



CGI



La tour d'acier de 3000 mètres en France

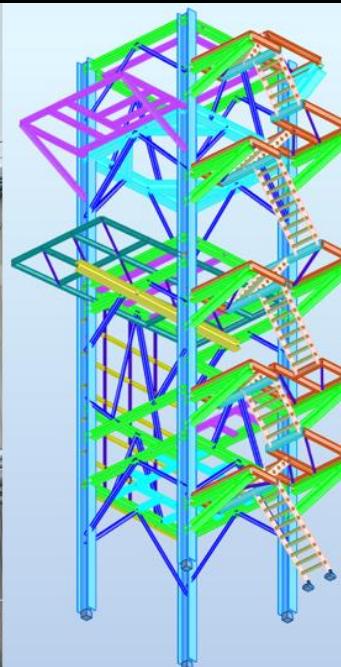
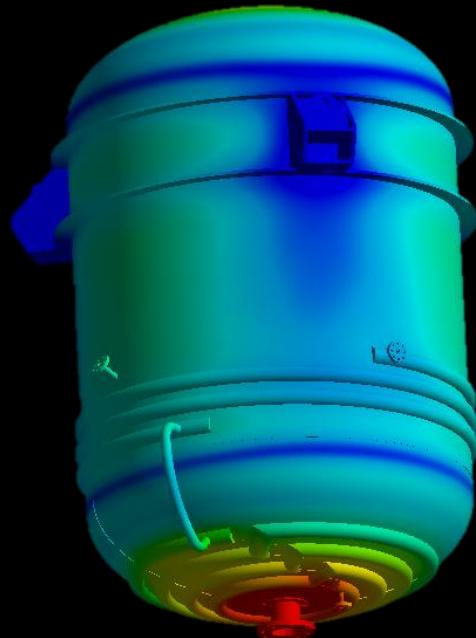
sebastien.besse@cgindustrie.com | 06 73 52 02 82

25/03/2025 – Paris Dock Pullman

www.cgindustrie.com

COMPAGNIE GÉNÉRALE DE L'INDUSTRIE (CGI)

- Fondée en 2013 par Sébastien Besse
- Bureau de calculs mécaniques industriels : nos spécialités mais pas que, sont la charpente acier, la tuyauterie industrielle, les appareils à pression



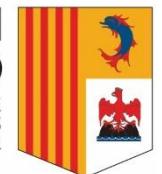
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RÉGION
SUD // INVEST:



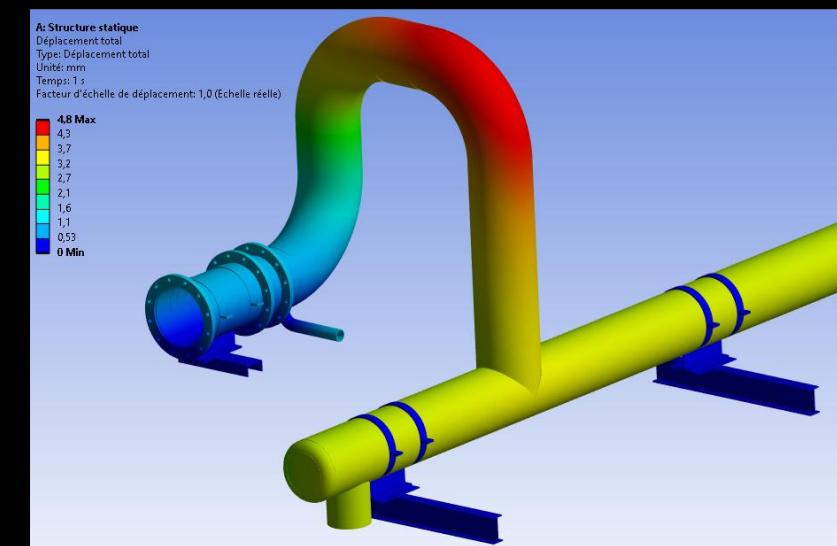
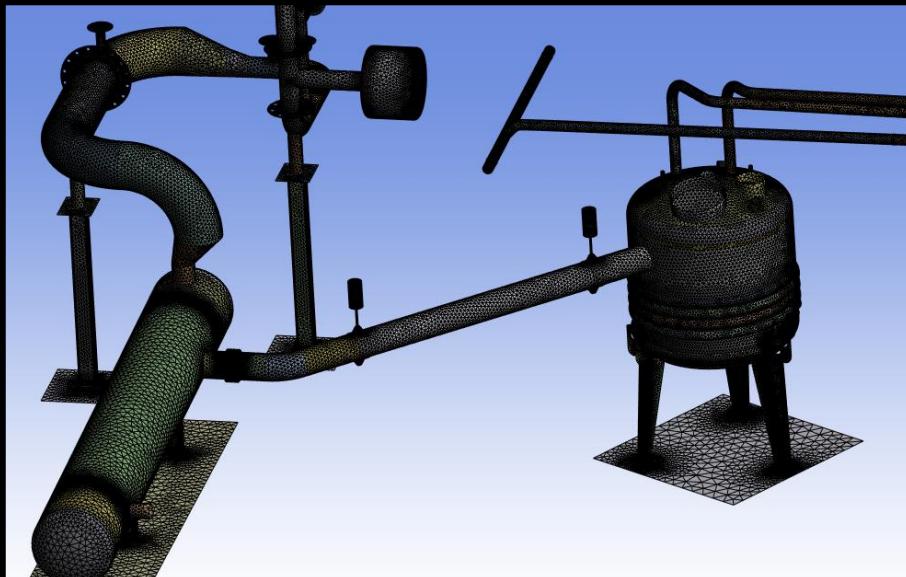
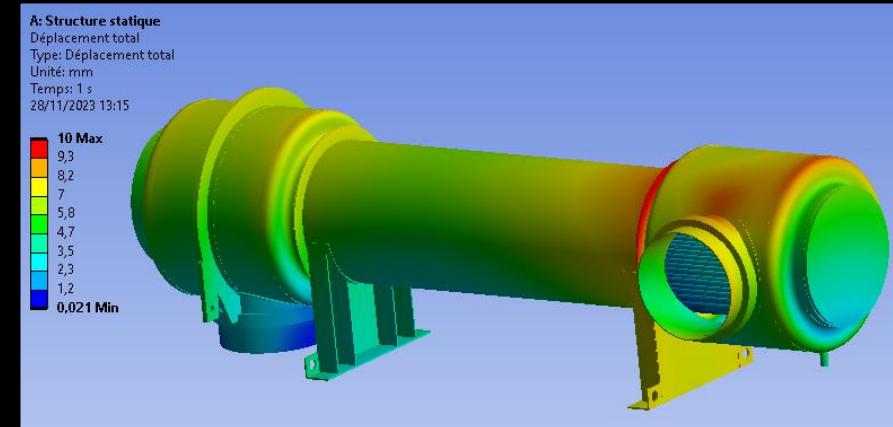
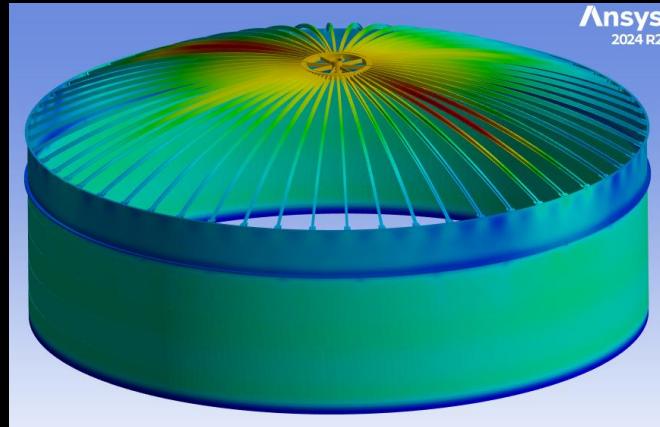
UNION EUROPÉENNE
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**RÉGION
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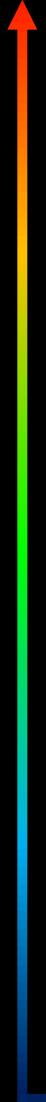


 CAISSE
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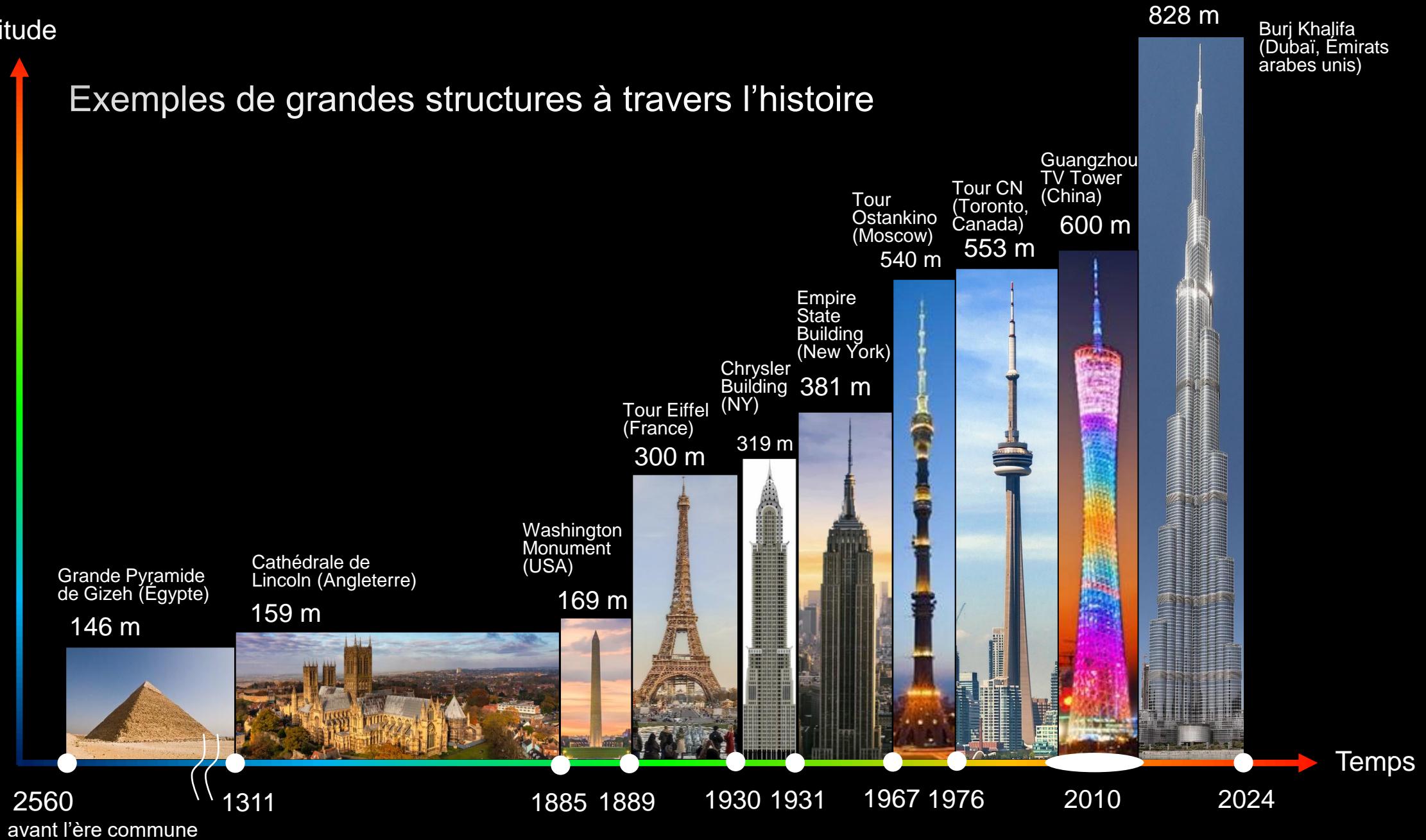
COMPAGNIE GÉNÉRALE DE L'INDUSTRIE (CGI)



Altitude



Exemples de grandes structures à travers l'histoire



Exemples de projets de tours de très grandes hauteurs

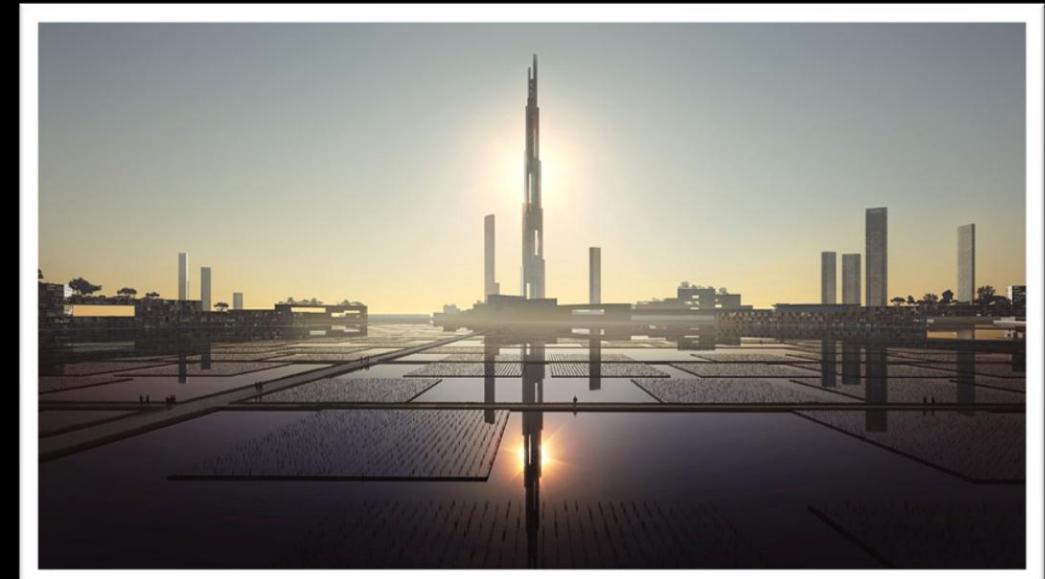
Tour Djeddah 1007 m
(Arabie Saoudite)



Oblisco Capitale 1000 m
(Egypte)



Sky Mile Tower 1700 m
Tokyo (Japan)



X-Seed 4000 (Tokyo, 1995)

