THE 3000 METER TOWER

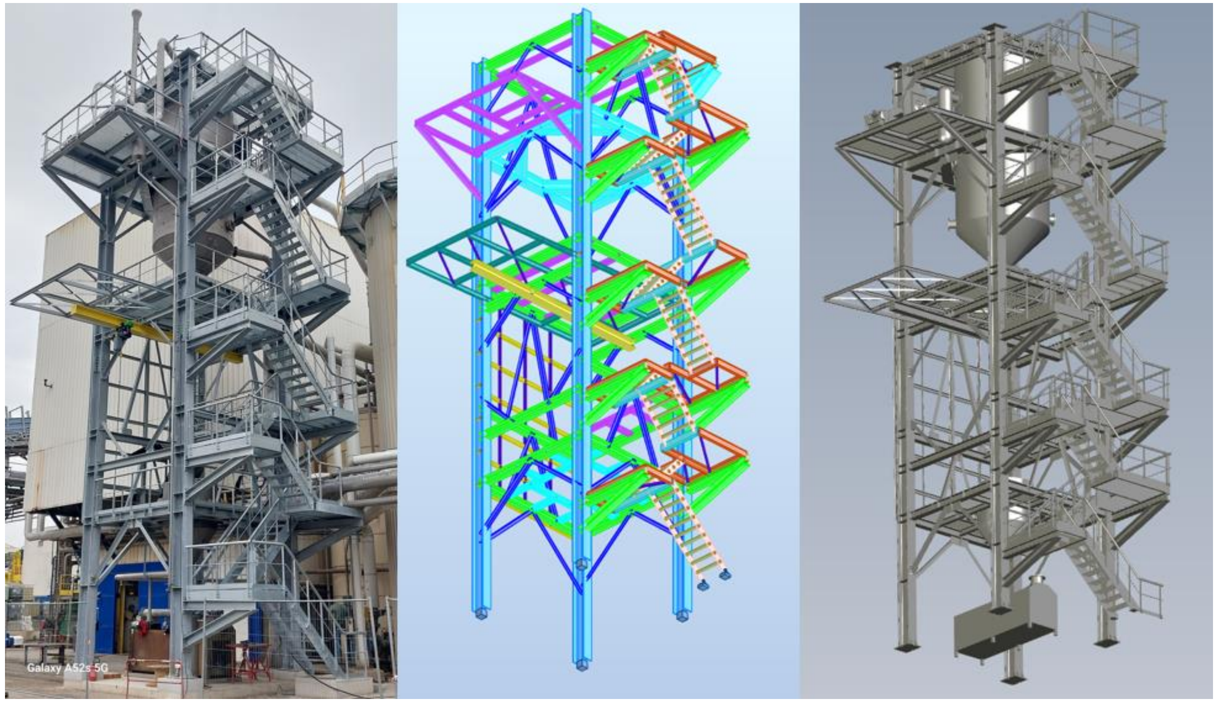
COMPAGNIE GÉNÉRALE DE L’INDUSTRIE (CGI)

sebastien.besse@cgindustrie.com

www.cgindustrie.com

COMPAGNIE GÉNÉRALE DE L'INDUSTRIE

- Founded in 2013 by Sebastien Besse
- Industrial design office: our specialty is, but not limited to, steel frames, industrial piping, pressure vessels



