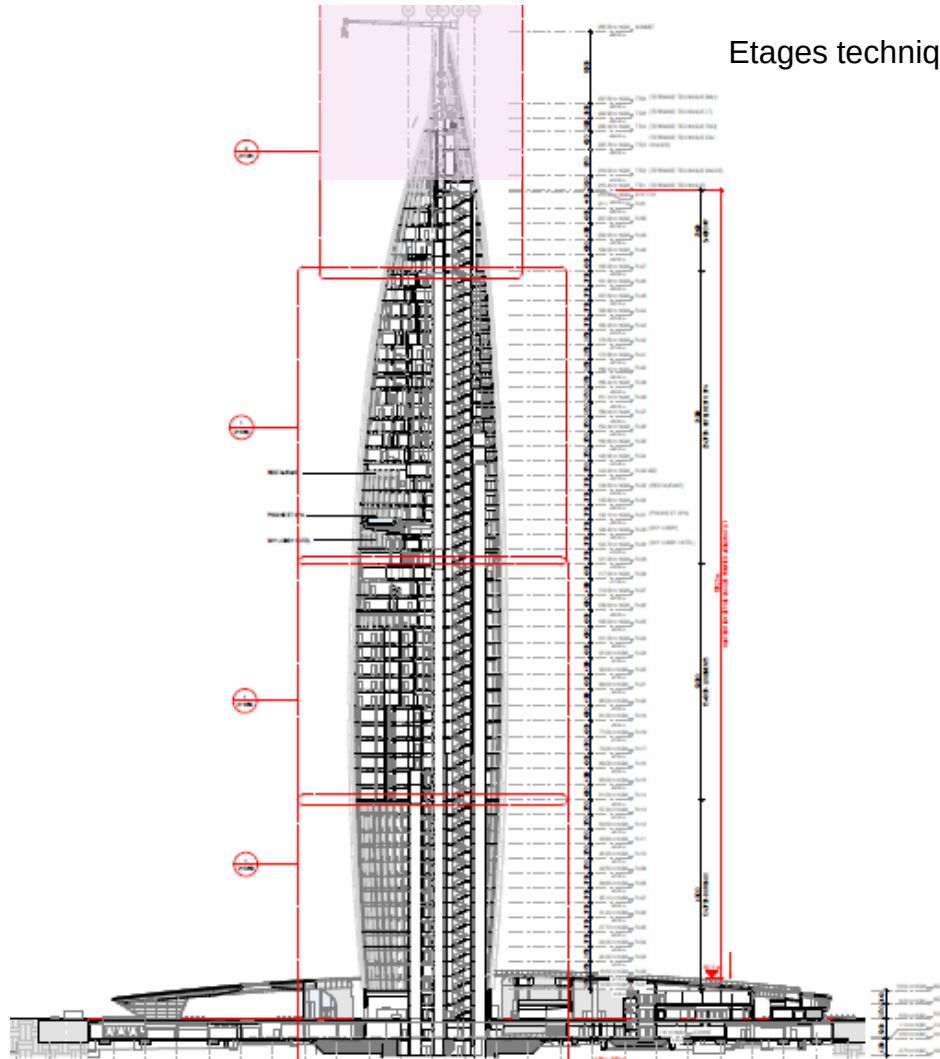
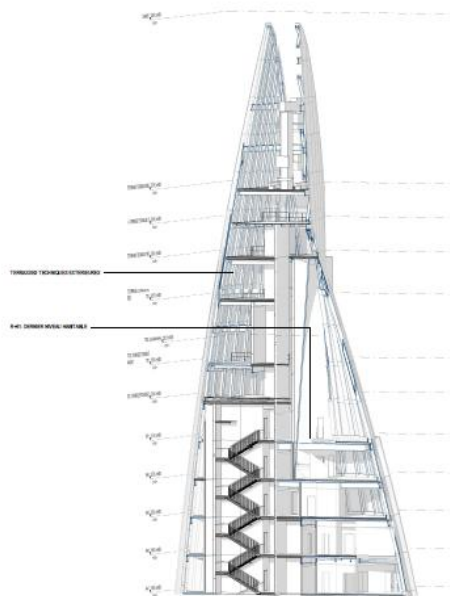
Croquis de principe



Particularités IGH

■ Réduction hauteur tour

- Coiffe considérée extérieure au top pour réduction hauteur & classement Immeuble de Grande Hauteur



Etages techniques extérieurs

Particularités IGH

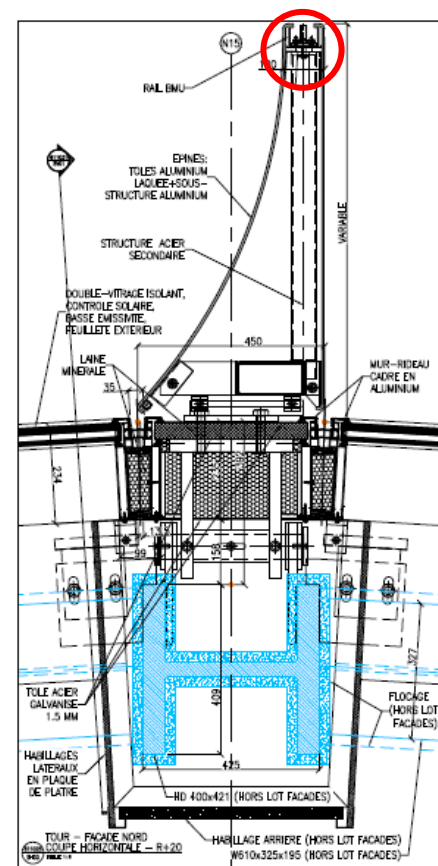
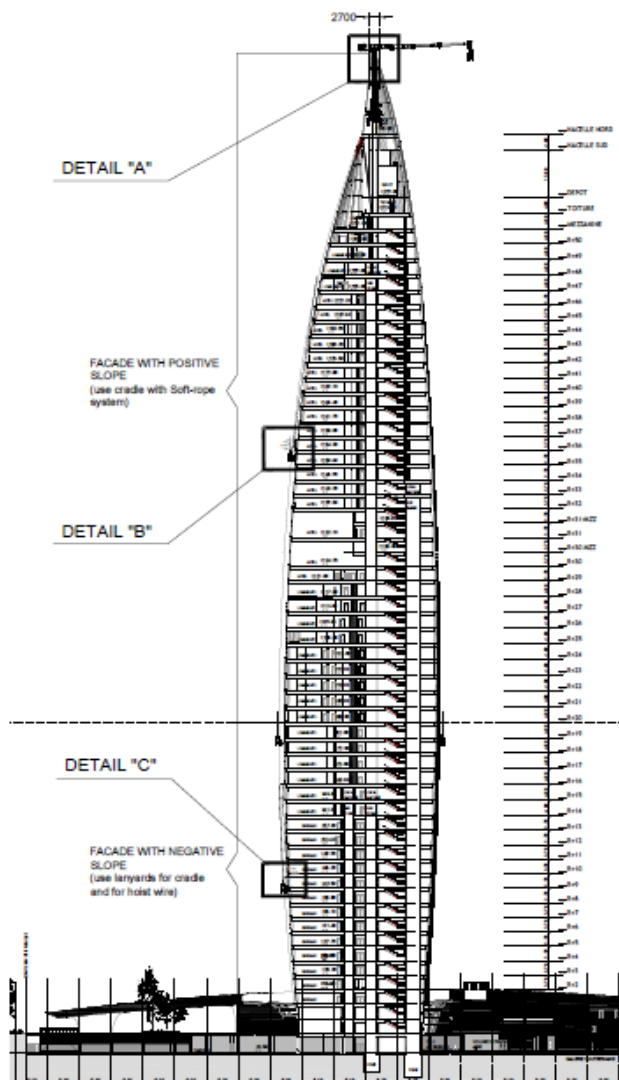
- Coiffe et BMU