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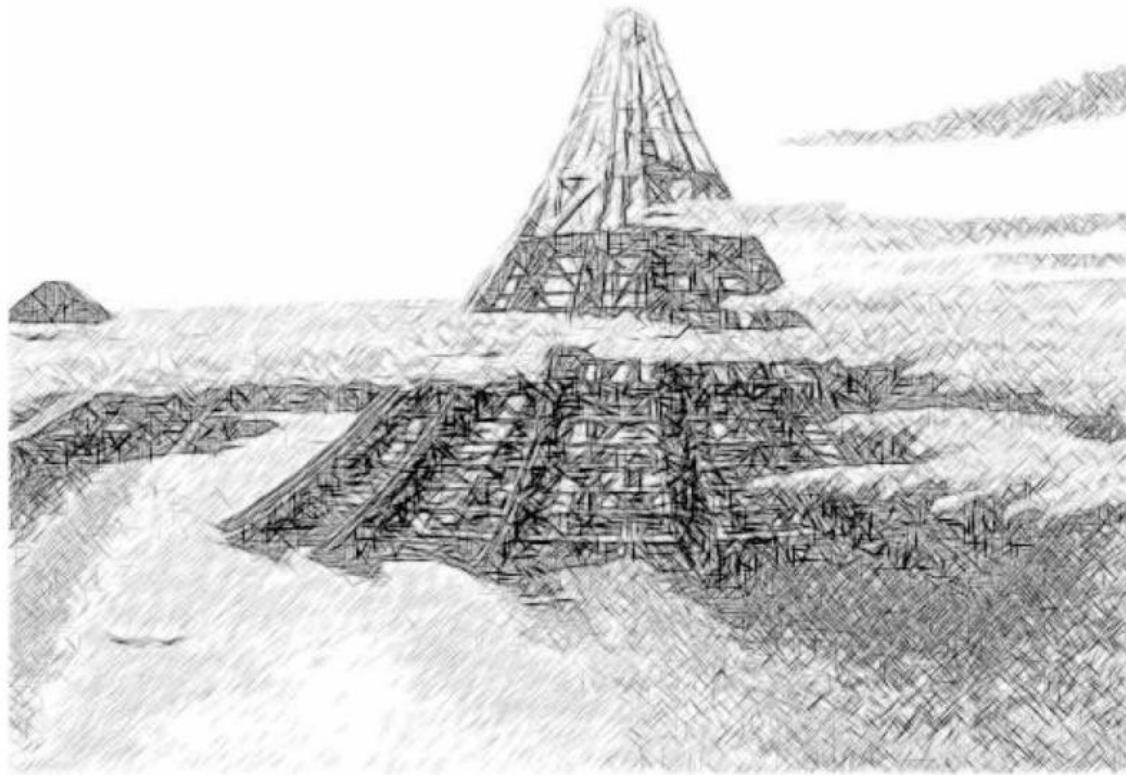
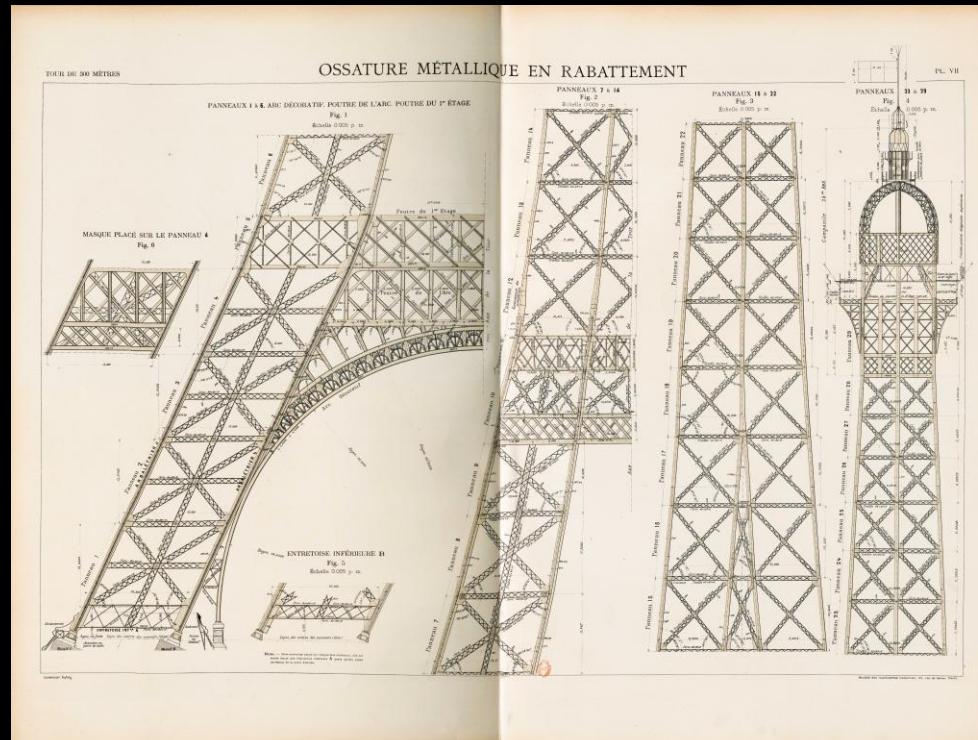
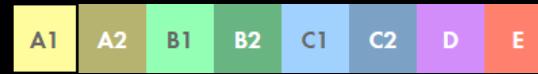
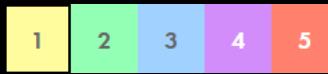
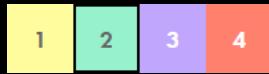


Figure 11. X-seed 4000, proposed by the Taisei Corporation, is a 4 km (2.485 miles) height, and 6 km (3.728 miles) wide sea-base structure. It contains 800 floors that could accommodate up to one million inhabitants.

Drawing by K. Al-Kodmany

Le « prototype » de la Tour Eiffel

- ▶ Construite en 1889 avec de la cornière, des plates et des rivets
- ▶ Conçue sans électricité ni les ordinateurs ni la méthode des éléments finis
- ▶ Eurocodes : vent zone 2, sismicité zone 1, neige zone A1

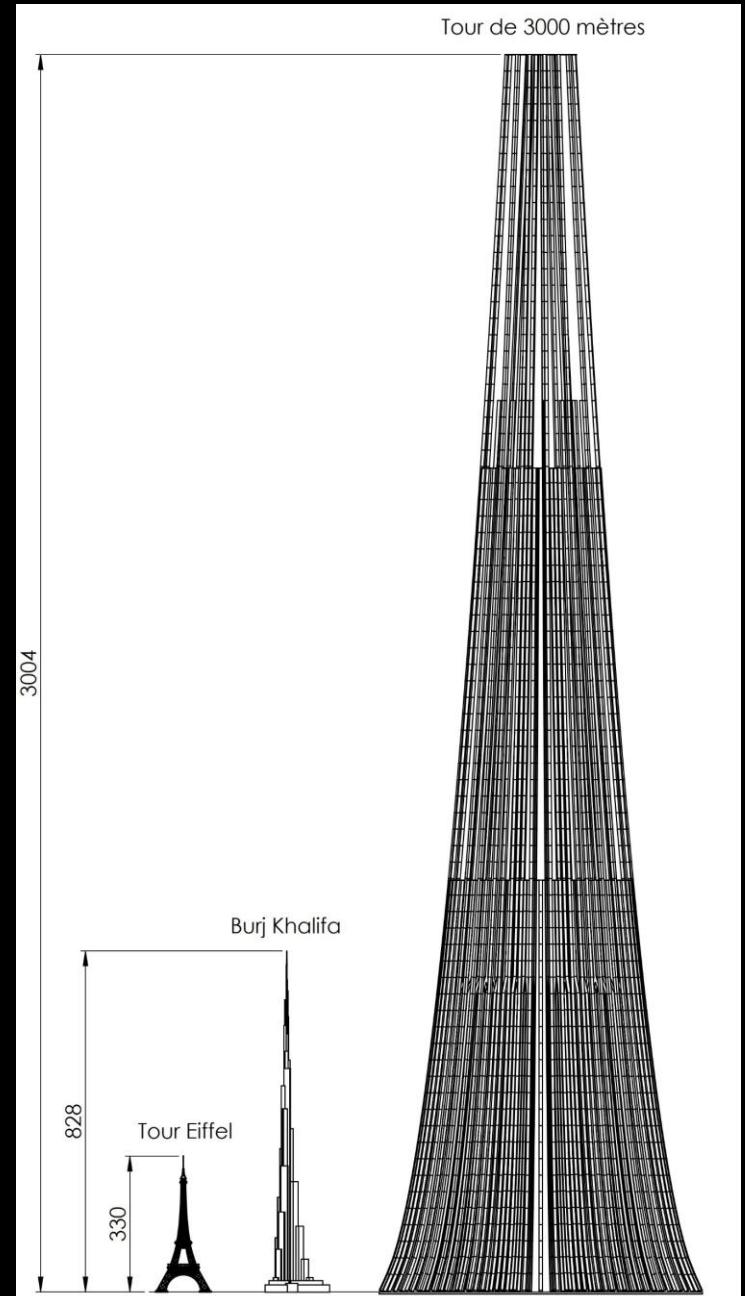


Pourquoi une tour de 3000 mètres n'est pas construite en 2025 ?

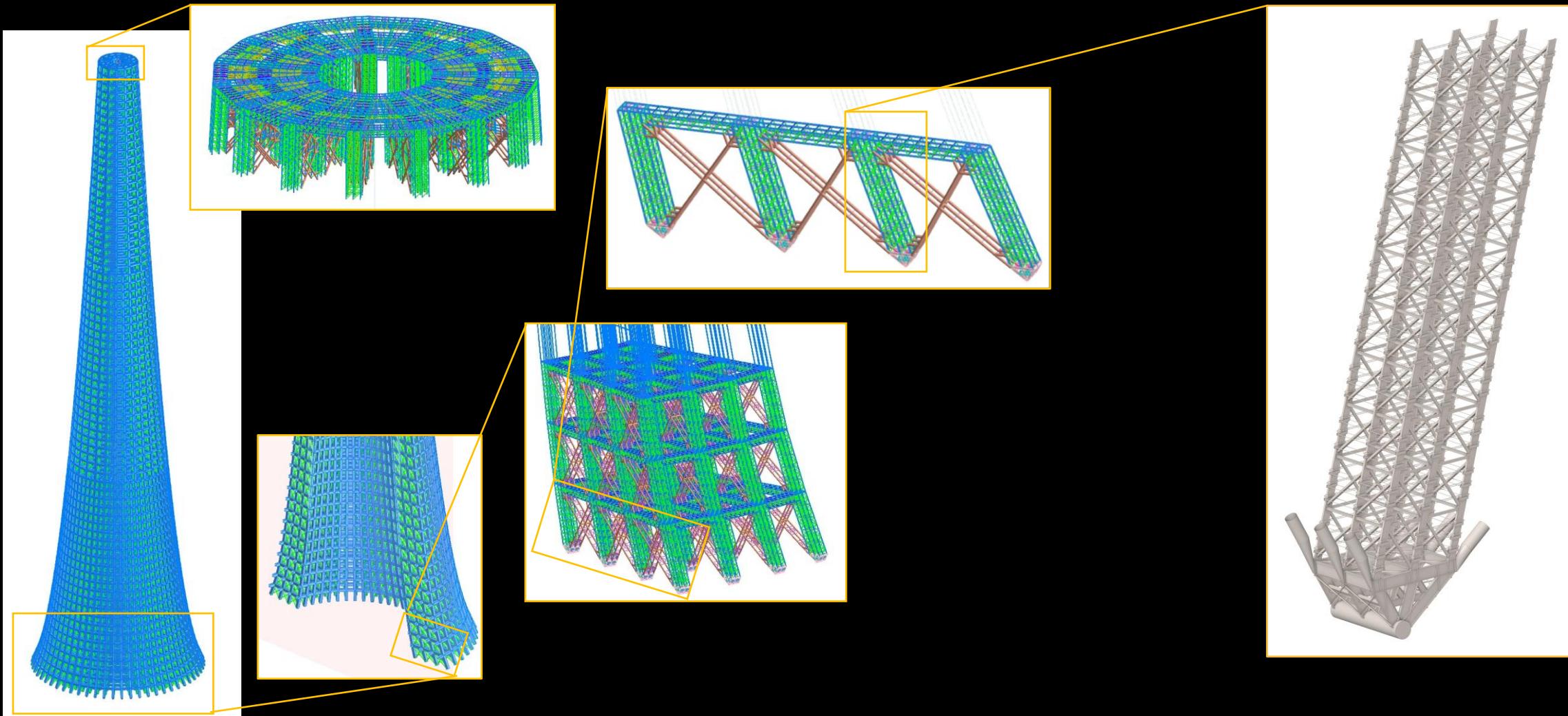
- ▶ Construire une tour de 3000 mètres de hauteur pose de nombreux défis techniques, économiques, environnementaux et logistiques. Voici quelques-unes des principales raisons pour lesquelles une telle structure n'a jamais été construite.
- ▶ Problèmes techniques et ingénierie
 - ▶ **Stabilité structurelle : résistance au vent et aux séismes**
 - ▶ Charges de compression sur les poteaux du rez-de-chaussée et risque de flambement
 - ▶ Matériaux
 - ▶ Ascenseurs
- ▶ Coût
- ▶ Problèmes environnementaux
- ▶ Logistique et accessibilité
- ▶ Limites humaines et confort