JEI jeune entreprise innovante

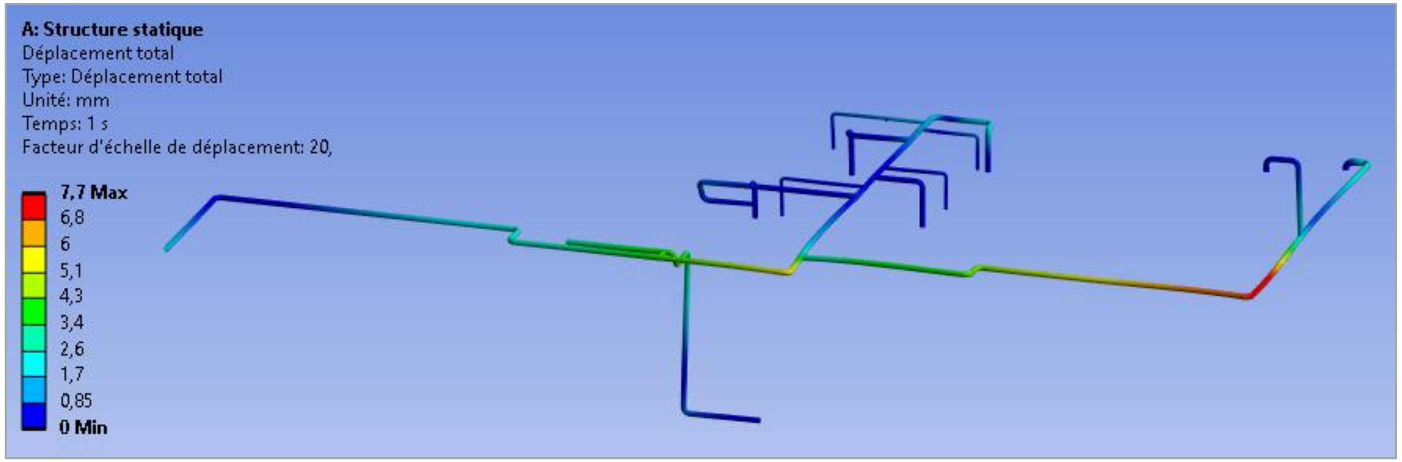
bpifrance

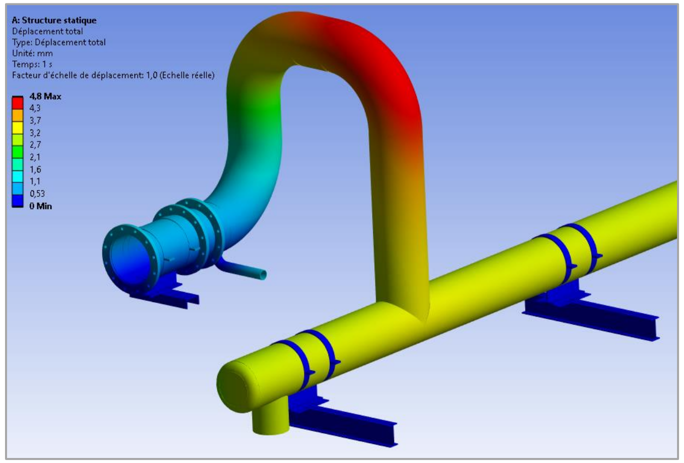
RÉGION SUD /INVEST:

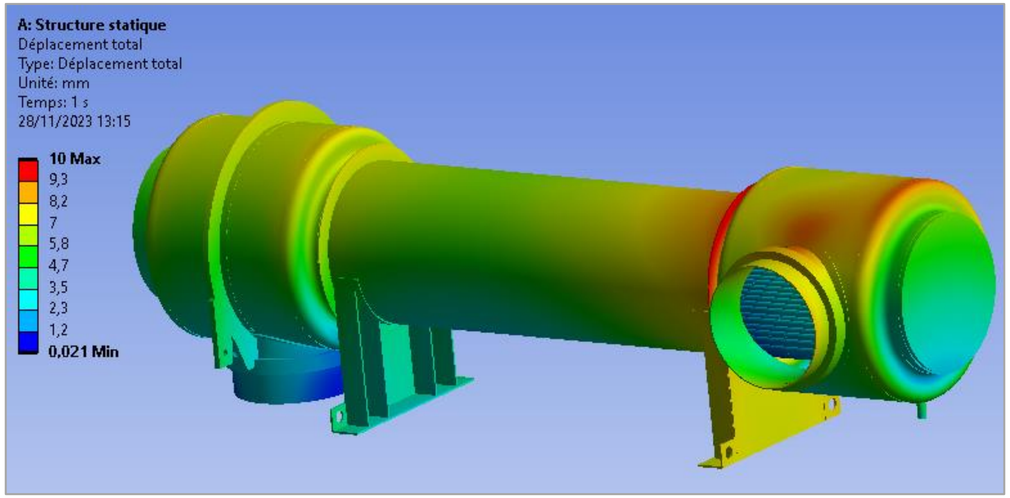
UNION EUROPÉENNE
Fonds Européen de Développement Régional

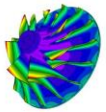
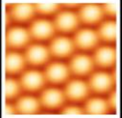
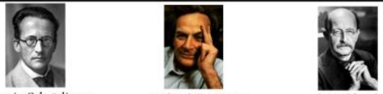
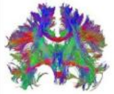
RÉGION SUD
PROVENCE ALPES CÔTE D'AZUR