- Principe nacelle de nettoyage <> épines



- **Coiffe et BMU**

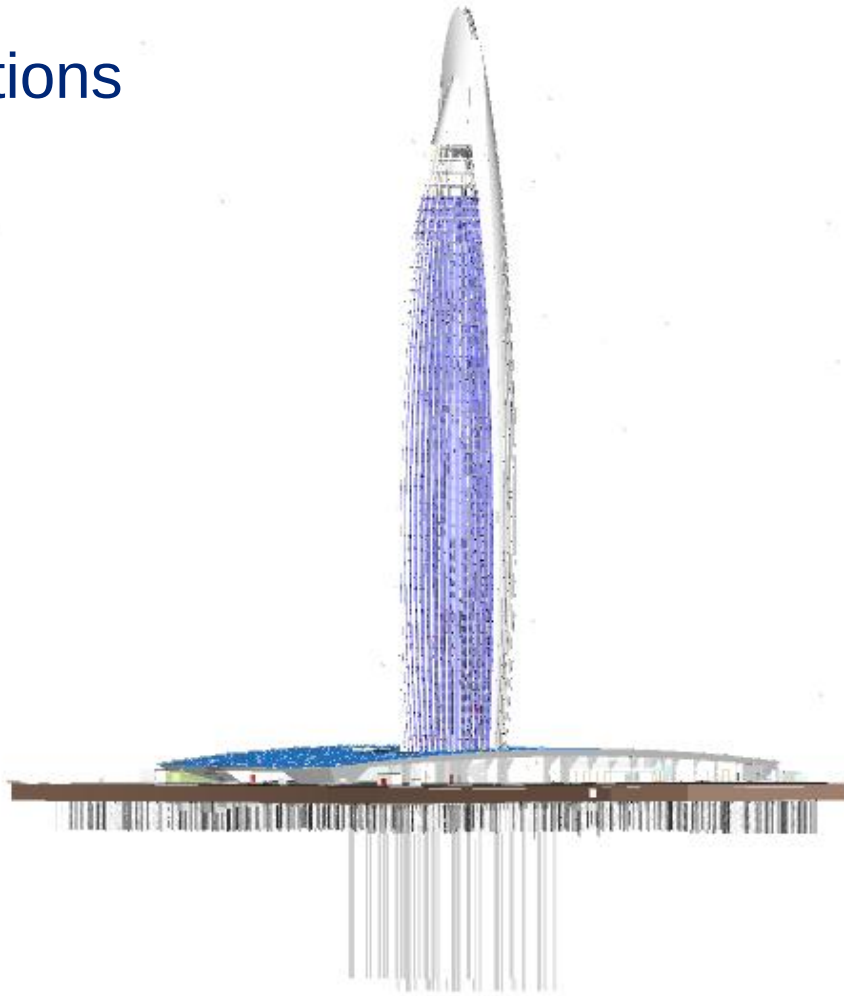
-



Détail épine nord avec
accroche pour BMU

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Fondations



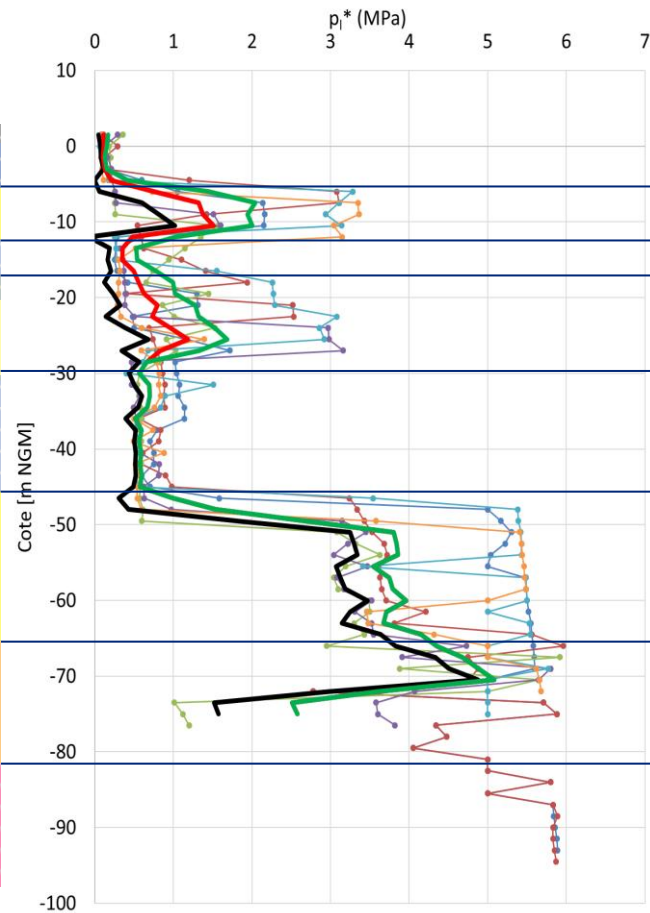
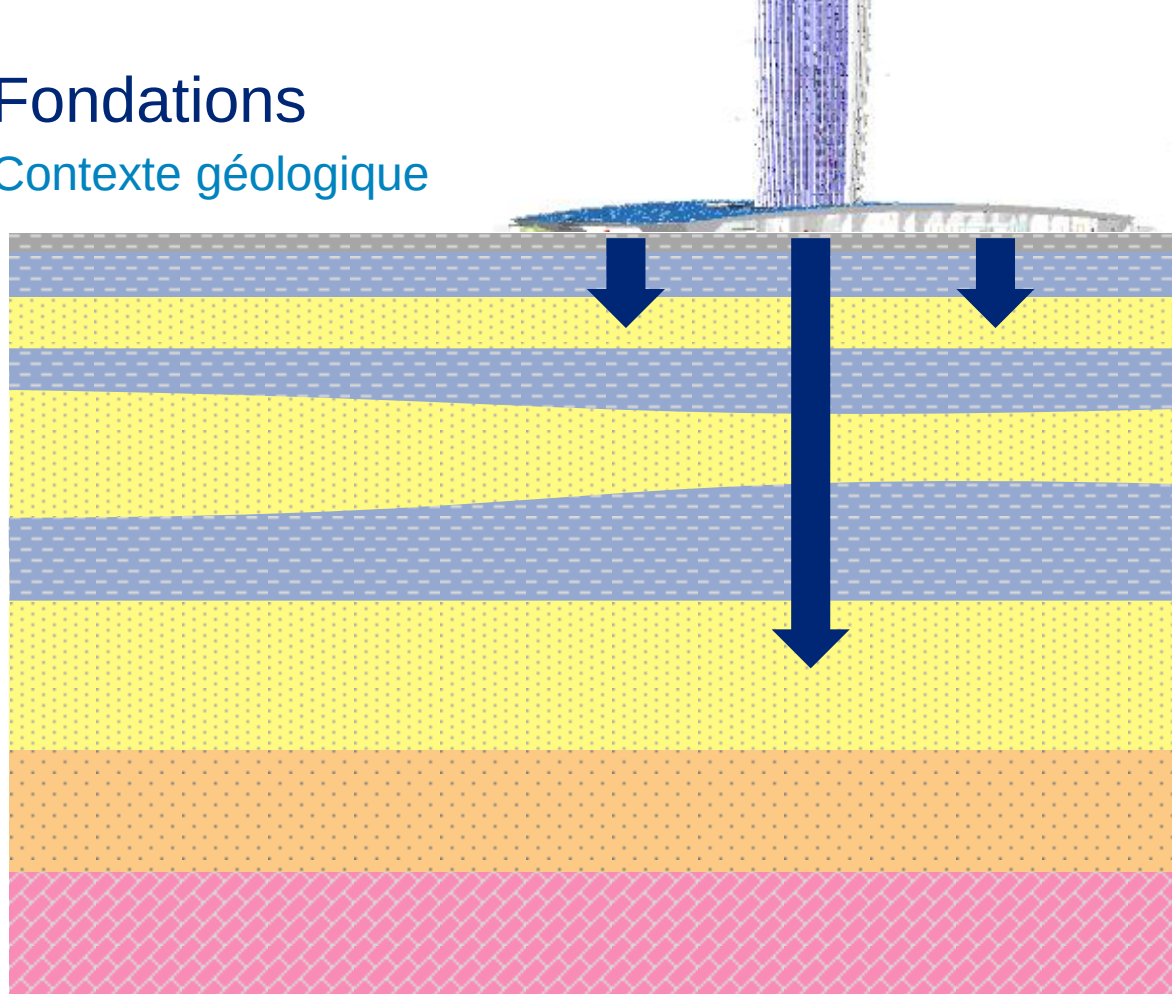
Fondations

- Contexte alluvionnaire (Rabat vs. Casablanca)



Fondations

Contexte géologique



Fondations

Contexte hydrogéologique



Mars 2005



Juillet 2018

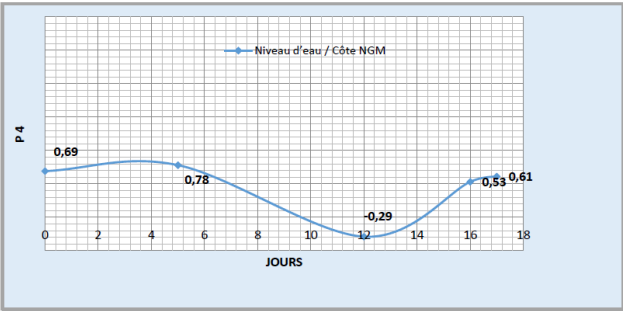
Fondations

Contexte hydrogéologique



Fondations

Contexte hydrogéologique



+5.50 Terrain Fini (RDC)

EE = +4.50 (crue 100 ans)

EH = +3.00

+2.50 Terrain Naturel

EB = +0.63

-0.10 Niveau radier

Colonnes ballastées

Hydrologie de surface

Hauteur piezométrique

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Fondations

Pieux socle

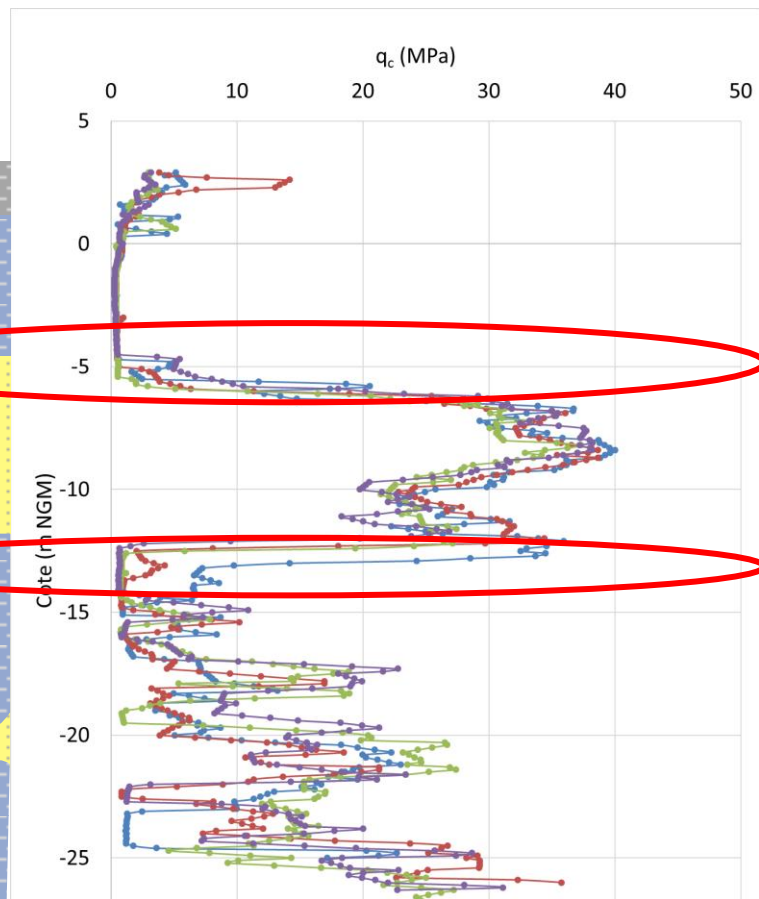
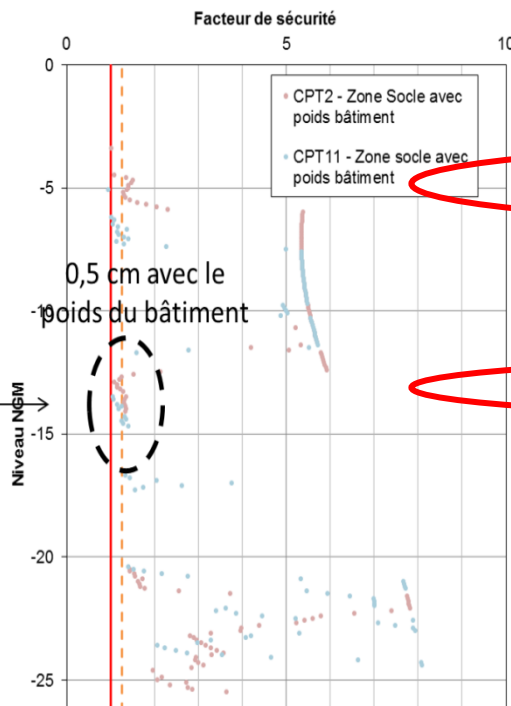
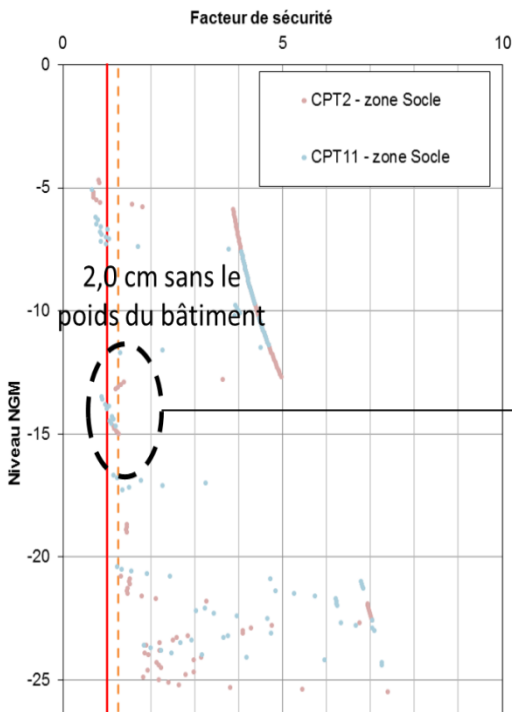
- Pieux à la tarière continue
- 1737 pieux
- Diamètre 600mm
- Longueur ± 10 m
 - Variation de la charge = variation nombre de pieux
- Traction