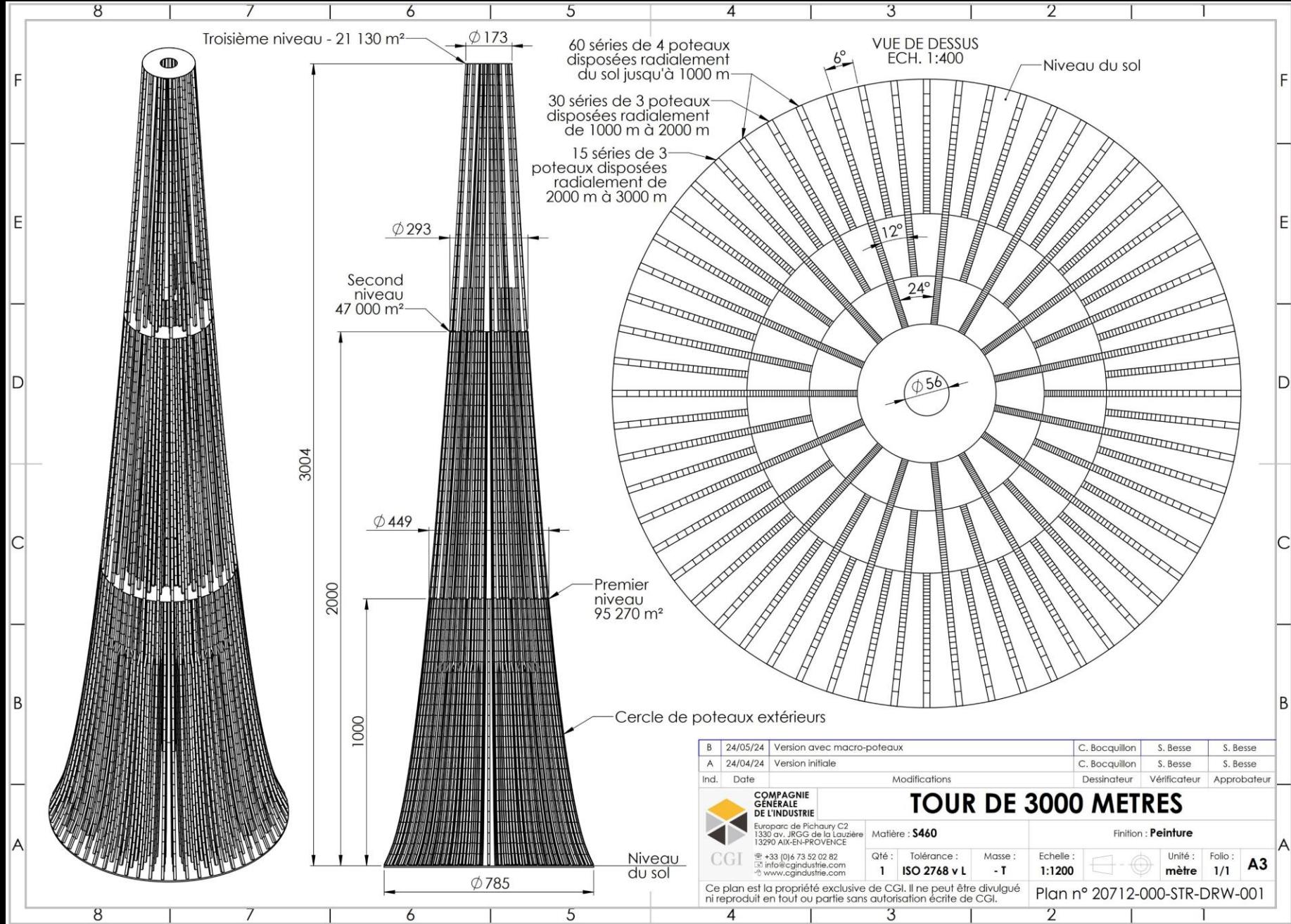
La tour de 3000 mètres

- ▶ Hauteur : 3000 mètres
- ▶ Fonction : centre commercial (70%) + tourisme (30%)
- ▶ Planchers : 4 (RDC, 1000, 2000, 3000 mètres)
- ▶ Structure en dentelle pour réduire les charges de vent
- ▶ Poids : ~ 750 000 tons (hors fondations)
- ▶ Matériaux : acier au carbone S460
- ▶ Utilité sociale :
 - ▶ Centre d'observation des incendies
 - ▶ Observatoire astronomique à 3000 mètres
 - ▶ Zone de rassemblement de la population en cas d'inondation
 - ▶ Fermes agricoles
 - ▶ Zone de base jump
 - ▶ Plancher en verre



Géométrie

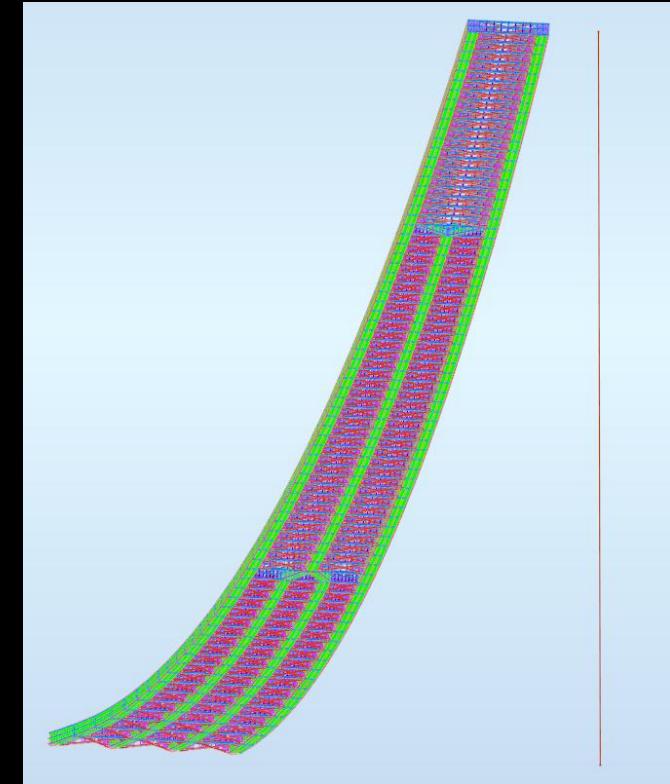
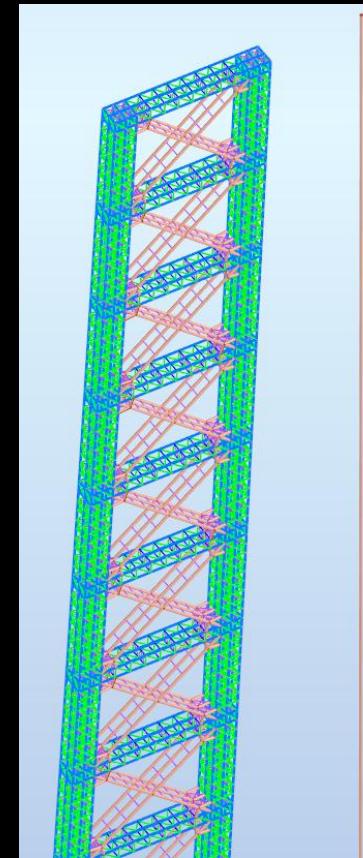
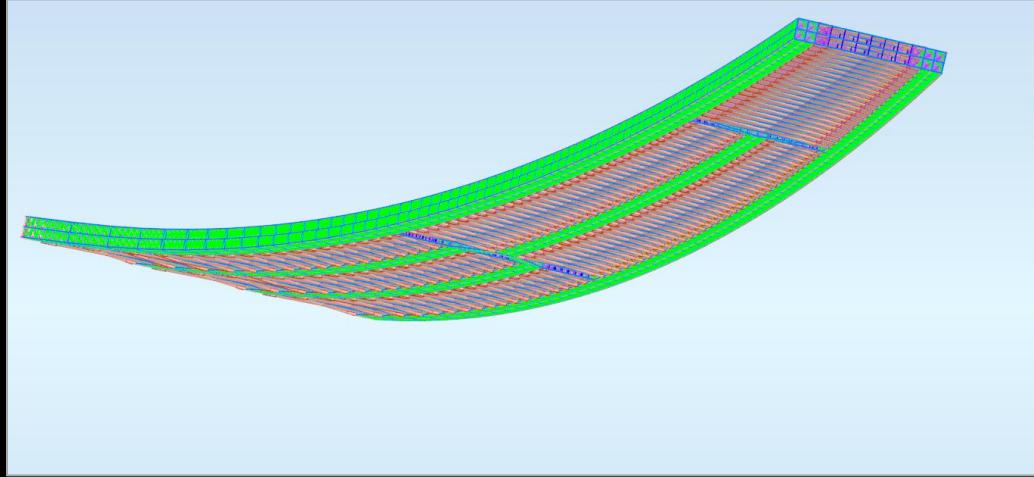
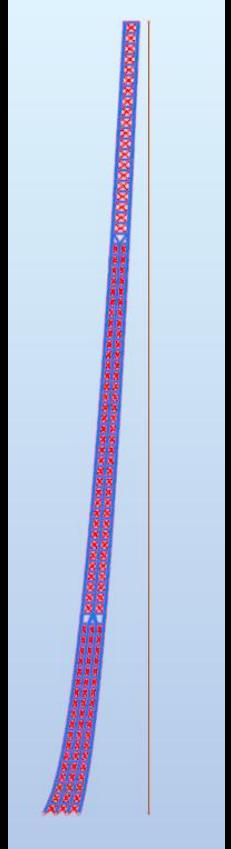




Vues 3D (0° , de $z = 0$ à 3000 m)

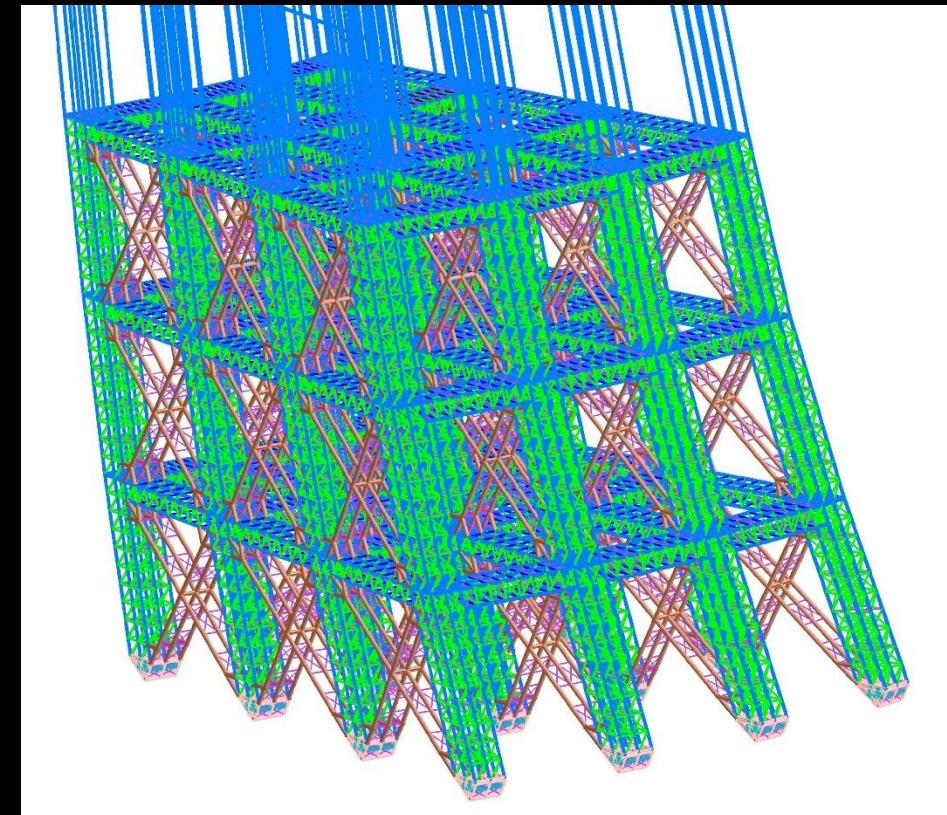
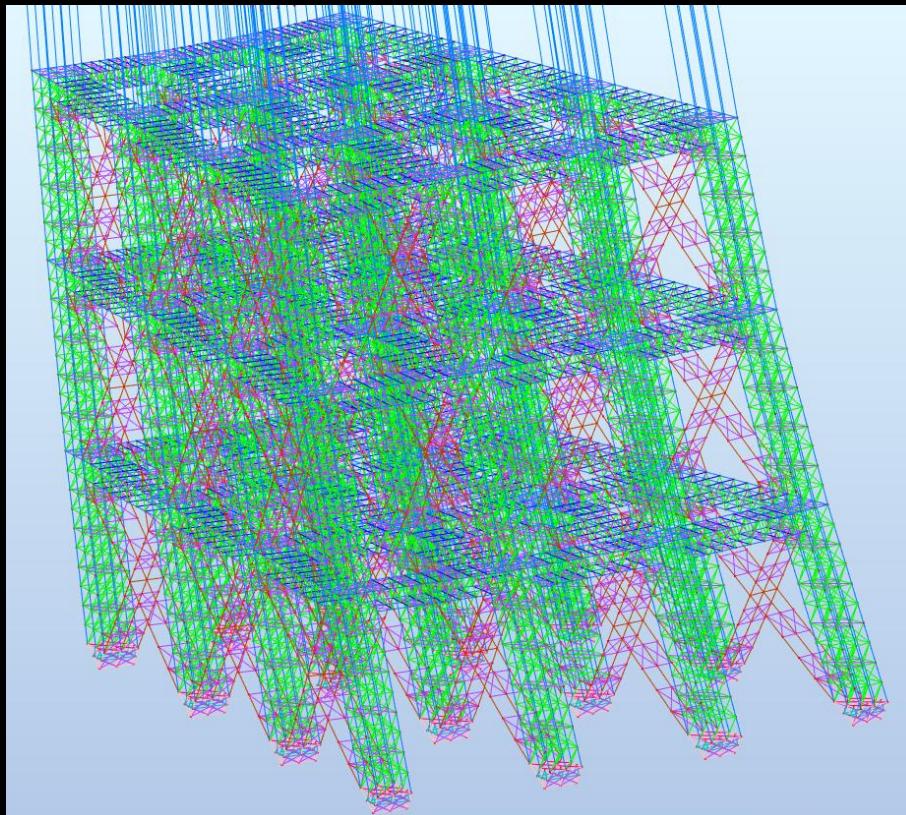
75 niveaux de 40 mètres

- 115 000 éléments poutres / 34 000 noeuds



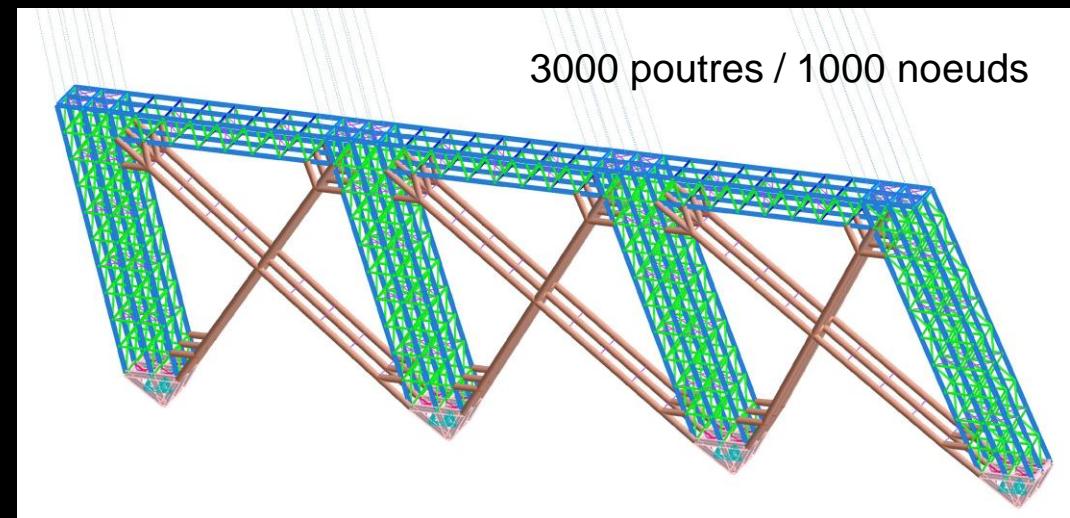
Vue 3D (de 0 à 18°, de z = 0 à 120 m)