COMPAGNIE GÉNÉRALE DE L'INDUSTRIE

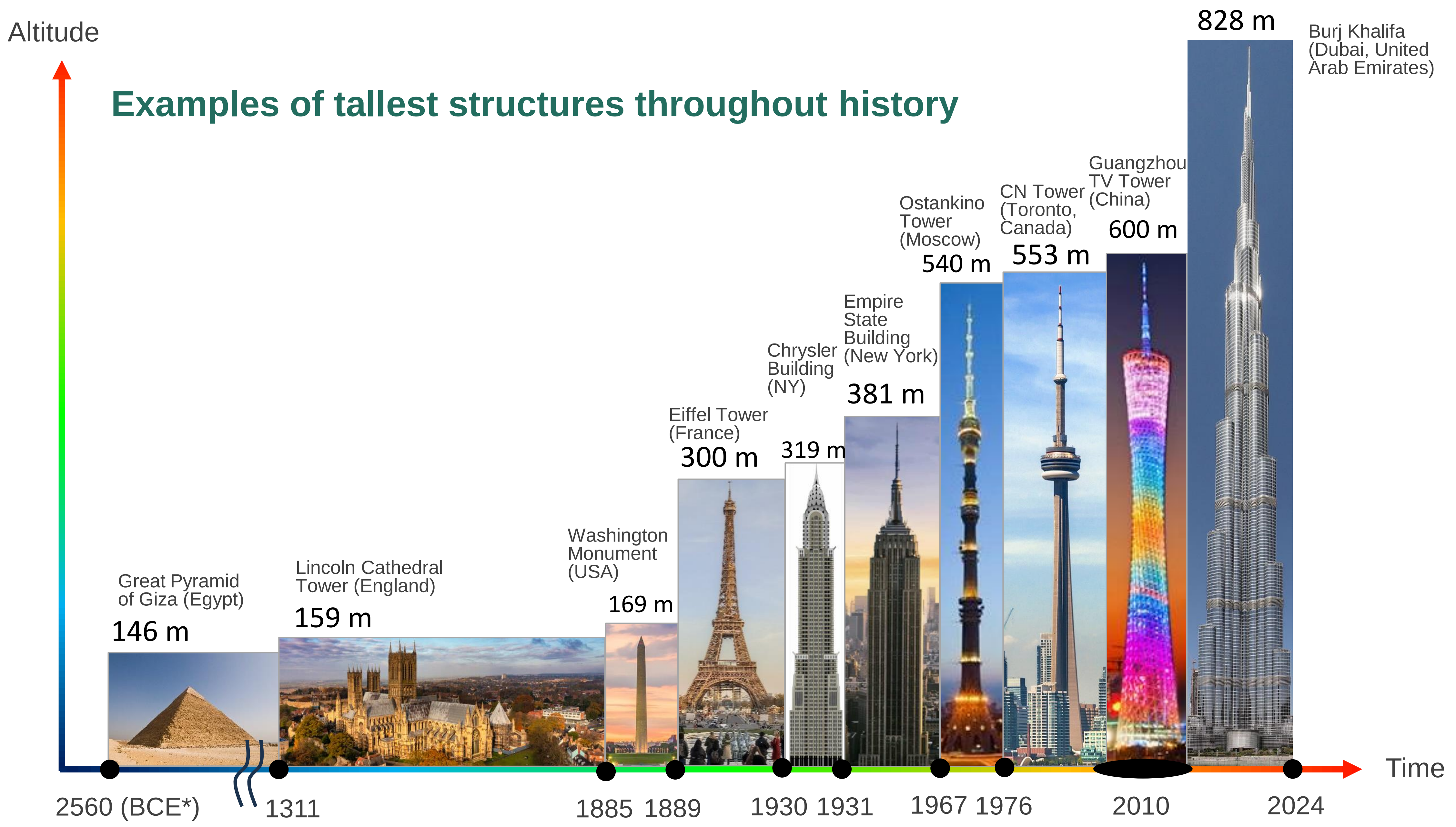






MECANIQUE DU SOLIDE		$\begin{pmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{33}\\ \sigma_{23}\\ \sigma_{13}\\ \sigma_{12}\end{pmatrix} = \begin{pmatrix} C_{1111} & C_{1122} & C_{1133} & C_{1123} & C_{1113} & C_{1112}\\ C_{2211} & C_{2222} & C_{2233} & C_{2223} & C_{2213} & C_{2212}\\ C_{3311} & C_{3322} & C_{3333} & C_{3323} & C_{3313} & C_{3312}\\ C_{2311} & C_{2322} & C_{2333} & C_{2323} & C_{2313} & C_{2312}\\ C_{1311} & C_{1322} & C_{1333} & C_{1323} & C_{1313} & C_{1312}\\ C_{1211} & C_{1222} & C_{1233} & C_{1223} & C_{1213} & C_{1212}\end{pmatrix}\begin{pmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{33}\\ \varepsilon_{23}\\ \varepsilon_{13}\\ \varepsilon_{12}\end{pmatrix}$	$\rho \frac{d\vec{v}}{dt} = \rho \sum_i \vec{f_i} + div(\underline{\sigma})$	$\begin{cases} \frac{d\vec{p}}{dt} = \sum_i \vec{F_i} \\ \vec{\delta_a} = \sum_i \overrightarrow{M_A}(\vec{F_i}) \end{cases}$	 Isaac Newton (1643-1727) · Gustave Eiffel (1832-1923) · Robert Hooke (1635-1703)
MECANIQUE DES FLUIDES		$\frac{\partial \rho \vec{v}}{\partial t} + div(\rho \vec{v} \otimes \vec{v}) = -\overrightarrow{grad}\, p + div\, \bar{\bar{\tau}} + \rho \vec{f}$	$\vec{v_d} = -\frac{k}{\eta}\left(\overrightarrow{grad}\, p - \rho \vec{g}\right)$	$\frac{\partial \rho}{\partial t} + div(\rho \vec{v}) = 0$	 Henry Darcy (1803-1858) · Georges Gabriel Stokes (1819-1903) · Eugène Peclet (1793-1857)
GRAVITATION		$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$	$\overrightarrow{F_{1\to2}} = -G \frac{m_1 m_2}{r^2} \overrightarrow{u_{1\to2}}$	$T = \frac{1}{8\pi k_B} \cdot \frac{\hbar c^3}{GM}$	 Albert Einstein (1879-1955) · Stephen Hawking (1942-) · Isaac Newton (1643-1727)