Fondations

Pieux socle

■ Risque de liquéfaction



Fondation

Pieux socle

- Epaisseur de la couche de sable



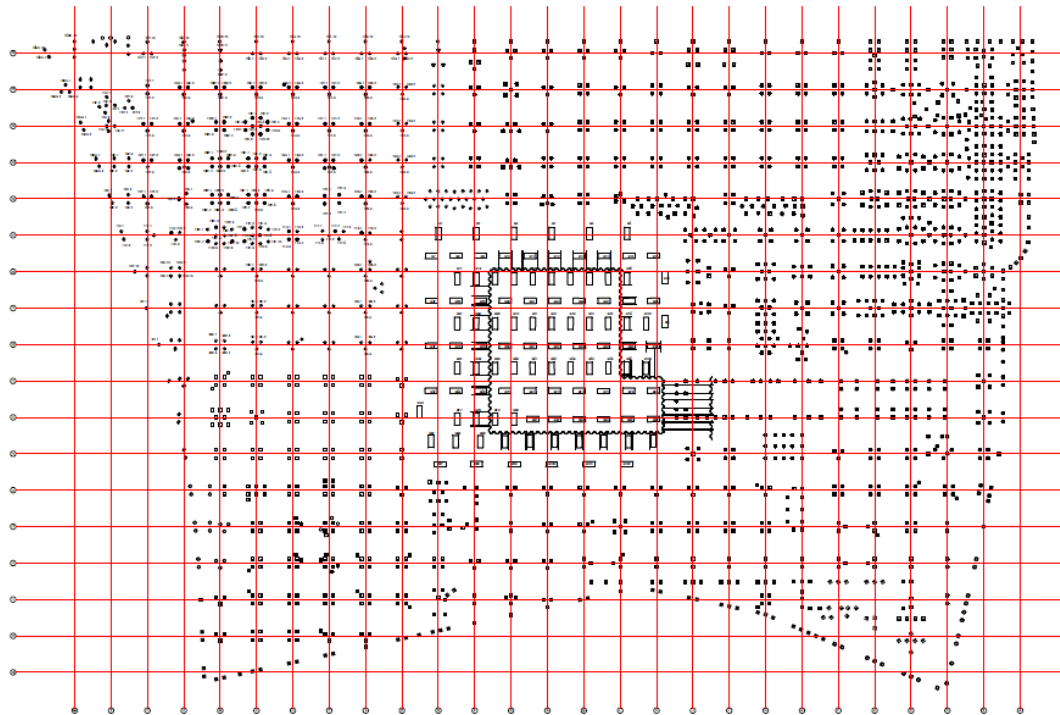
Pieux socle

-
- The map displays a study area with 16 sub-plots and 10 numbered zones. The sub-plots are labeled A, B, C1, C2, C3, D1, D2, E, F1, F2, F3, F4, F5. The numbered zones are 1 through 10, indicated by a color scale on the right. The map includes various points of interest (CPT, SP, ALU) with numerical values. A central area is highlighted with a red border. The map also shows a 'Servitude de protection PANNEAU PUBLICITAIRE' and a 'Voie d'accès'.
- Key points and values on the map:
- Sub-plot A:** CPT6 (7.815), SP6 (8.571), CPT10 (8.10).
 - Sub-plot B:** CPT19 (6.037), CPT002 (8.841).
 - Sub-plot C1:** CPT32 (7.188), SP5 (8.764), CPT01 (8.032), CPT00 (8.427), CPT11 (8.622), CPT14 (8.731).
 - Sub-plot C2:** CPT17 (8.622), CPT14 (8.731), CPT15 (8.201).
 - Sub-plot C3:** CPT16 (4.273), CPT17 (8.622), CPT15 (8.201).
 - Sub-plot D1:** CPT06 (7.184), SP5 (8.571), CPT003 (7.800).
 - Sub-plot D2:** CPT7 (7.800).
 - Sub-plot E:** CPT03 (8.428), CPT04 (7.476), SP4 (7.94), CPT001 (6.996).
 - Sub-plot F1:** CPT18 (8.241).
 - Sub-plot F2:** CPT1 (9.515), CPT15 (8.201).
 - Sub-plot F3:** CPT5 (8.704), CPT20 (8.853).
 - Sub-plot F4:** SP3 (7.552), ALU1 (7.473).
 - Sub-plot F5:** CPT15 (8.201).
- The color scale on the right indicates values from 1 to 10, with colors ranging from purple (1) to orange (10).

Fondation

Pieux socle

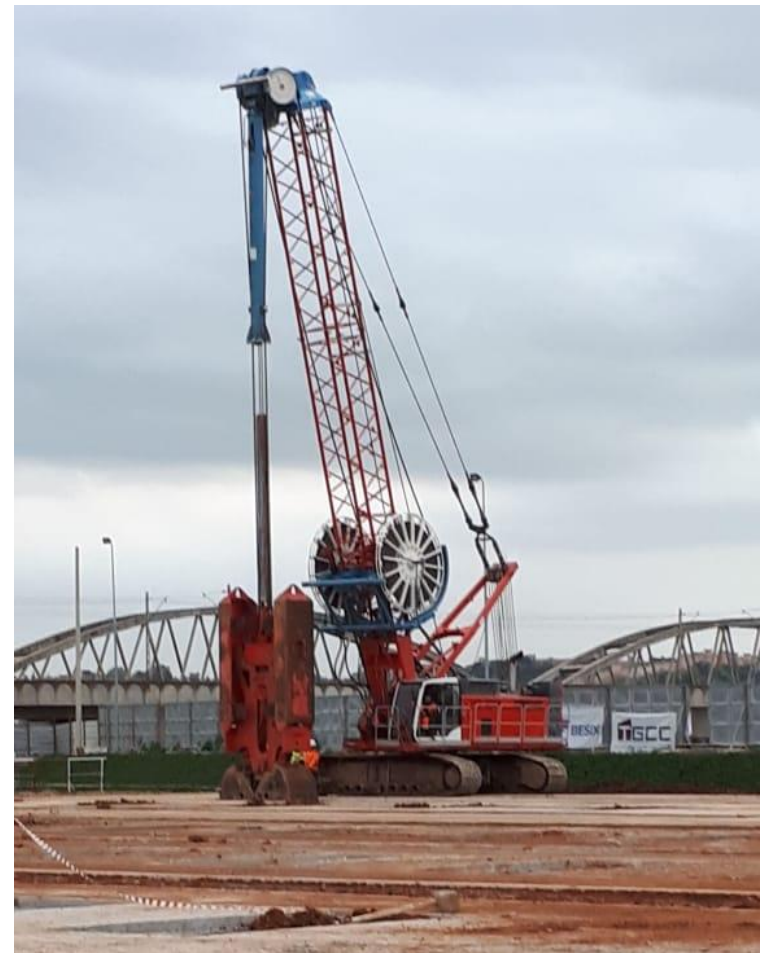
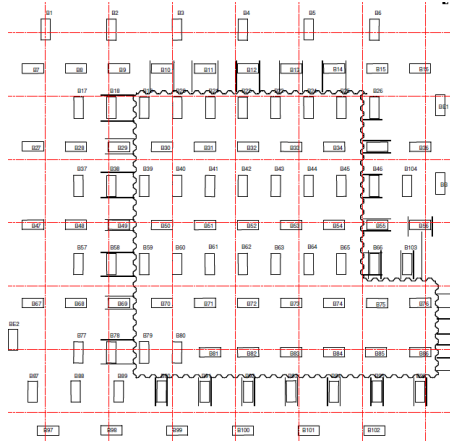
- Epaisseur de la couche de sable



Fondations

Barrettes tour

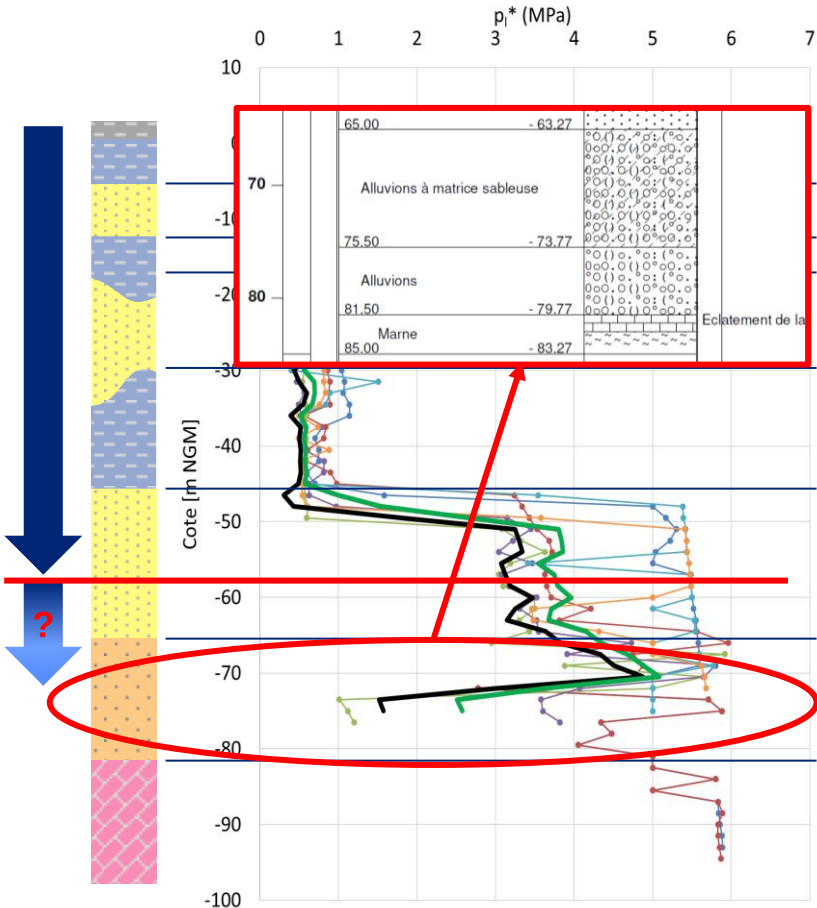
- Barrettes (forées bouées)
- 104 barrettes
- 1200mm x 2700mm
- Longueur 61.5m – 65.5m
 - Variation de la charge = variation de la longueur