- 26 000 éléments poutres / 12 000 noeuds



Logiciels et ressources informatiques

- ▶ Plus de 30 millions de poutres
- ▶ Impossibilité de faire un modèle 3D réaliste sur un ordinateur en 2025 même en éléments poutres
- ▶ Calculs réalisés avec Robot Structural Analysis et ANSYS Mechanical (4CAD)
- ▶ Modélisation du premier tronçon de 40 mètres
- ▶ Code de calculs : Eurocodes 0, 1, 3, 8
- ▶ Méthode des éléments finis avec ANSYS Mechanical
- ▶ Résolution de millions of degrés of liberté en secondes
- ▶ Devrait être avec la théorie élastique linéaire et un matériau linéaire
- ▶ Symétrie cylindrique
- ▶ Longueur de flambement : 1 mètre

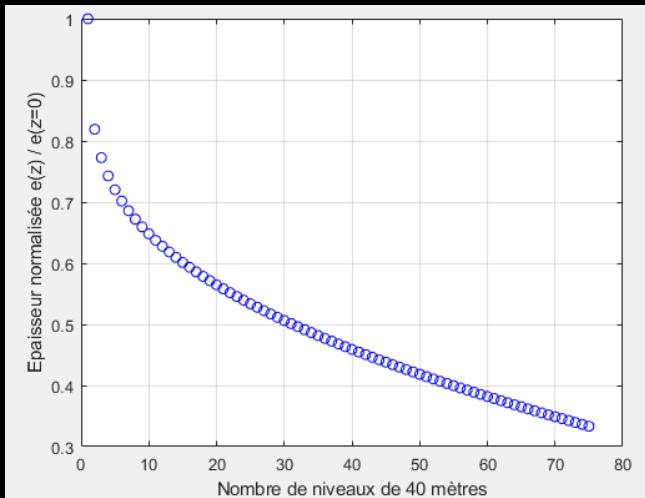


Méthode de calcul global

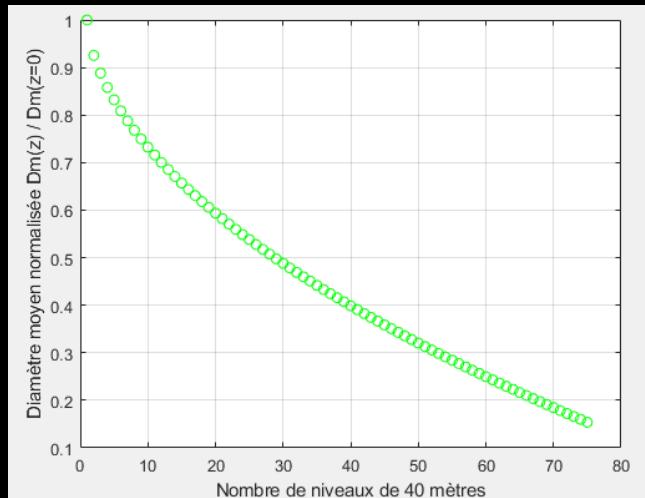
- Poids total

$$P_{tot} = \alpha P_1 = P_1 \sum_{i=1}^N \prod_{k=0}^{i-1} (1 - t_k)^k$$

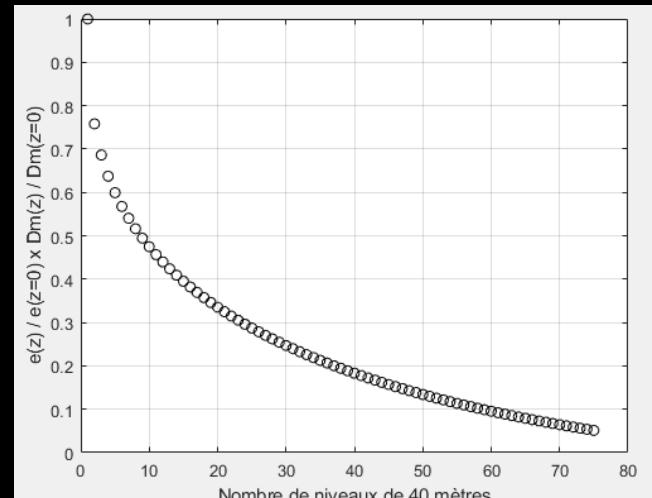
$$t_k = \frac{e(z)}{e(z=0)} \times \frac{D_m(z)}{D_m(z=0)}$$



X



=



Facteur α

N nombre de niveau de 40 mètres ($N = 75$)

P_1 poids du premier niveau ($z = 0$ à 40 mètres)

t_k taux de réduction du niveau $k - 1$ au niveau k

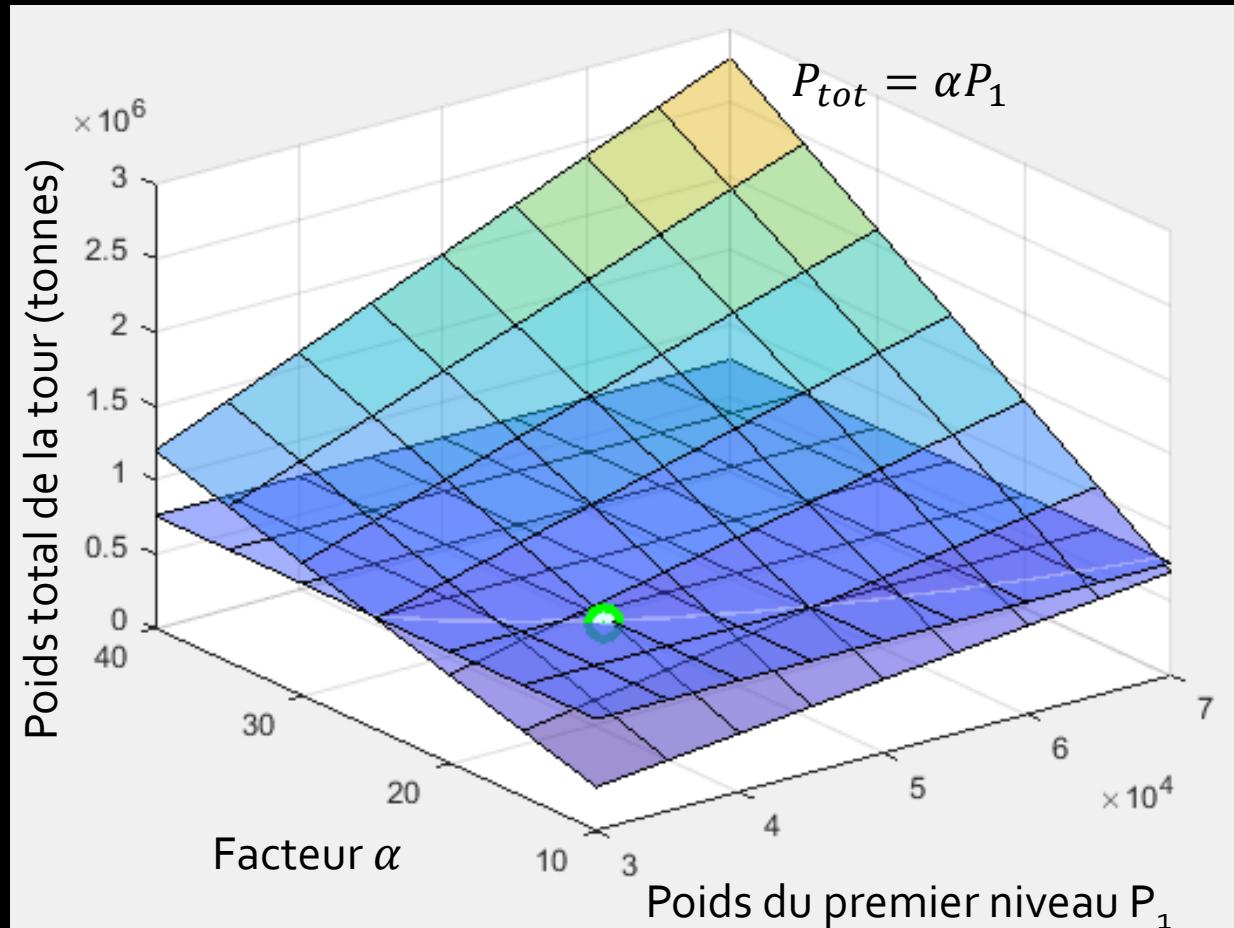
$e(z)$ épaisseur apparente de la tour suivant z

$D_m(z)$ diamètre moyen de la tour suivant z

$$P_{tot} < P_1 + 60 \times 4 \times 3000 \text{ tonnes}$$

► Surface de poids total

$$P_{tot} < 39\ 612 \text{ tonnes} + 60 \times 4 \times 3000 \text{ tonnes} = 759\ 612 \text{ tonnes}$$



$$(P_1, \alpha, P_{tot}) =$$

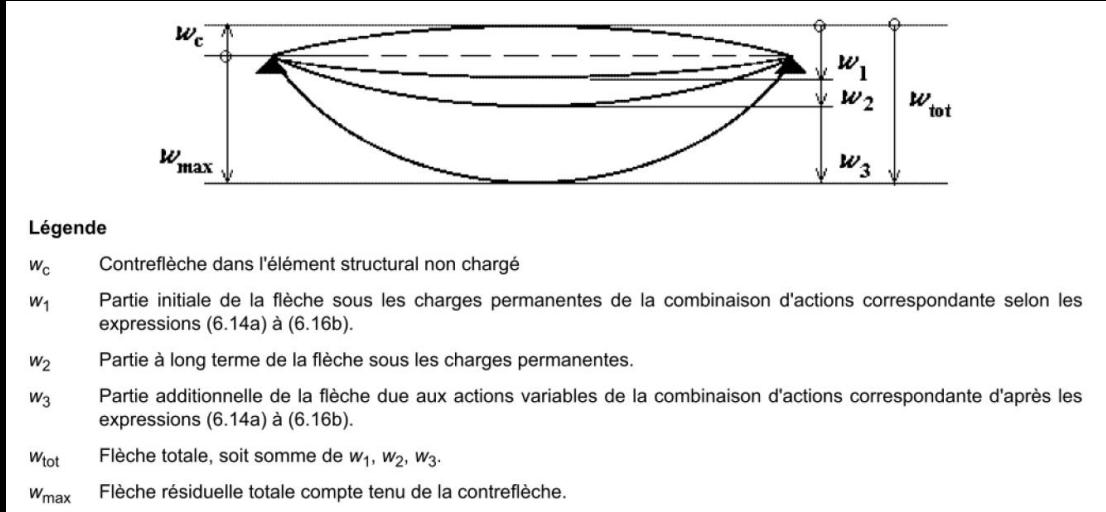
$$(39\ 612 \text{ tonnes}, 18.866, 747\ 320 \text{ tonnes})$$

Etat Limite Ultime (ELU)

- Acier S460
- Taux de travail maximal : 99 %
- Contrainte maximale : 454 MPa
(< 460 MPa)

Pièce	Profil	Matériau	Lay	Laz	Ratio▲	Cas
479	IPE 600	S 460 M	2.06	10.73	0.99	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
529	IPE 600	S 460 M	2.06	10.73	0.99	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
321	IPE 600	S 460 M	2.06	10.73	0.98	110 ACC:SEV4=1*1.00 + 2*0.30 + 8*-1.00
519	IPE 600	S 460 M	2.06	10.73	0.97	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
550	IPE 600	S 460 M	2.06	10.73	0.95	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
410	IPE 600	S 460 M	2.06	10.73	0.95	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
509	IPE 600	S 460 M	2.06	10.73	0.93	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
311	IPE 600	S 460 M	2.06	10.73	0.93	110 ACC:SEV4=1*1.00 + 2*0.30 + 8*-1.00
272	IPE 600	S 460 M	2.06	10.73	0.92	47 ELU/21=1*1.35 + 2*1.05 + 5*1.50
301	IPE 600	S 460 M	2.06	10.73	0.91	110 ACC:SEV4=1*1.00 + 2*0.30 + 8*-1.00
551	IPE 600	S 460 M	2.06	10.73	0.90	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
282	IPE 600	S 460 M	2.06	10.73	0.90	47 ELU/21=1*1.35 + 2*1.05 + 5*1.50
400	IPE 600	S 460 M	2.06	10.73	0.89	110 ACC:SEV4=1*1.00 + 2*0.30 + 8*-1.00
262	IPE 600	S 460 M	2.06	10.73	0.89	47 ELU/21=1*1.35 + 2*1.05 + 5*1.50
390	IPE 600	S 460 M	2.06	10.73	0.88	110 ACC:SEV4=1*1.00 + 2*0.30 + 8*-1.00
548	IPE 600	S 460 M	2.06	10.73	0.87	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
558	IPE 600	S 460 M	2.06	10.73	0.87	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
539	IPE 600	S 460 M	2.06	10.73	0.86	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
461	IPE 600	S 460 M	2.06	10.73	0.84	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
552	IPE 600	S 460 M	2.06	10.73	0.84	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
9	IPE 600	S 460 M	2.06	10.73	0.83	51 ELU/25=1*1.35 + 2*1.05 + 6*1.50
273	IPE 600	S 460 M	2.06	10.73	0.82	110 ACC:SEV4=1*1.00 + 2*0.30 + 8*-1.00
553	IPE 600	S 460 M	2.06	10.73	0.81	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
372	IPE 600	S 460 M	2.06	10.73	0.81	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
263	IPE 600	S 460 M	2.06	10.73	0.80	47 ELU/21=1*1.35 + 2*1.05 + 5*1.50
540	IPE 600	S 460 M	2.06	10.73	0.80	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
520	IPE 600	S 460 M	2.06	10.73	0.79	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
541	IPE 600	S 460 M	2.06	10.73	0.78	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
521	IPE 600	S 460 M	2.06	10.73	0.77	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
274	IPE 600	S 460 M	2.06	10.73	0.77	110 ACC:SEV4=1*1.00 + 2*0.30 + 8*-1.00
554	IPE 600	S 460 M	2.06	10.73	0.76	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
542	IPE 600	S 460 M	2.06	10.73	0.76	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
469	IPE 600	S 460 M	2.06	10.73	0.76	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
522	IPE 600	S 460 M	2.06	10.73	0.76	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
528	IPE 600	S 460 M	2.06	10.73	0.75	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
283	IPE 600	S 460 M	2.06	10.73	0.75	51 ELU/25=1*1.35 + 2*1.05 + 6*1.50
264	IPE 600	S 460 M	2.06	10.73	0.75	110 ACC:SEV4=1*1.00 + 2*0.30 + 8*-1.00
380	IPE 600	S 460 M	2.06	10.73	0.75	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
842 Poutre st	IPE 200	S 460 M	48.43	178.90	0.74	51 ELU/25=1*1.35 + 2*1.05 + 6*1.50
543	IPE 600	S 460 M	2.06	10.73	0.74	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
265	IPE 600	S 460 M	2.06	10.73	0.74	47 ELU/21=1*1.35 + 2*1.05 + 5*1.50
987 Poutre st	IPE 200	S 460 M	48.43	178.90	0.74	47 ELU/21=1*1.35 + 2*1.05 + 5*1.50
518	IPE 600	S 460 M	2.06	10.73	0.74	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
547	IPE 600	S 460 M	2.06	10.73	0.74	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
523	IPE 600	S 460 M	2.06	10.73	0.74	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
557	IPE 600	S 460 M	2.06	10.73	0.74	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50