Fondations

Barrettes tour

- Couches profondes

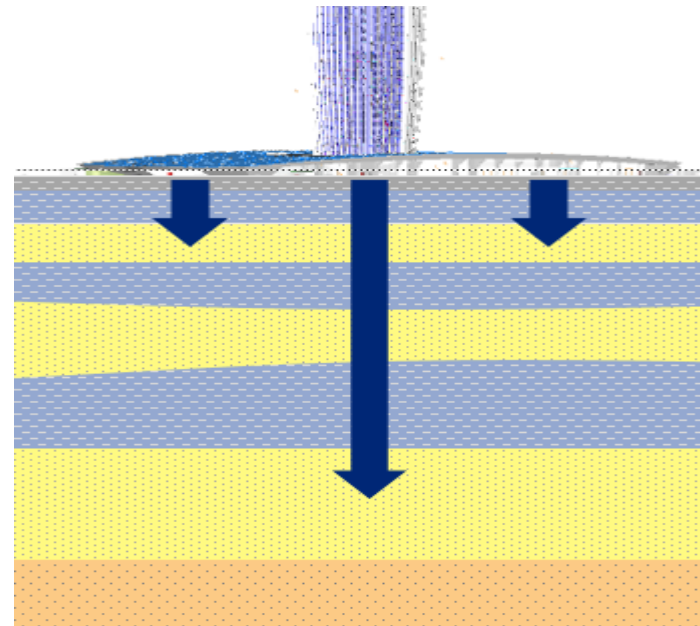
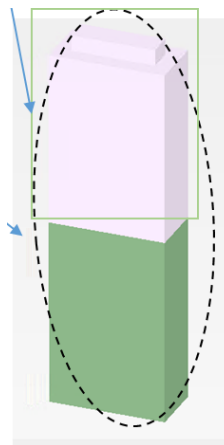
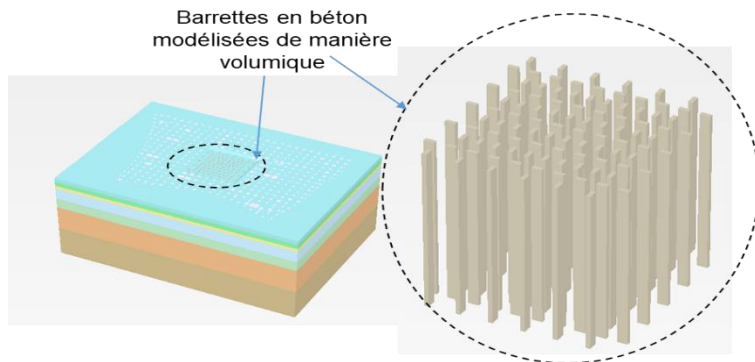
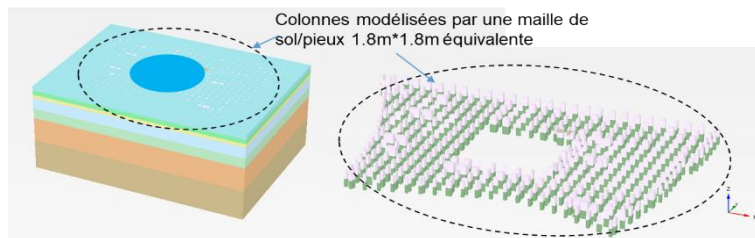


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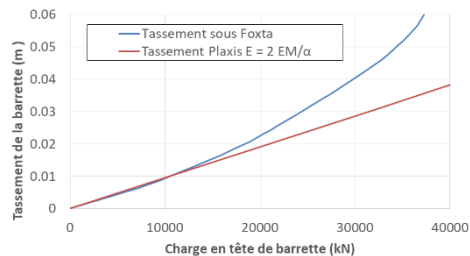
Fondations

Interaction sol-structure

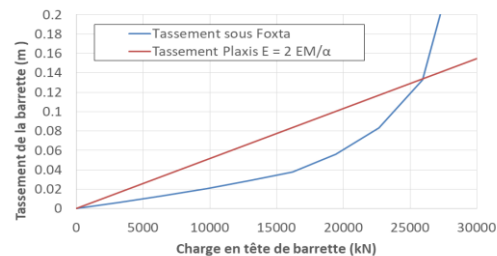
- Effets de groupe
- Interaction tour-socle



Comparaison Foxta / Plaxis, barrette isolée



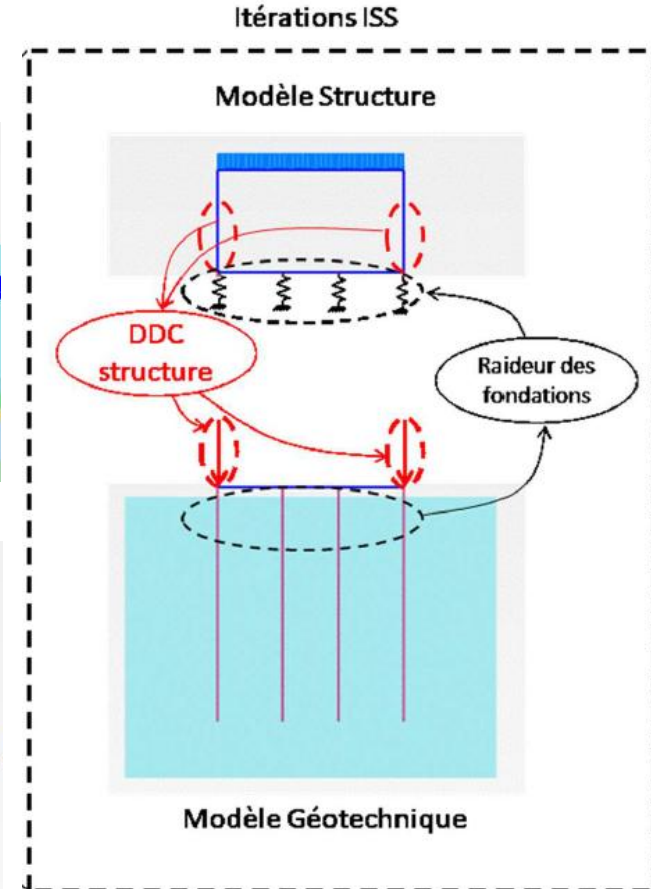
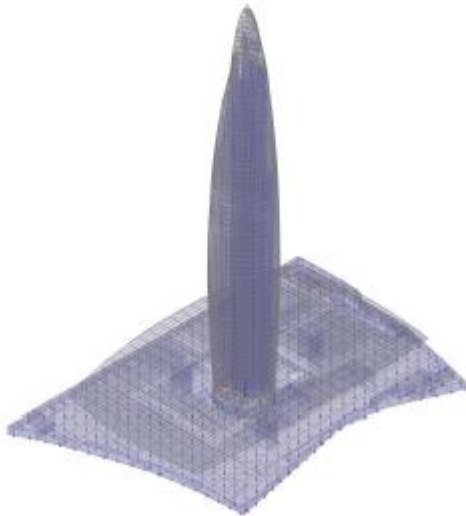
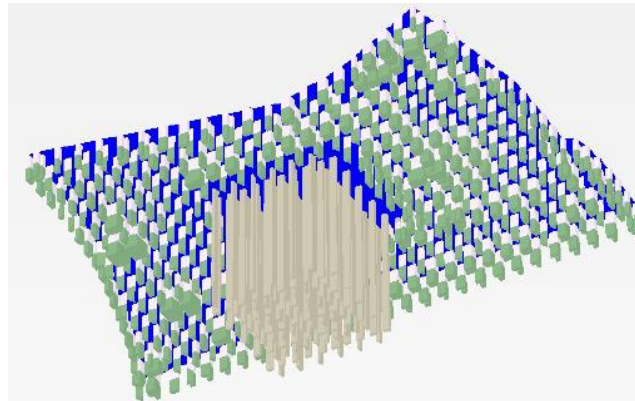
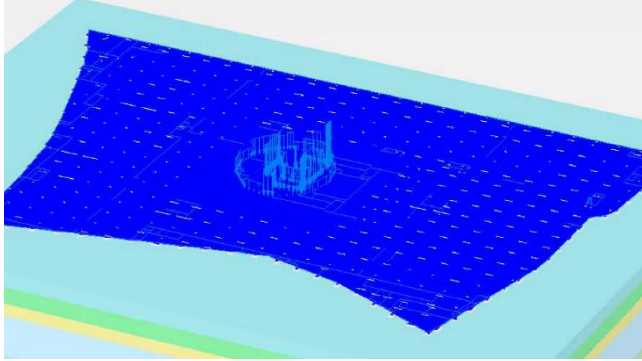
Comparaison Foxta / Plaxis, barrette en groupe



Fondations

Interaction sol-structure – Vert.

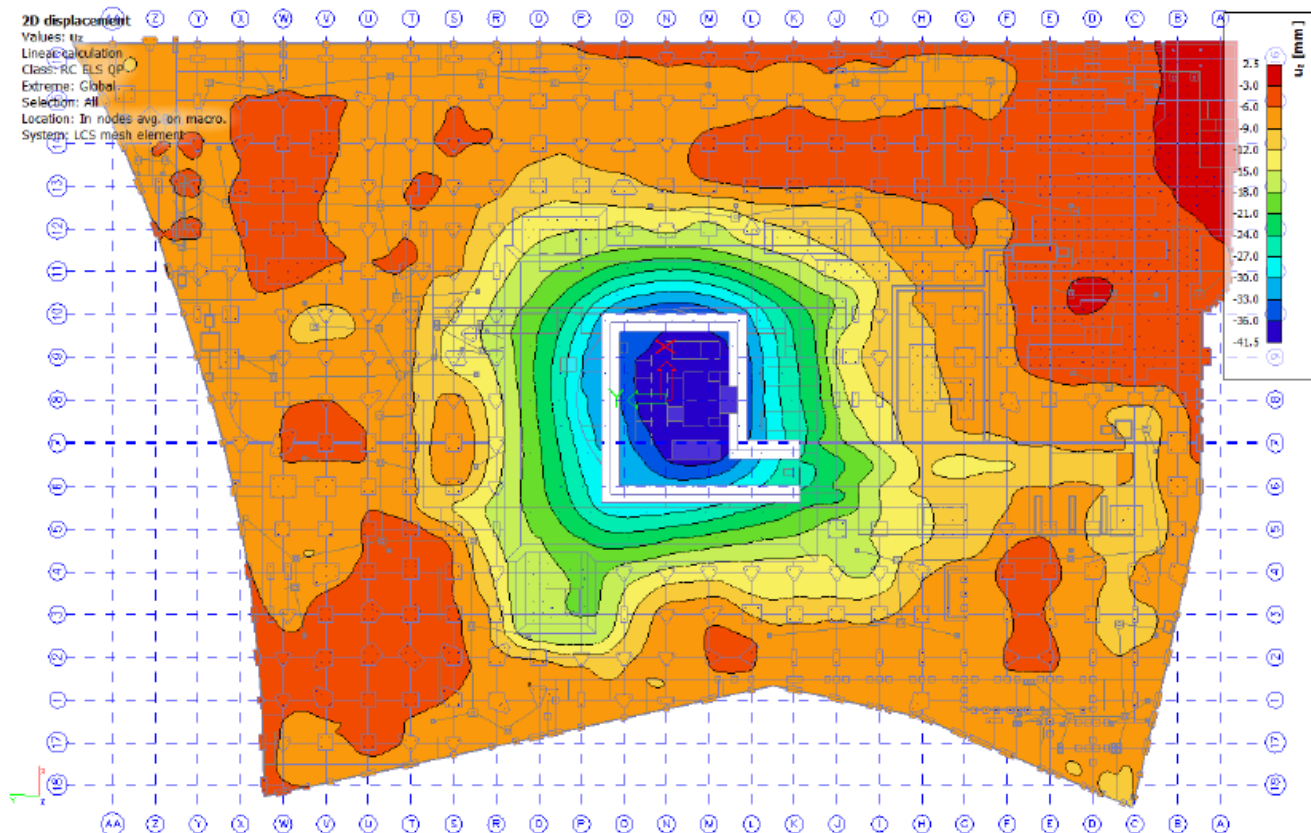
- 4 itérations
- 3 bureaux impliqués



Fondations

Interaction sol-structure - Tassements

- Tour: 50mm
- Socle: 20mm



Fondations

Interaction sol-structure – Hor.