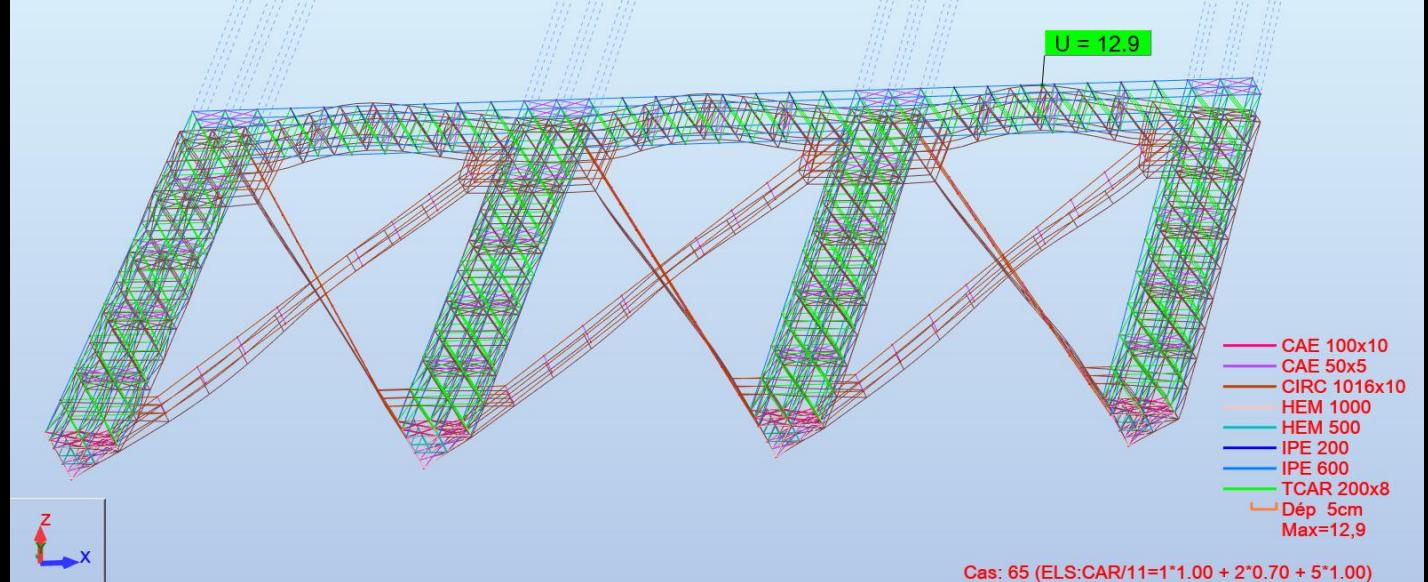
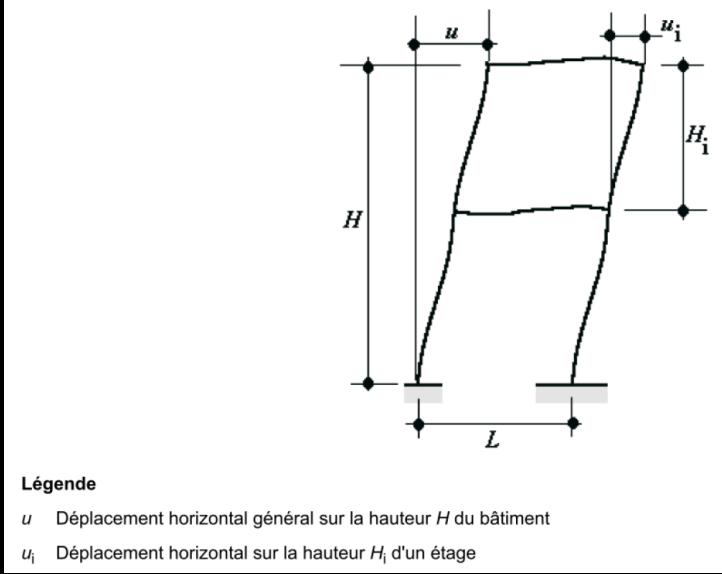
Etat Limite de Service (ELS)



Pièce	Profil	Matériau	Ratio(uy)	Cas (uy)	Ratio(uz)	Cas (uz)
1045	IPE 600	S 460 M	0.31	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.01	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
1024	IPE 600	S 460 M	0.31	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.00	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
1038	IPE 600	S 460 M	0.30	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.01	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
865	IPE 600	S 460 M	0.30	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.01	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
899	IPE 600	S 460 M	0.29	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.01	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
885	IPE 600	S 460 M	0.29	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.01	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
757	IPE 600	S 460 M	0.28	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00	0.00	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
741	IPE 600	S 460 M	0.28	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00	0.01	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
1050	IPE 600	S 460 M	0.28	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.01	61 ELS:CAR/7=1*1.00 + 2*0.70 + 3*1.00
1029	IPE 600	S 460 M	0.27	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.01	61 ELS:CAR/7=1*1.00 + 2*0.70 + 3*1.00
749	IPE 600	S 460 M	0.27	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00	0.01	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
1043	IPE 600	S 460 M	0.27	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.01	61 ELS:CAR/7=1*1.00 + 2*0.70 + 3*1.00
870	IPE 600	S 460 M	0.26	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.01	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
904	IPE 600	S 460 M	0.26	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.02	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
890	IPE 600	S 460 M	0.26	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.02	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
746	IPE 600	S 460 M	0.25	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.02	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
762	IPE 600	S 460 M	0.25	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00	0.01	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00
1033	IPE 600	S 460 M	0.25	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00	0.00	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
999	IPE 600	S 460 M	0.25	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00	0.00	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00
12047 Poutre stab IPE200_12047	IPE 200	S 460 M	0.25	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00	0.04	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00
12046 Poutre stab IPE200_12046	IPE 200	S 460 M	0.25	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00	0.05	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00

Etat Limite de Service (ELS)

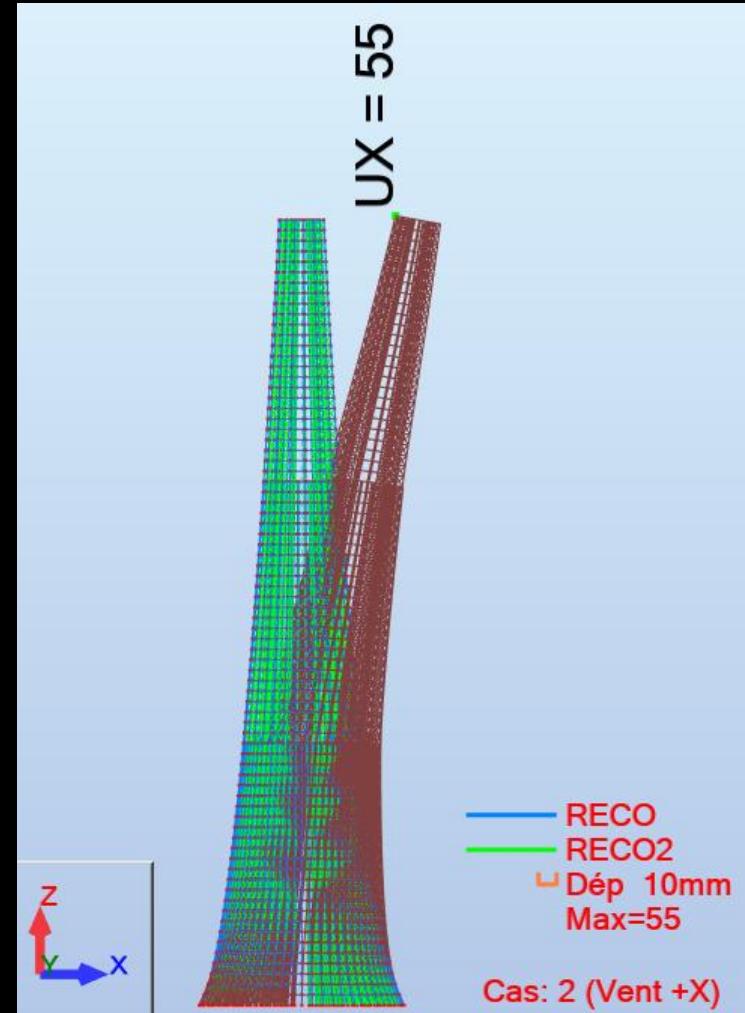
130 mm



Pièce	Profil	Matériau	Ratio(vx)	Cas (vx)	Ratio(vy)▲	Cas (vy)
267	IPE 600	S 460 M	0.07	61 ELS:CAR/7=1*1.00 + 2*0.70 + 3*1.00	0.18	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
232	IPE 600	S 460 M	0.11	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00	0.17	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
282	IPE 600	S 460 M	0.14	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00	0.17	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
272	IPE 600	S 460 M	0.14	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00	0.17	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
209	IPE 600	S 460 M	0.05	61 ELS:CAR/7=1*1.00 + 2*0.70 + 3*1.00	0.16	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
219	IPE 600	S 460 M	0.06	61 ELS:CAR/7=1*1.00 + 2*0.70 + 3*1.00	0.16	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
273	IPE 600	S 460 M	0.11	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00	0.16	67 ELS:CAR/13=1*1.00 + 2*0.70 + 6*1.00
277	IPE 600	S 460 M	0.07	61 ELS:CAR/7=1*1.00 + 2*0.70 + 3*1.00	0.15	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
242	IPE 600	S 460 M	0.11	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00	0.15	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
229	IPE 600	S 460 M	0.07	61 ELS:CAR/7=1*1.00 + 2*0.70 + 3*1.00	0.15	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
222	IPE 600	S 460 M	0.09	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00	0.15	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
234	IPE 600	S 460 M	0.09	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00	0.15	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
212	IPE 600	S 460 M	0.10	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00	0.14	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00

Déflexion horizontale due au vent à $z = 3000$ m

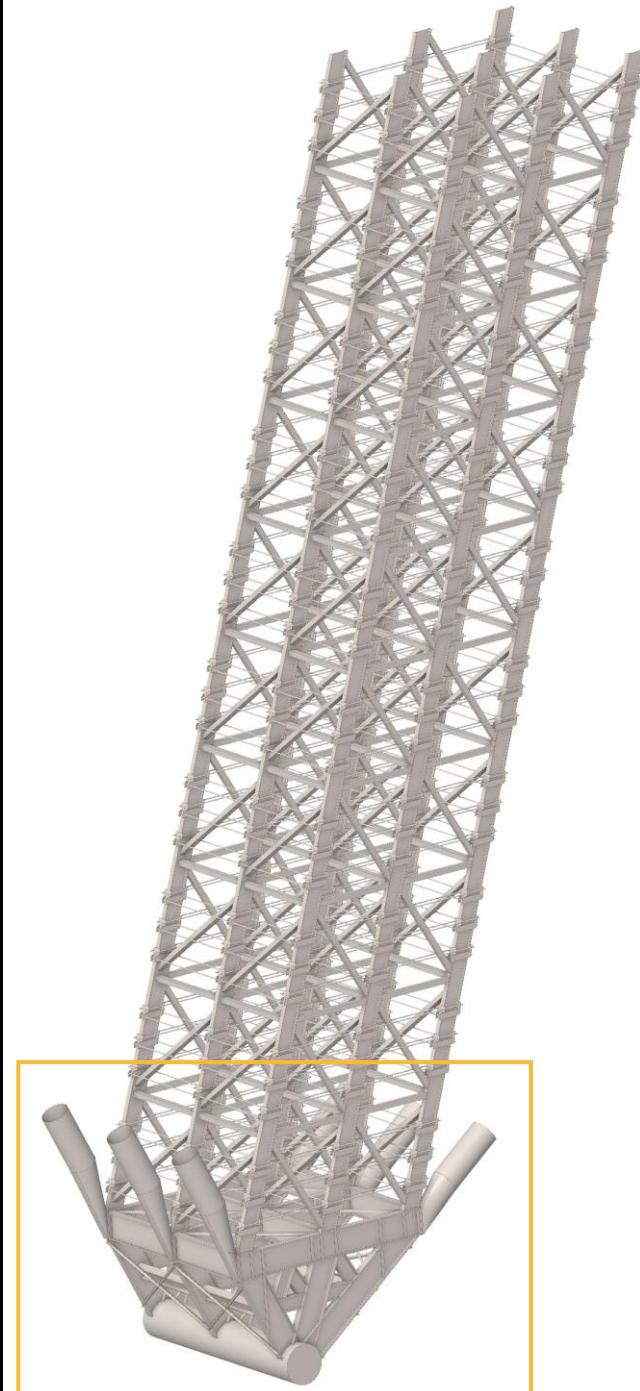
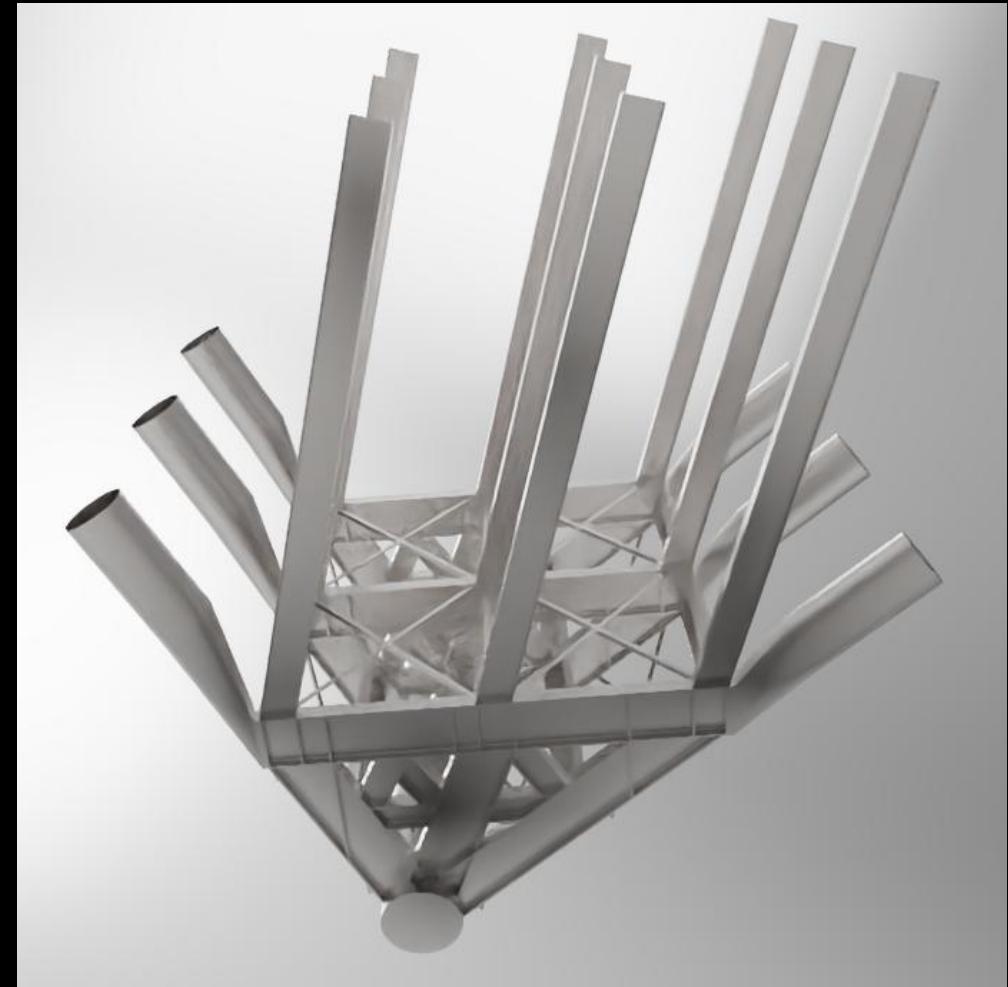
- Déflexion due au vent, basé sur 300 daN/m^2
- Pour la Tour Eiffel, Eurocode : $H / 150$
 - $H / 150 = 300\ 000 \text{ mm} / 150 = 2 \text{ mètres}$
 - Experimental : max 130 mm (tempête, 1999)
 - La tour Eiffel respecte un critère $H / 2300$
- La Tour de 3000 m respecte un critère $H / 54\ 000$



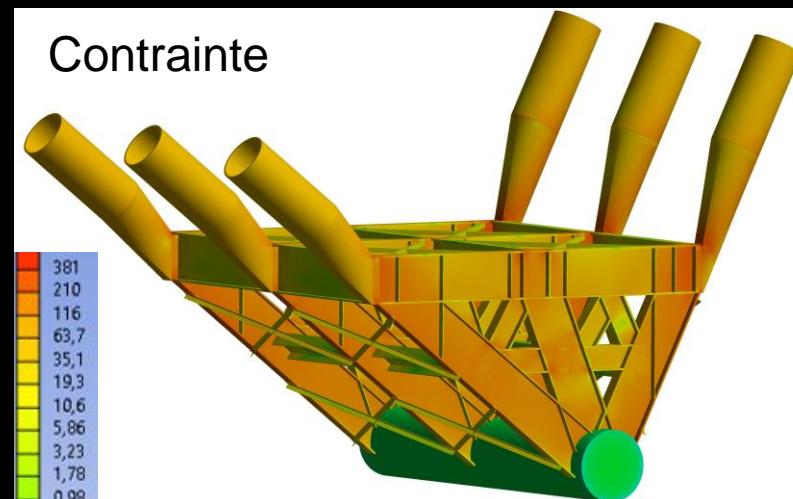
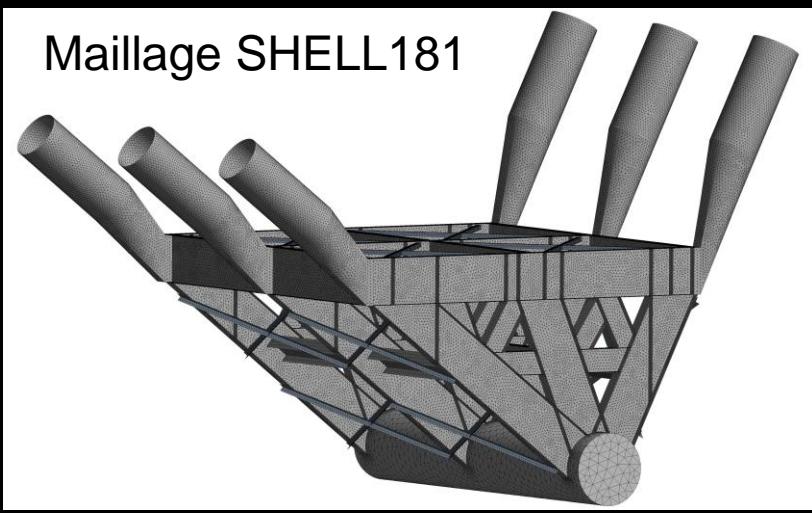
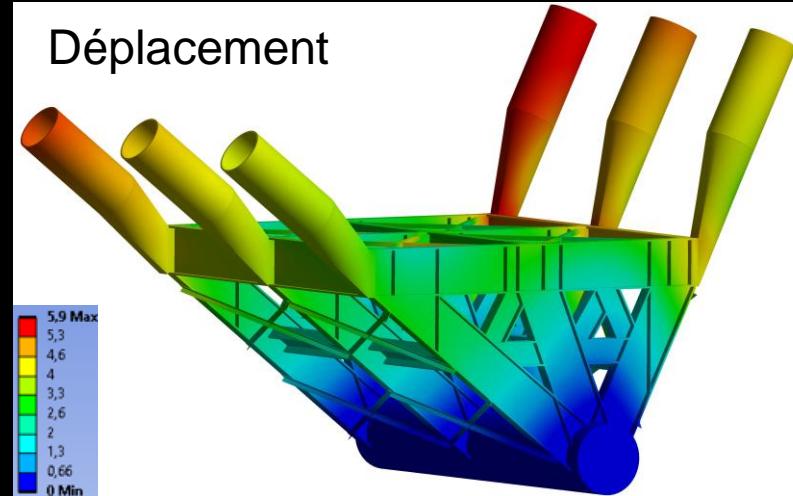
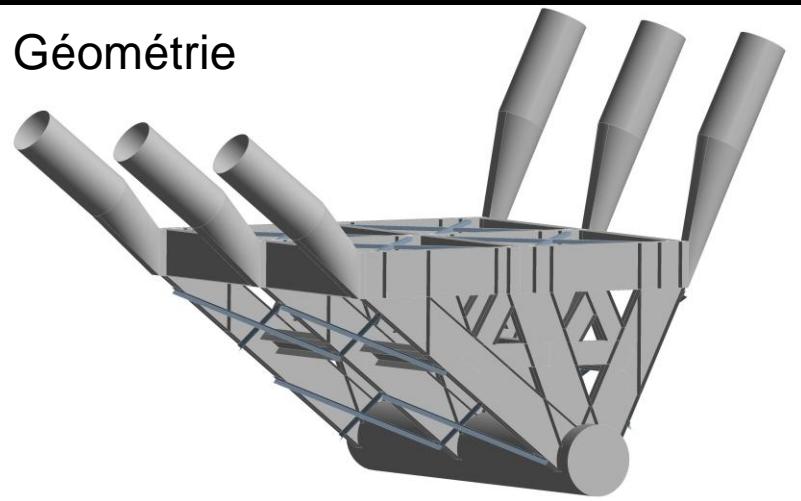
Supports articulés en pieds de poteaux (160 tonnes x 240 supports)

- IPE 600
- HEM 1000
- HEM 500
- CAE 100x10
- BAR 1500
- DN1000
- acier S460

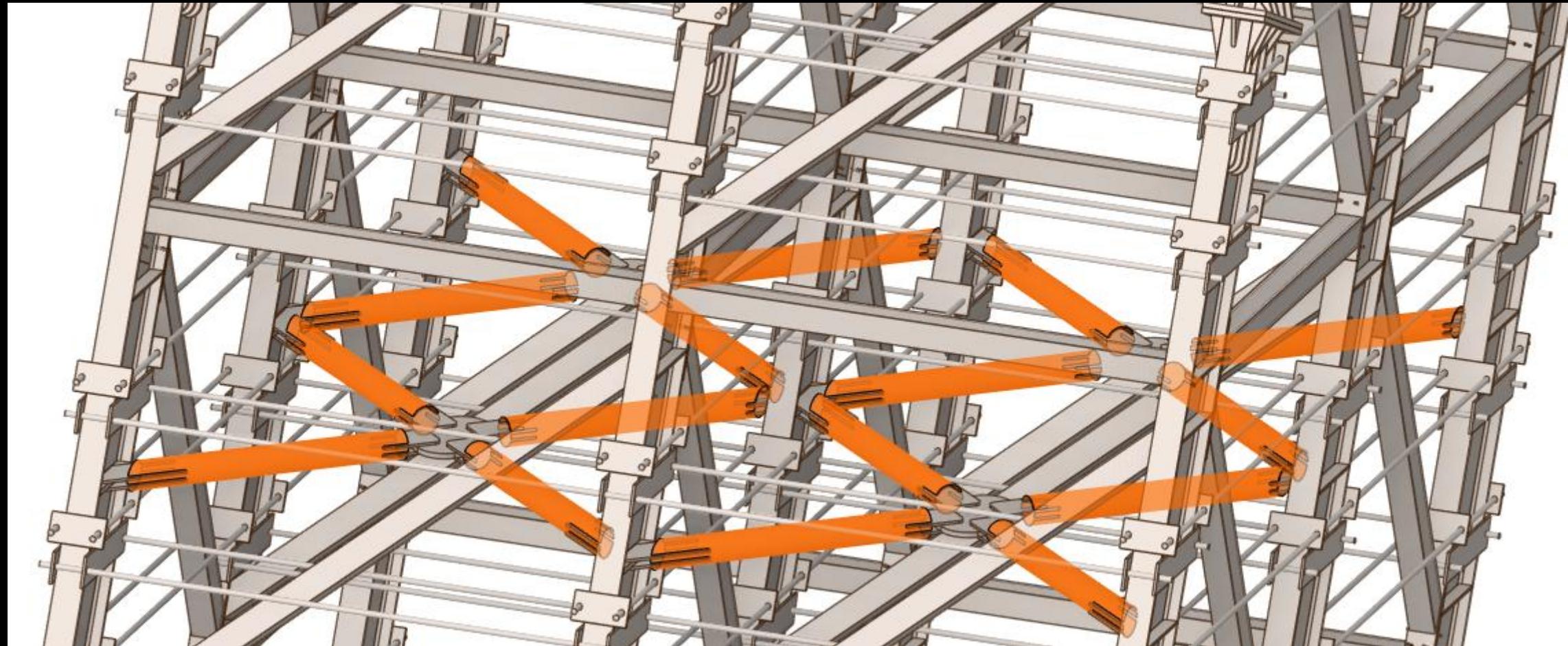
(tonnage de tous les supports
≈ 6500 éléphants)



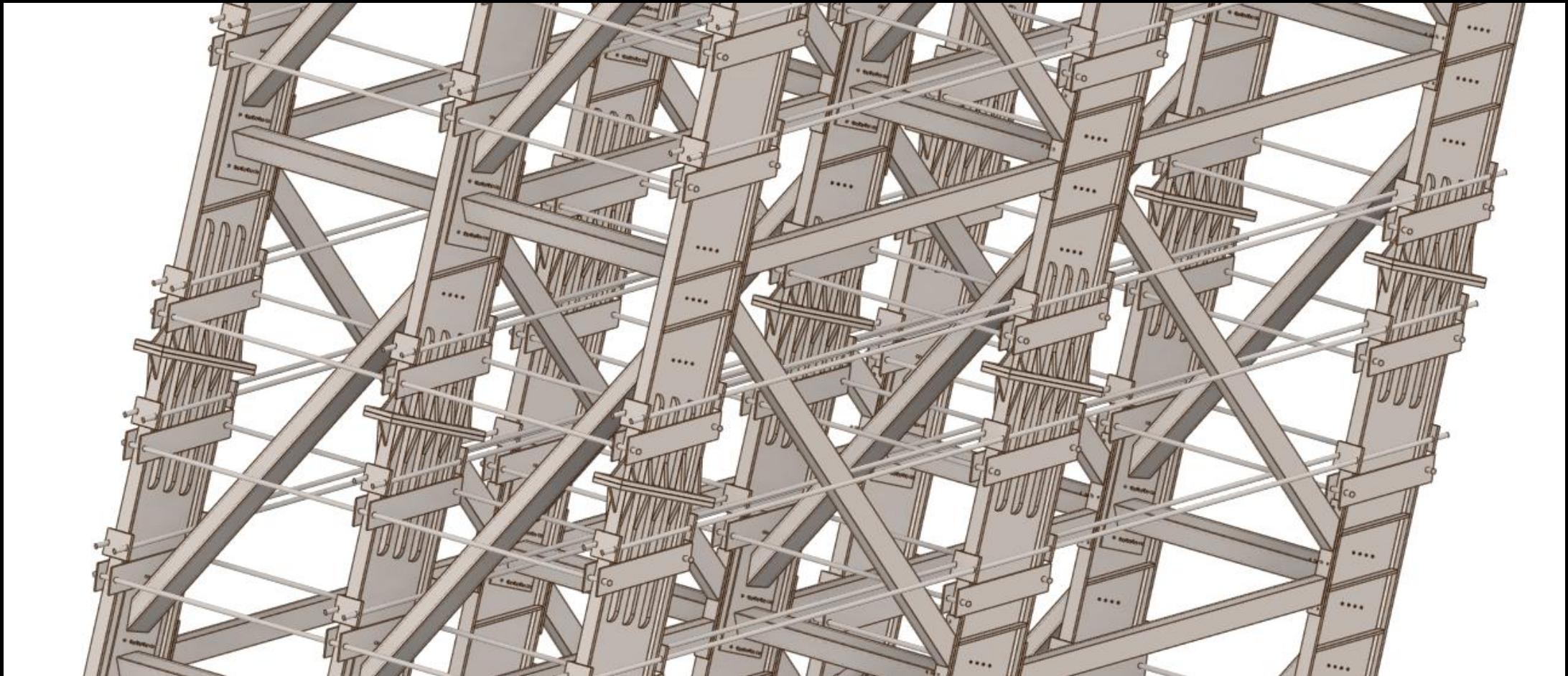
Calculs mécaniques des articulations



Croix de stabilité dans le macro-poteau



Détails des assemblages des 9 poteaux IPE600



Analyse modale et méthode du spectre de réponse (RSM)

- Méthode du mode de superposition
- 15 modes
- Combinaison de la réponse modale avec la méthode Complete Quadratic Combination (CQC)

$$R = \sqrt{\sum_{i=1}^N \sum_{j=1}^N \left(R_i R_j \frac{(\omega_i + \omega_j)^2 \xi^2}{(\omega_i - \omega_j)^2 + (\omega_i - \omega_j)^2 \xi^2} \right)} \quad \xi \text{ ratio d'amortissement constant}$$