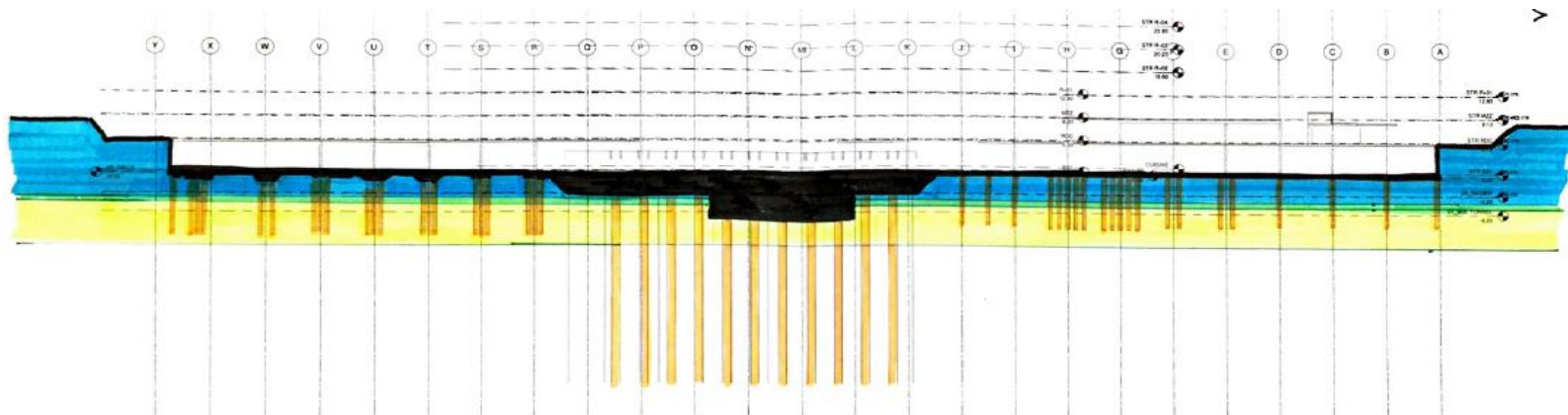
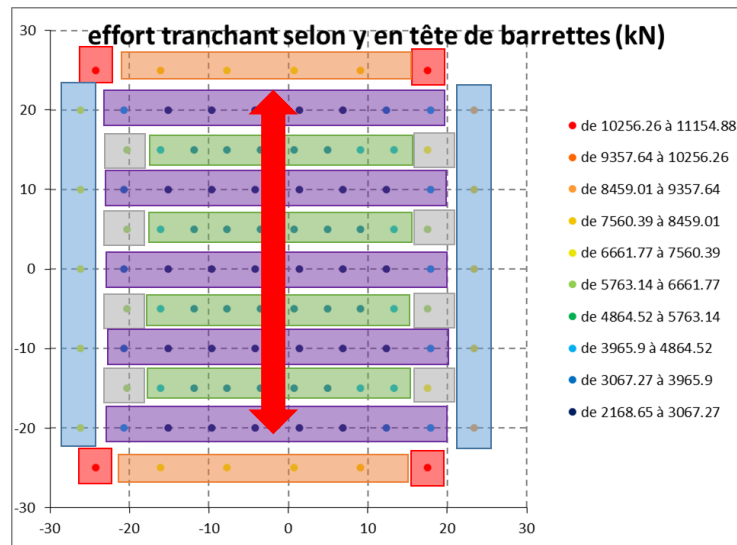
- Base shear
 - Séisme dimensionnant
 - Partie socle prépondérante
 - Masse du radier double le base shear

Partie	Direction	Vent [kN]	Séisme [kN]	
			Sans masse du radier	Avec masse du radier
Tour	X	17223	33478	72664
	Y	19456	31186	67712
Socle	X	4037	156501	252021
	Y	5475	154426	237190

Fondations

Interaction sol-structure

- Charge sismique:
 - Tour: 25%
 - Socle: 75%
- Réaction:
 - Barrettes: 10 à 30%
 - Pieux: 70 à 90%



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Structure de la tour - Généralité

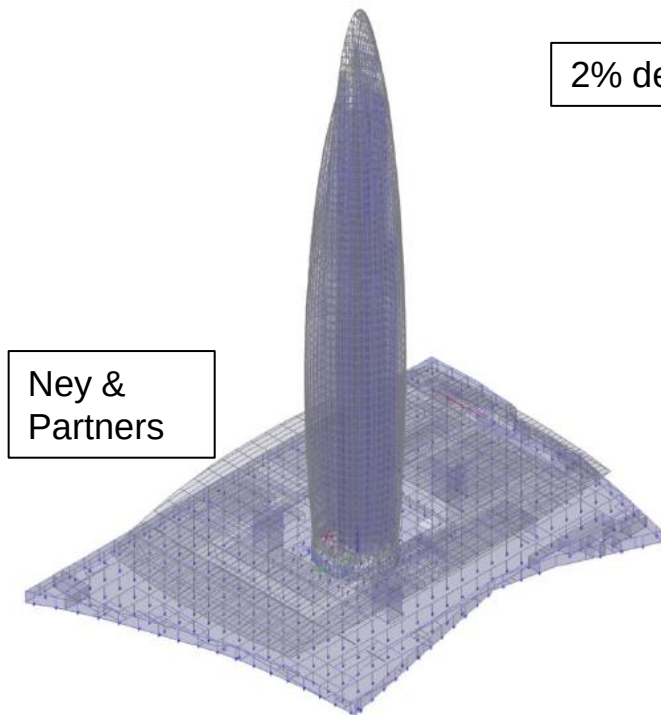


Collaboration de différents
bureaux internationaux
±60 personnes



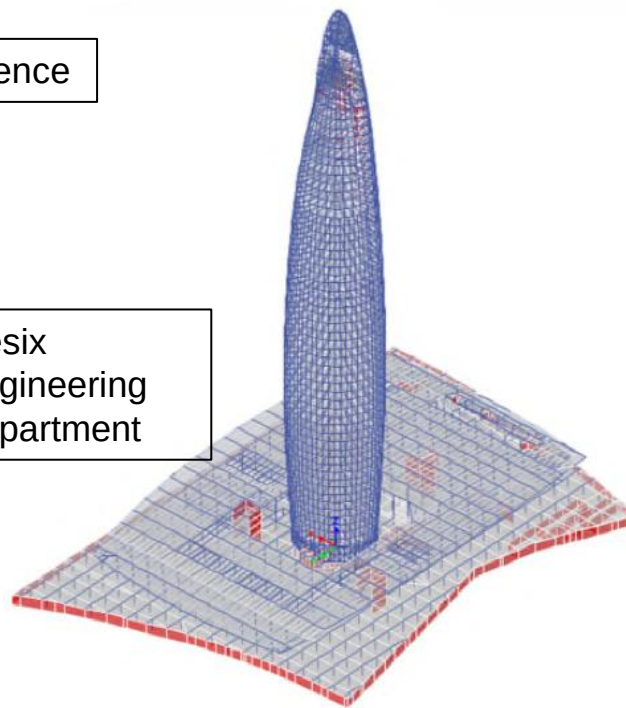
Structure de la tour - Modélisation

Vue 3D globale du modèle SCIA :



Ney &
Partners

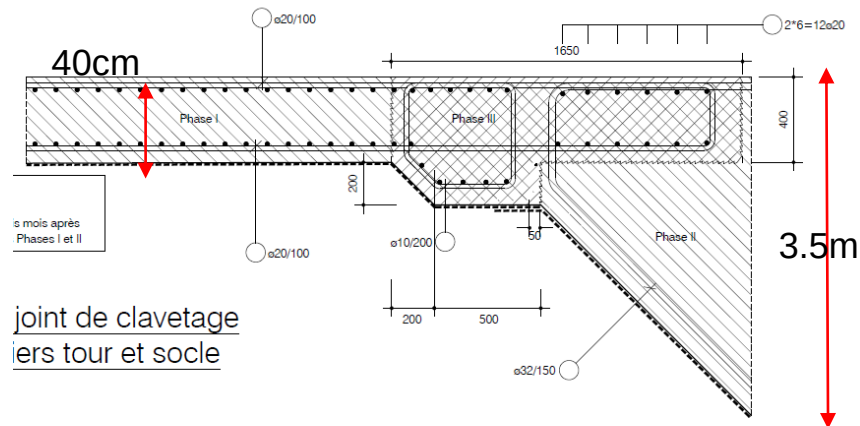
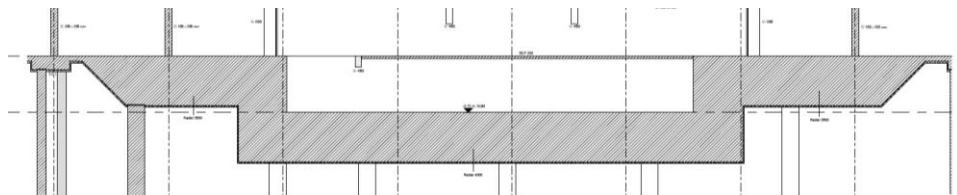
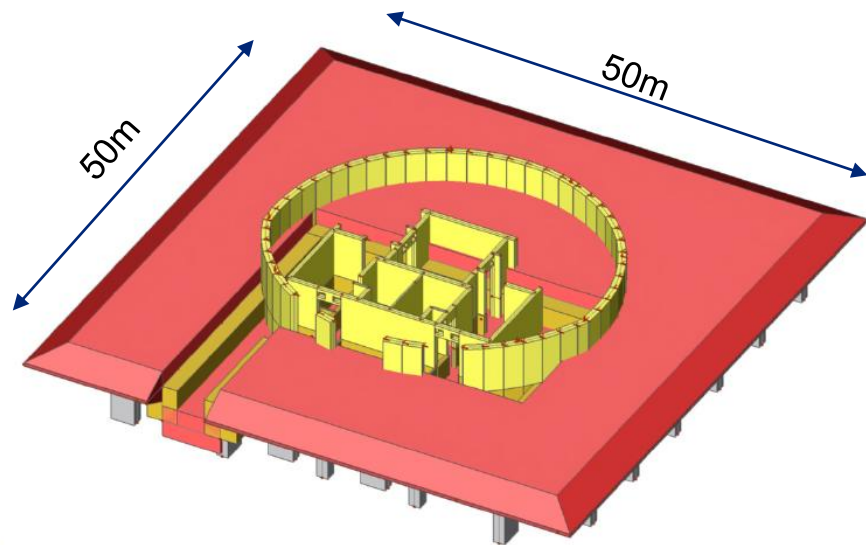
Vue 3D globale du modèle ETABS :



Besix
engineering
department

2% de différence

Structure de la tour - Radier



Structure de la tour - Radier



Structure de la tour - Radier



Structure de la tour - Radier

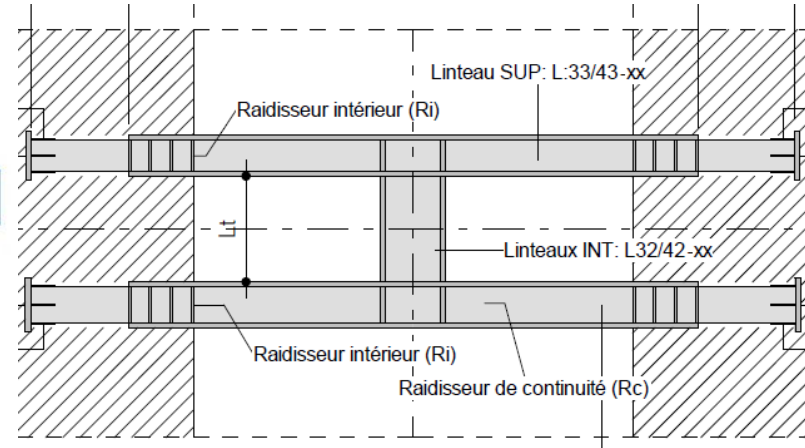
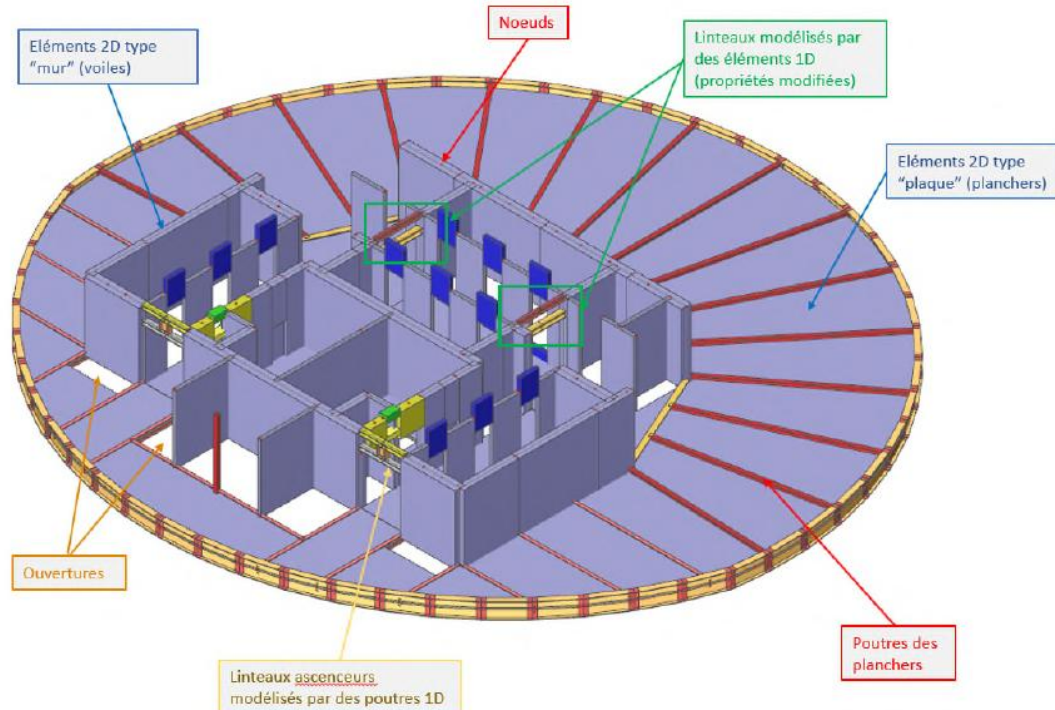
RADIER HAUT

POSE LES CHAISES



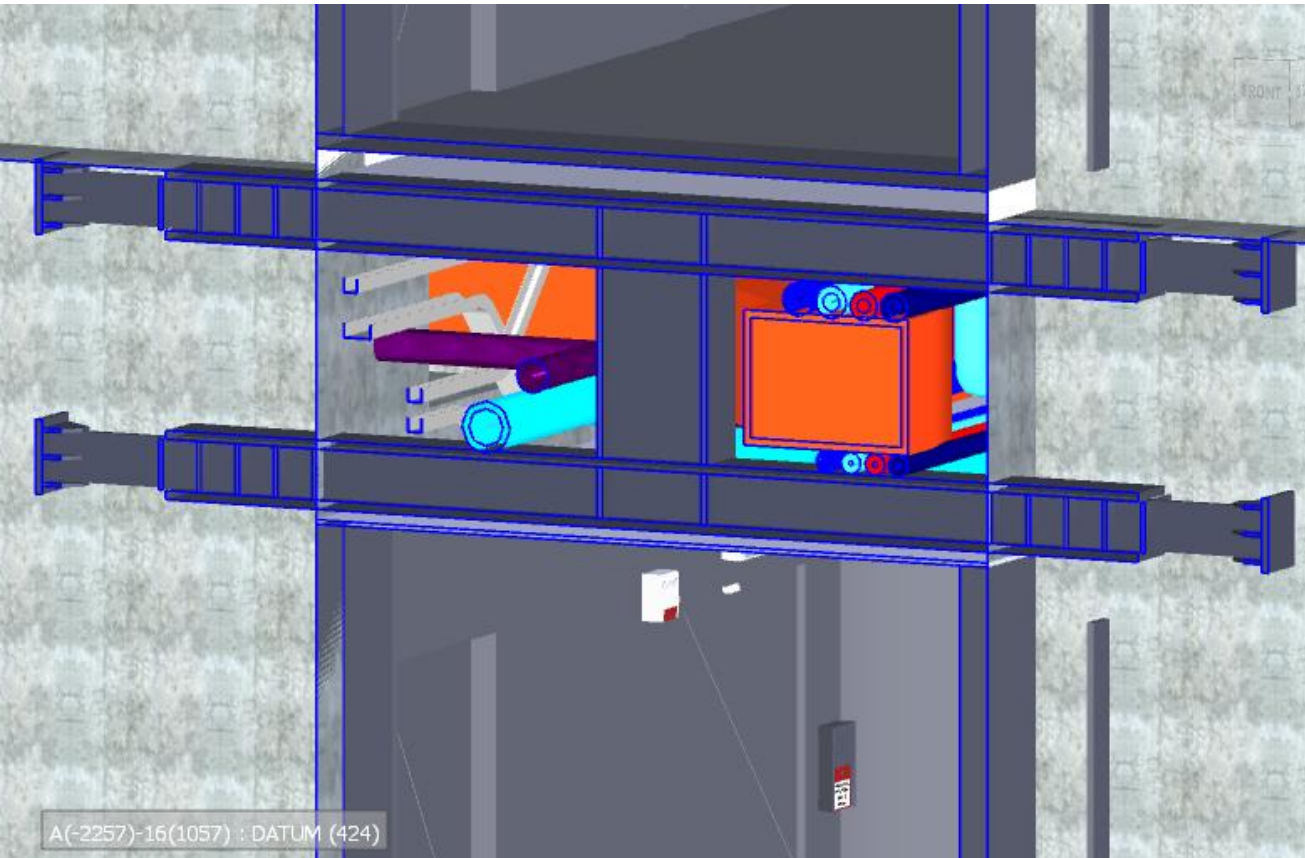
Structure de la tour – Système mixte de contreventement

Noyau Béton



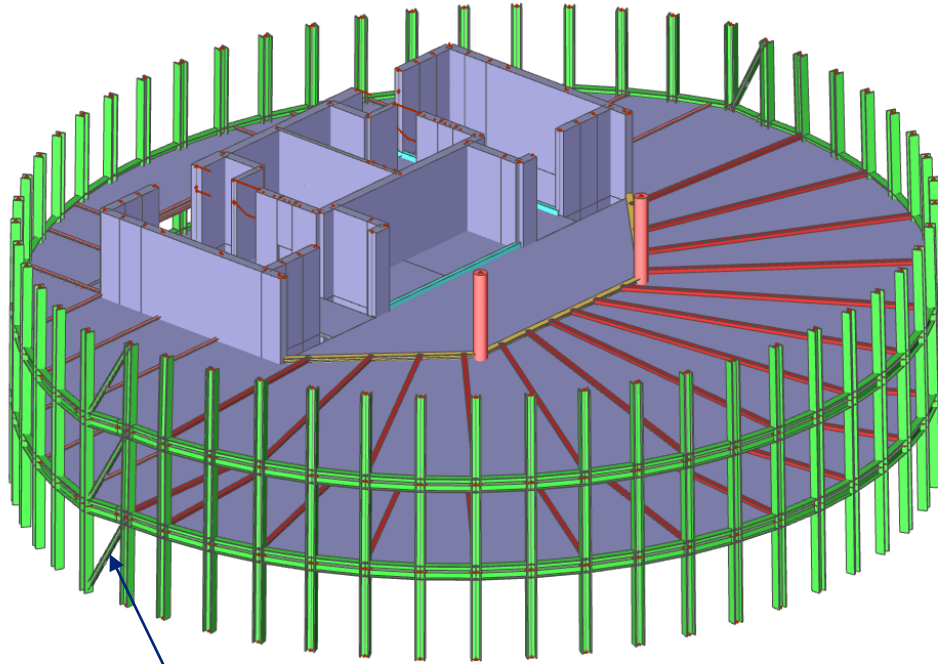
- Béton C60
- 60 à 80% de la raideur

Structure de la tour – Système mixte de contreventement

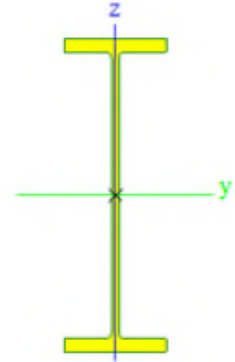
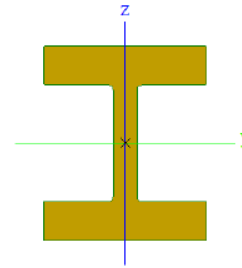