- Correction de la masse manquante : force due à la masse manquante

$$F = M \left\{ \{1\} - \sum_{i=1}^m \Gamma_i \{\phi_i\} \right\} S_{A \max}$$

M masse totale

S_{A max} accélération spectrale maximale à la fréquence de coupure

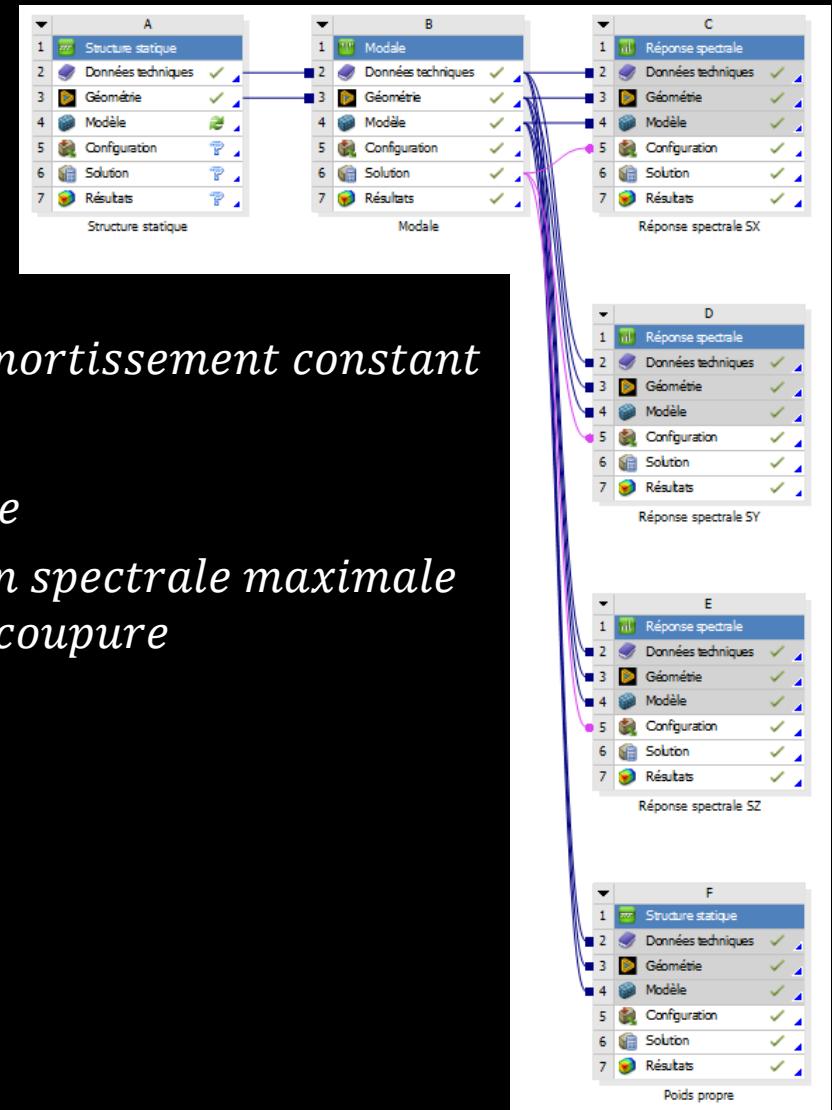
- Combinaison spatiale (réponse dynamique triaxiale)

- La réponse maximale due au séisme sera la plus grande parmi les trois suivants :

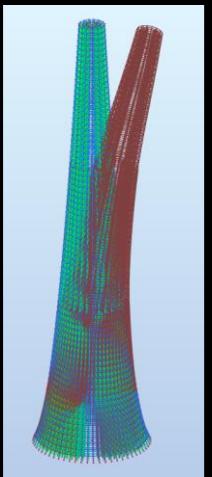
$$R = \pm R_x \pm 0.4R_y \pm 0.4R_z$$

$$R = \pm R_y \pm 0.4R_z \pm 0.4R_x$$

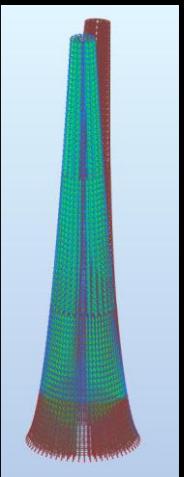
$$R = \pm R_z \pm 0.4R_x \pm 0.4R_y$$



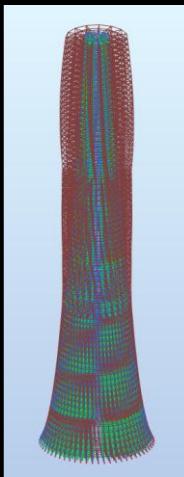
Analyse modale : résultats préliminaires



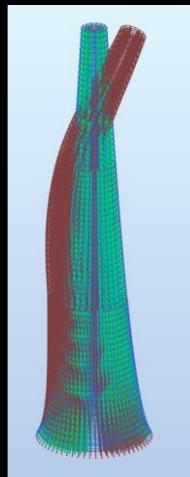
N°1 : 0.05 Hz



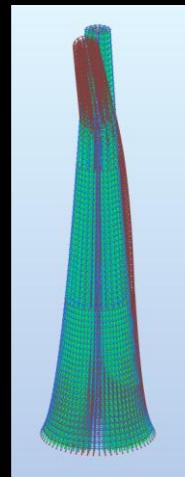
N°2 : 0.05 Hz



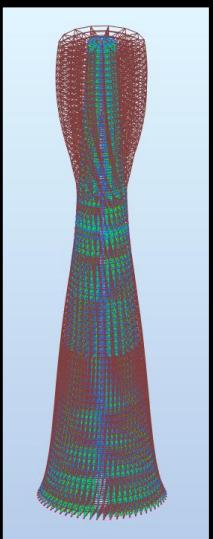
N°3 : 0.11 Hz



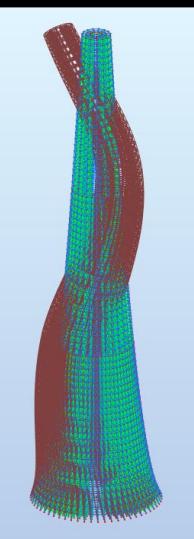
N°4 : 0.11 Hz



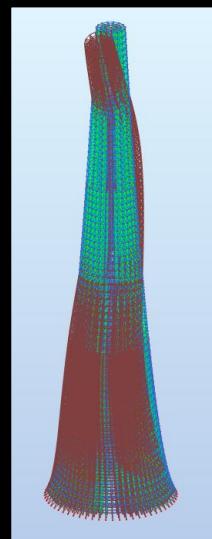
N°5 : 0.11 Hz



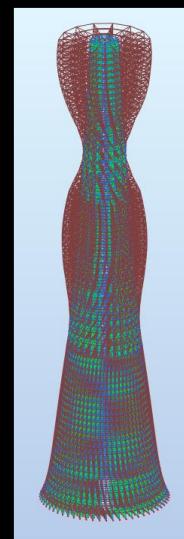
N°6 : 0.17 Hz



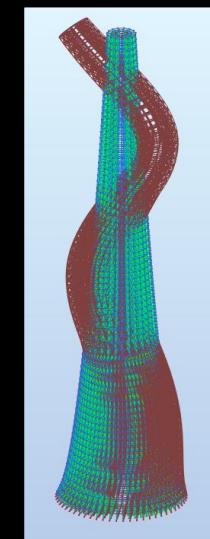
N°7 : 0.18 Hz



N°8 : 0.18 Hz



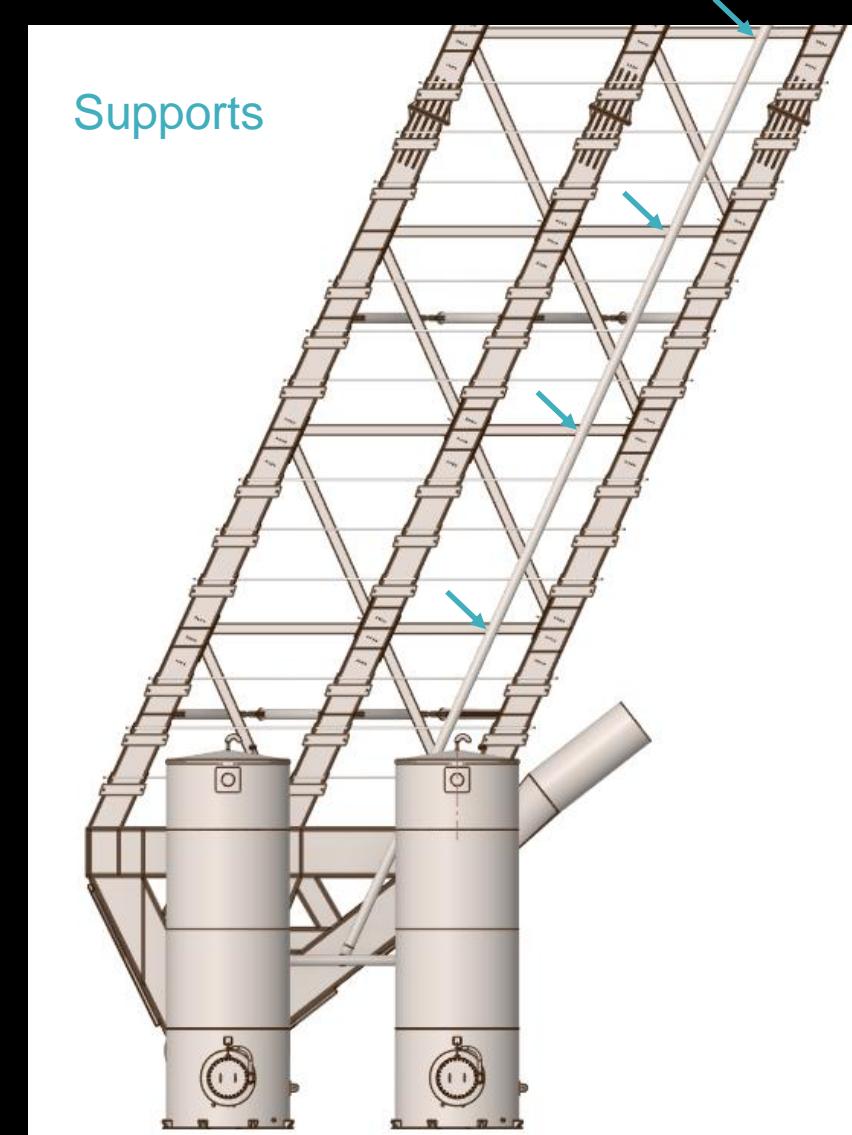
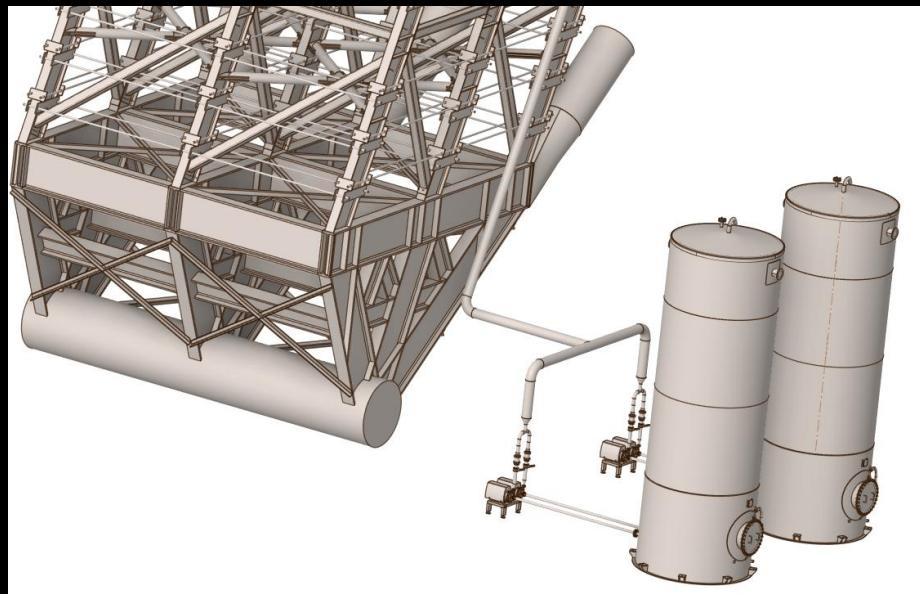
N°9 : 0.24 Hz



N°10 : 0.28 Hz

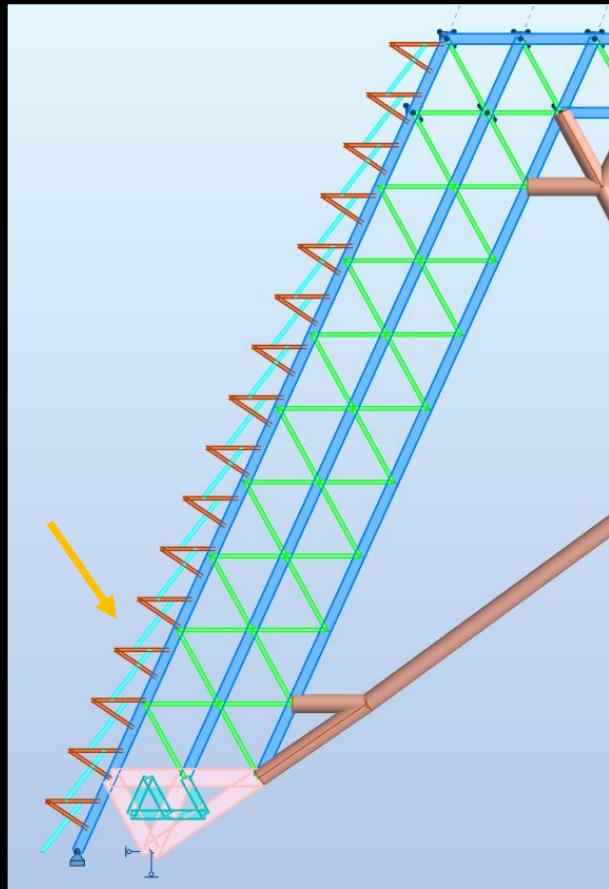
Réservoirs, tuyauteries sous pression et pompes

- 1 bar tous les 10 mètres d'altitude (eau) (hors pertes de charge)
- Pompes de relevage tous les 40 mètres
- Supports sur les traverses tous les 4 m
- Réservoirs suivant CODRES Div.1 2023
- Tuyauteries suivant CODETI Div.1 2023