Structure de la tour – Système mixte de contreventement

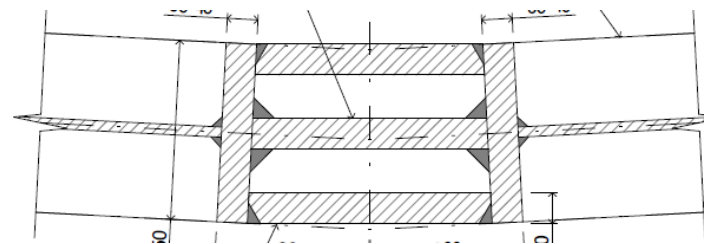
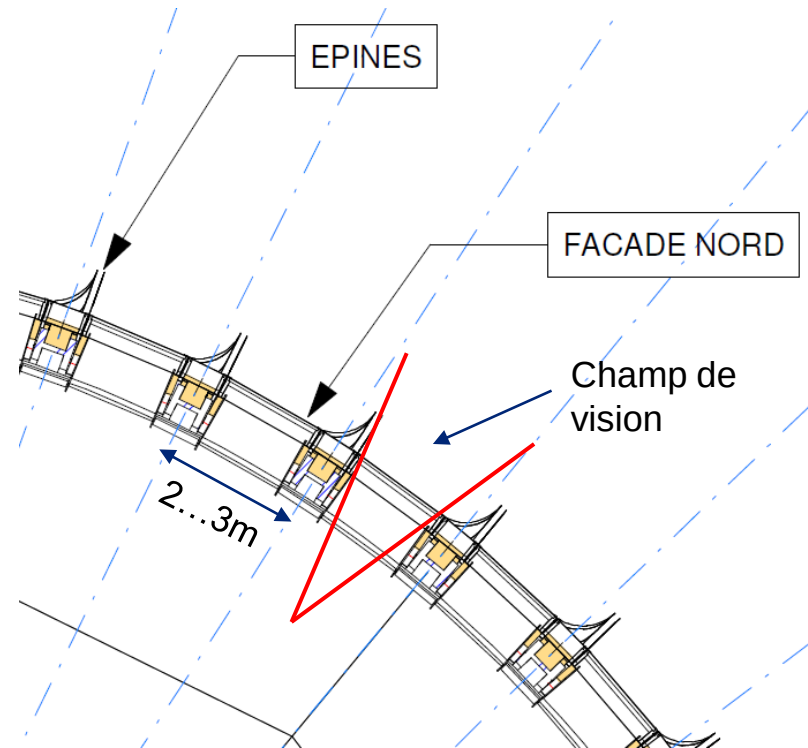
20 à 40% de la raideur



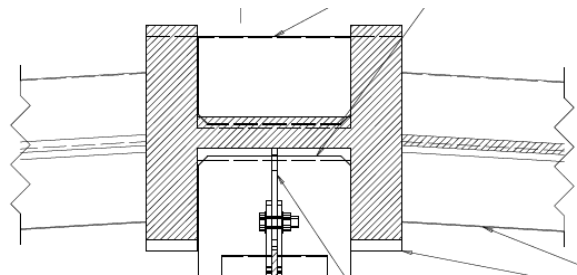
Diagonales de transition



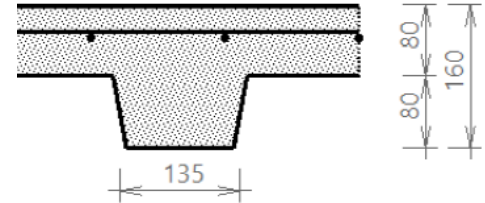
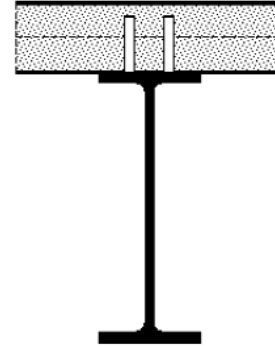
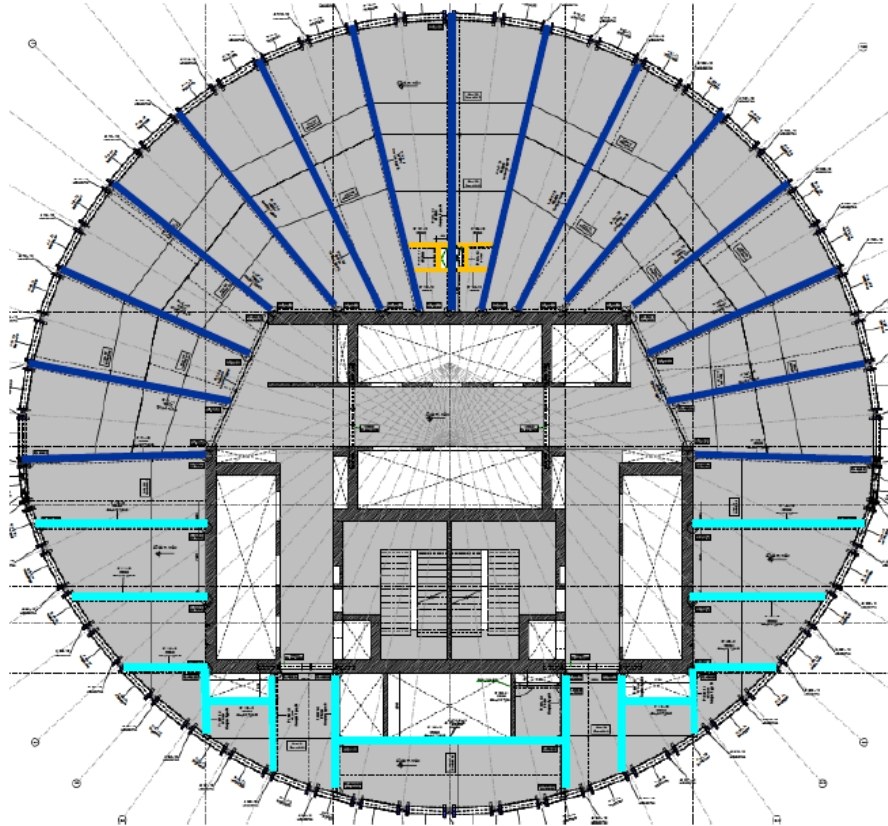
Structure de la tour – Système mixte de contreventement



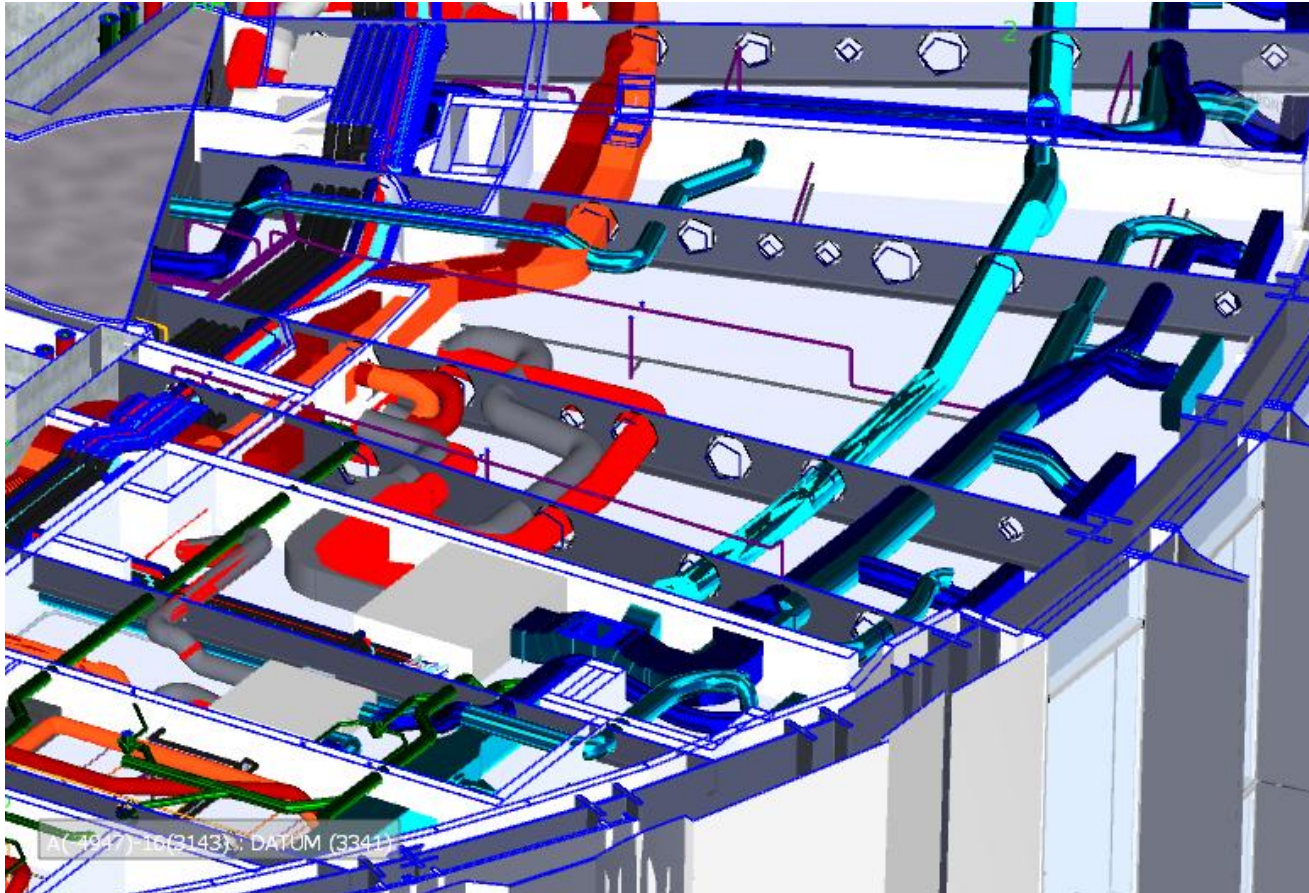
Value Engineering



Structure de la tour – Système de plancher



Structure de la tour – Système de plancher

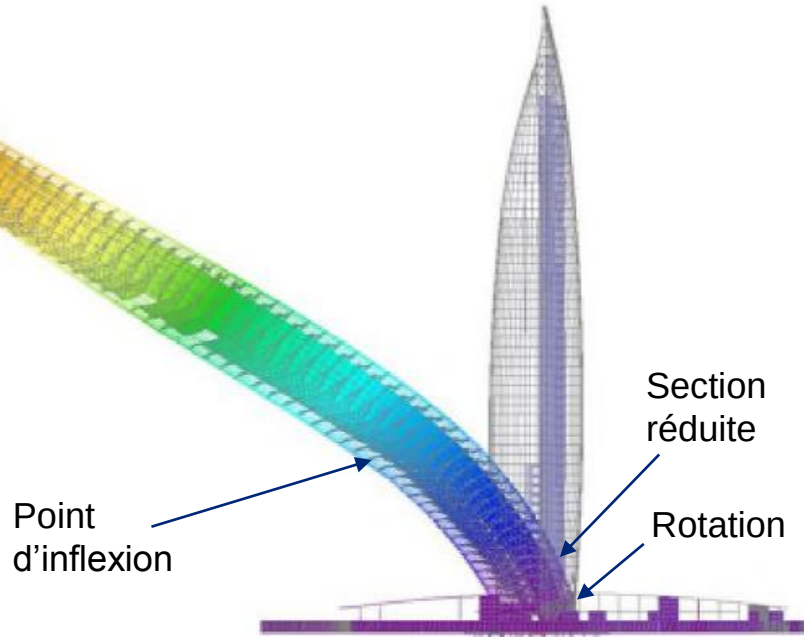


Etage type bureaux

- Description architecturale
- Description du système de fondations
- Description du système structurel
 - Conception de la structure
 - **Comportement dynamique**
 - Challenges client

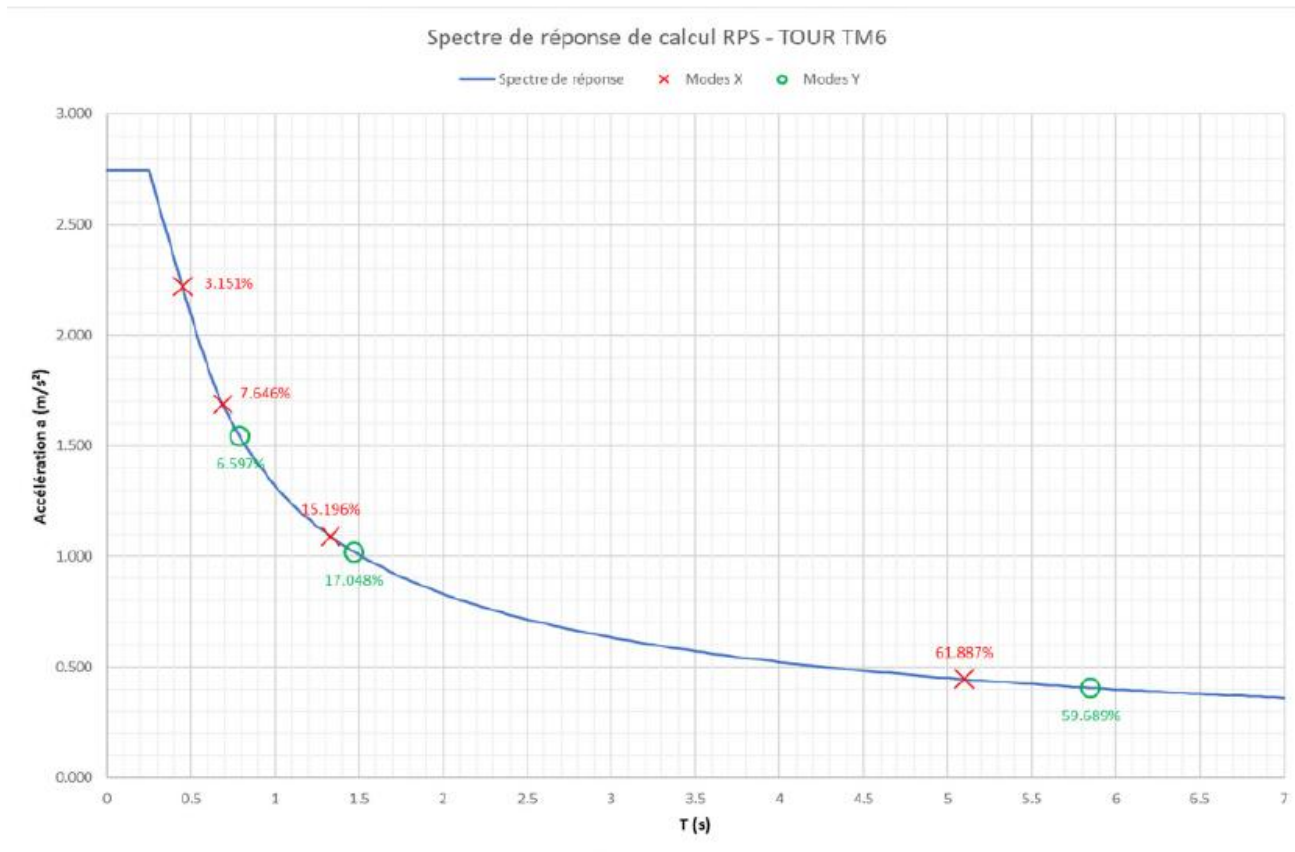
Cas de charge	Type de déformation	Déformation [mm]	
		X	Y
Vent	Story drift	8	13
	Total en tête	487	285
Séisme*	Story drift	8	8
	Total en tête	344	406

Modes	Direction	période [s]
1	Y	5.9
2	X	5.4
3	Torsion	2.0



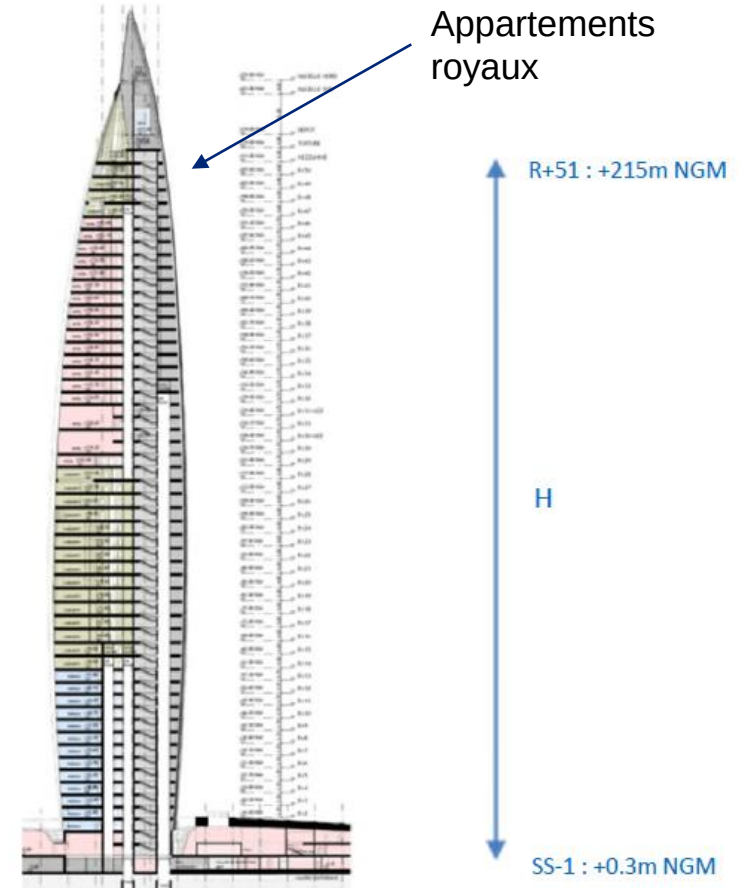
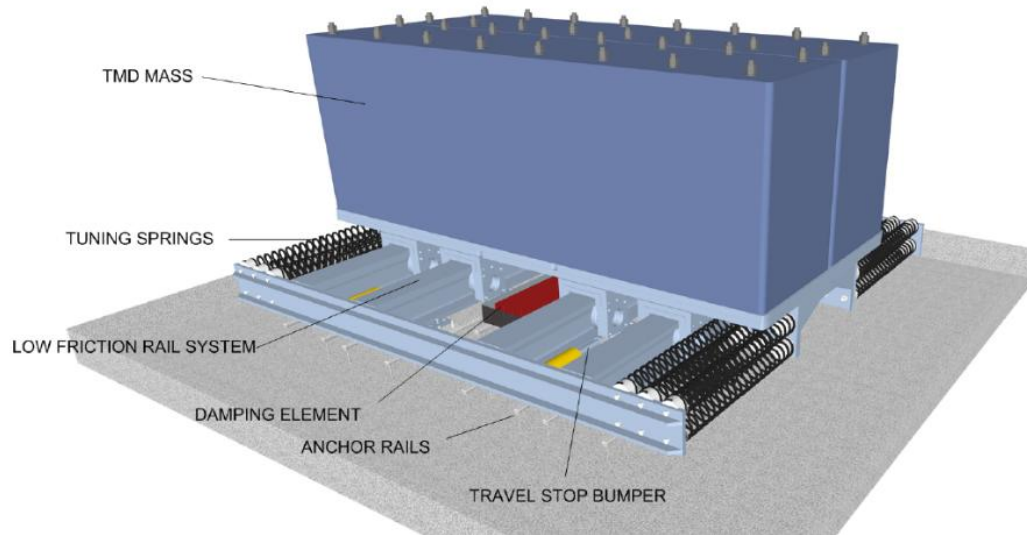
Structure de la tour – Analyse parasismique

- $A_{gR} = 0,1g$ (=Liège)
- $q = 1.5$
- Classe DCL



Tuned Mass Damper

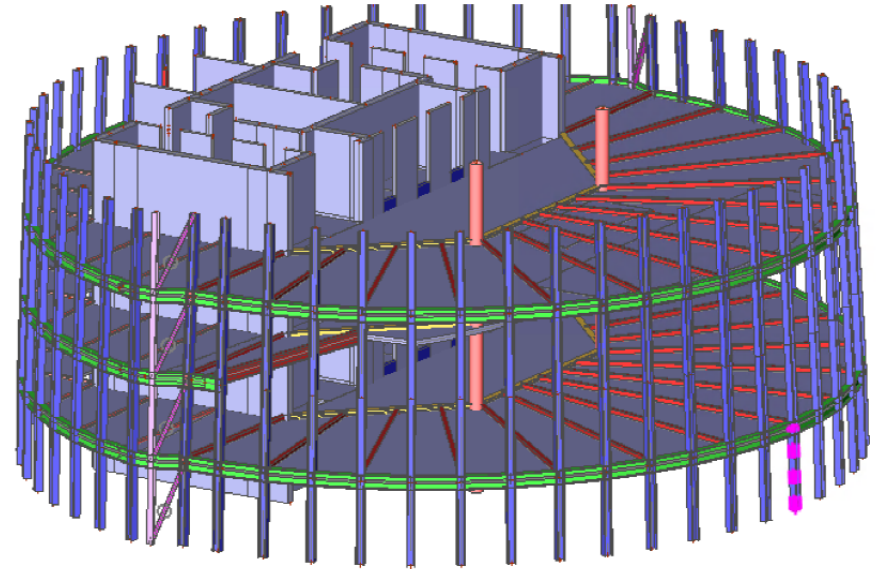
- P.R. 10 ans : $a < 10 \dots 15$ mili-g
- 200Ton
- Course de ± 50 cm



- Description architecturale
- Description du système de fondations
- Description du système structurel
 - Conception de la structure
 - Comportement dynamique
 - **Challenge client**

Structure – Demandes du client vs challenge technique

- Suppression des poutres périphériques sur plusieurs étages
- Perte de raideur global et local



Structure – Demandes du client vs challenge technique

- Module de Young à 90 jours
- Renfort avec diagonales
- Même répartition d'effort