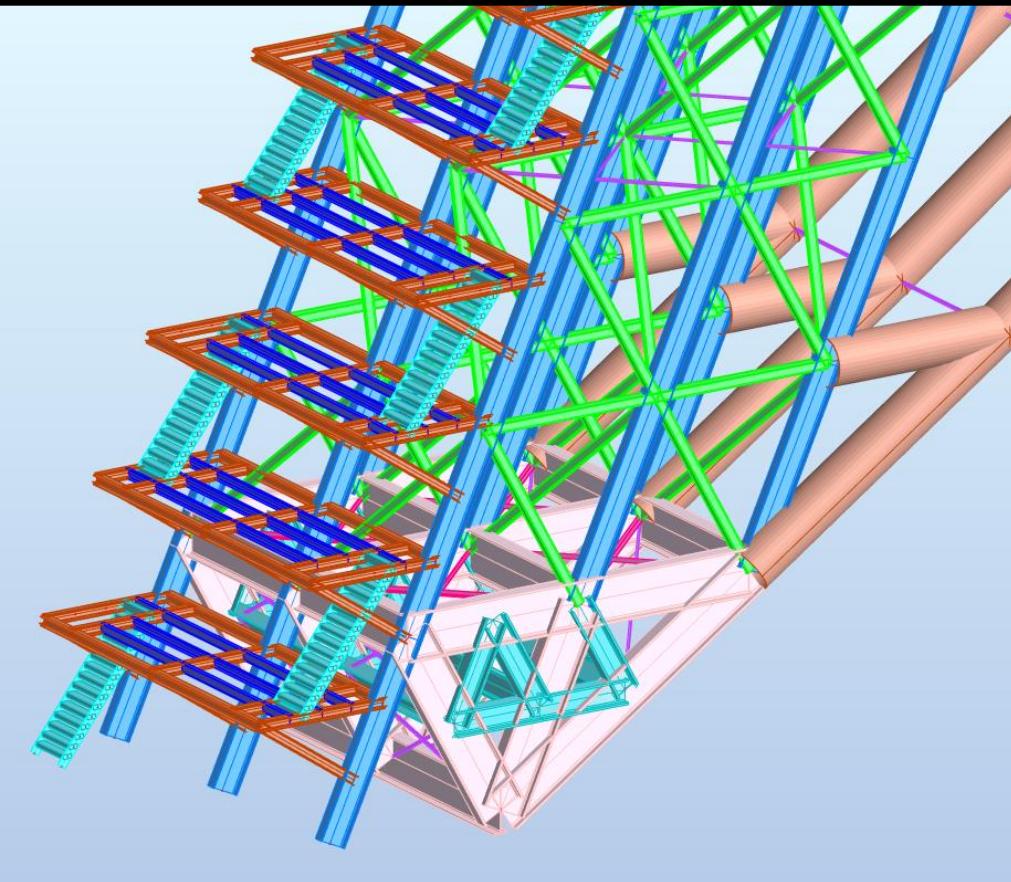


Escaliers et passerelles d'accès

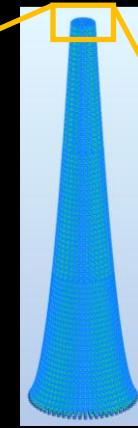
Vue de côté



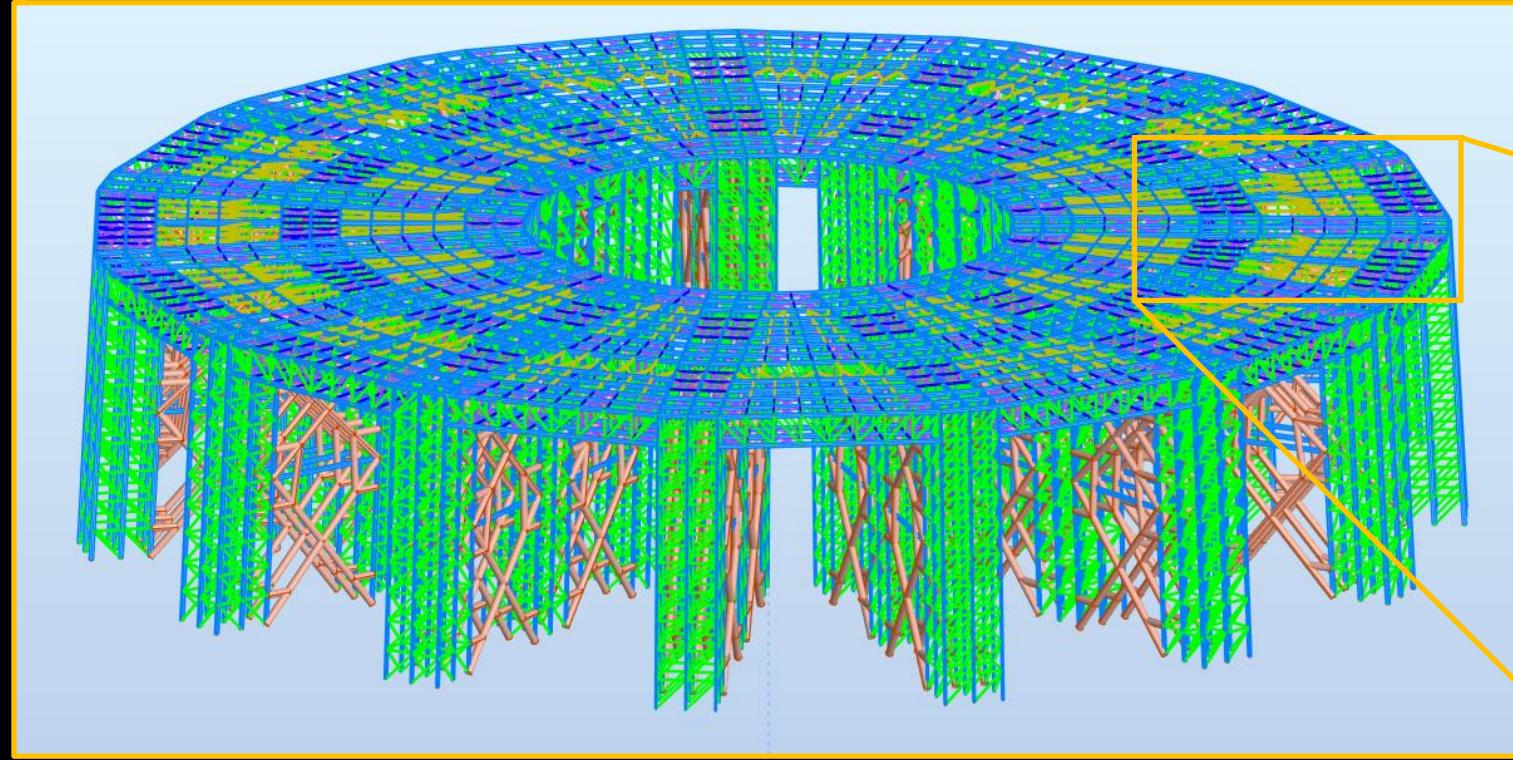
Vue en perspective



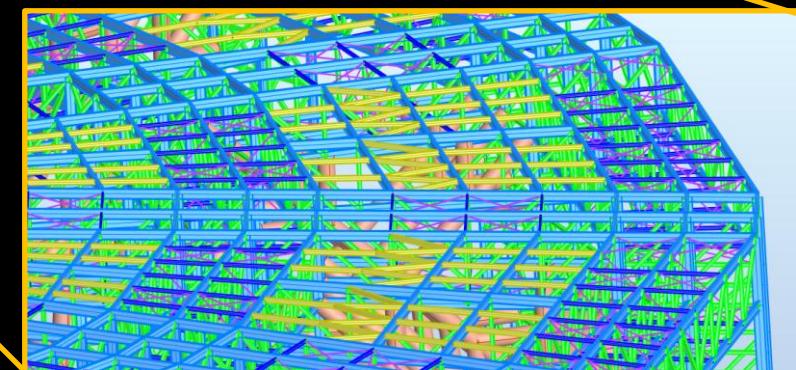
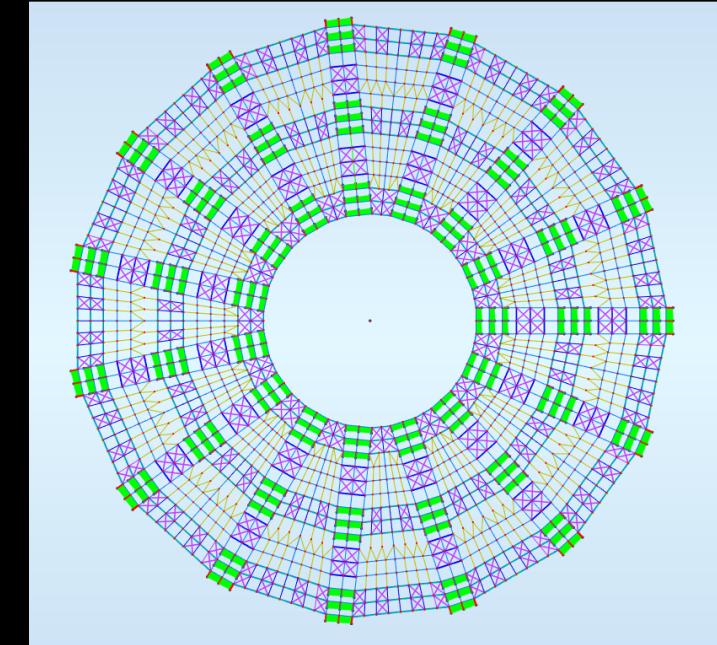
Plancher z = +3000 m
(10 300 tonnes)



Vue en perspective (23 000 éléments poutres, 8 000 noeuds)

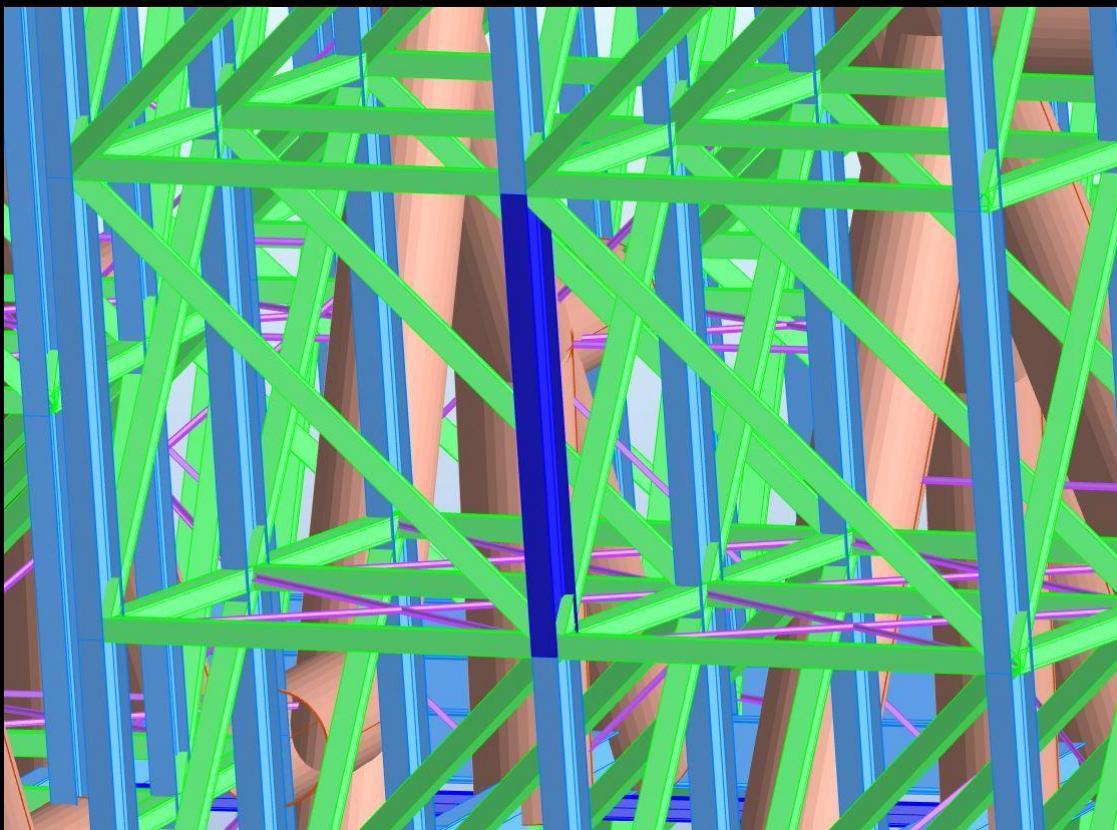


Vue aérienne

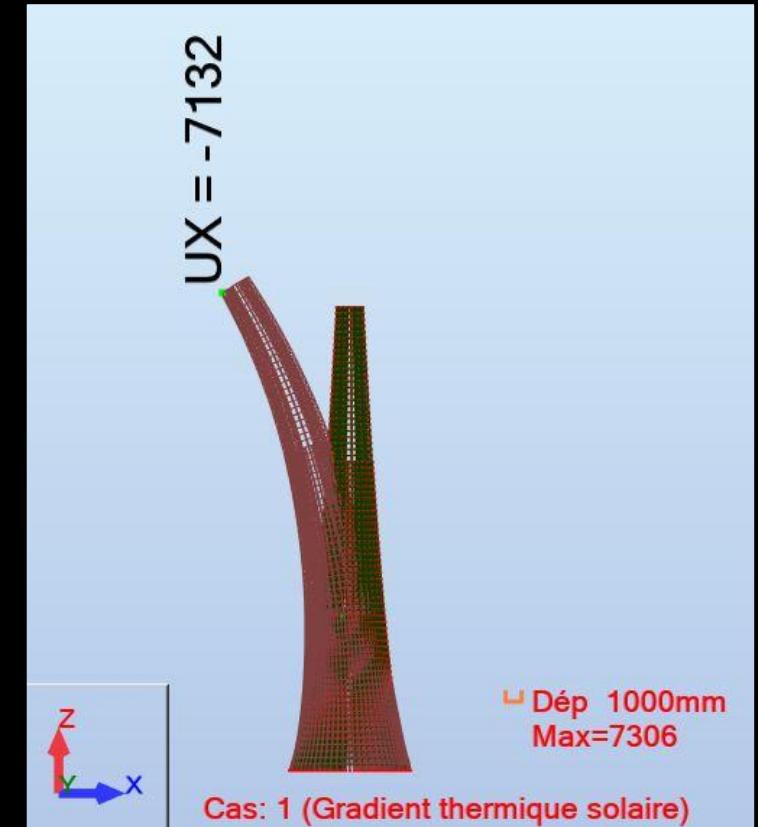


Gradient thermique causé par le soleil, négligeable

- L'ombrage par les poutres limite significativement le gradient thermique causé par le soleil



25°C/60°C gradient thermique
(ne se produit jamais)



Je vous laisserai avec cette question

- Comment cette structure peut-elle être intégrée aux besoins socio-écologiques et à la durabilité du futur ?



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