PHYSIQUE NUCLEAIRE		$E = \gamma \cdot mc^2 = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}}$	$a_0 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2q_1q_2}{\mu v^2}$	$N(t) = N_0 \cdot e^{-\lambda t}$	 Dmitri Mendeleïev (1834-1907) · Ernest Rutherford (1871-1937) · Pierre et Marie Curie (1859-1906; 1867-1934)
ELECTROMAGNETISME		$\begin{cases} div(\vec{E}) = \frac{\rho}{\varepsilon_0} \\ \overrightarrow{rot}\vec{E} = -\frac{\partial \vec{B}}{\partial t} \\ div(\vec{B}) = 0 \\ \overrightarrow{rot}\vec{B} = \mu_0 \cdot \left(\vec{j} + \varepsilon_0 \frac{\partial \vec{E}}{\partial t}\right) \end{cases}$	$\vec{B} = \frac{\mu_0 I}{2\pi r} \vec{e_\theta}$	$P = \frac{dE}{dt}$	 James Clerk Maxwell (1831-1879) · Nikola Tesla (1856-1943) · James Watt (1736-1819)
PHYSIQUE QUANTIQUE		$\frac{\hat{\vec{p}}}{2m}\lvert\psi(t)\rangle + V(\hat{\vec{r}}, t)\lvert\psi(t)\rangle = i\hbar \frac{\partial \lvert\psi(t)\rangle}{\partial t}$ $f(x,t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} A(k) \cdot e^{i(kx - w(k)t)}\, dk$	$\mathring{L}_{\Omega,\nu} = \frac{2h\nu^3}{c^2} \cdot \frac{1}{e^{h\nu/k_bT} - 1}$	$E = h\nu$	 Erwin Schrödinger (1887-1961) · Richard Feynman (1918-1988) · Max Planck (1858-1947)
THERMODYNAMIQUE		$W + Q_c + Q_m + Q_f = 0$ $\frac{Q_c}{T_c} + \frac{Q_m}{T_m} + \frac{Q_f}{T_f} = \Delta S$	$\Delta S = \Delta S_{syst} + \Delta S_{ext} \geq 0$	$U = W + Q$	 Ludwig Boltzmann (1844-1906) · James Prescott Joule (1818-1889) · Sadi Carnot (1796-1832)
DIFFUSION MOLECULAIRE		$\frac{\partial C}{\partial t} + div(\vec{j}) = P_+ + P_-$	$\vec{j} = -D\, \overrightarrow{grad}(C)$	$D = \frac{k_b T}{6\pi\eta R_h}$	 Adolf Eugène Fick (1829-1901) · Georges Gabriel Stokes (1819-1903) · Albert Einstein (1879-1955)
THERMIQUE		$\rho c \frac{\partial T}{\partial t} + div(\vec{j}) = P_+ + P_-$	$\vec{j} = -\lambda\, \overrightarrow{grad}(T)$	$P = \frac{\delta T}{dt}$	 Joule (1818-1889) · Joseph Fourier (1768-1830) · William Thomson Lord Kelvin (1824-1907)
OPTIQUE		$I(\theta) = I_0 \left(\frac{\sin\left(\frac{N\pi d}{\lambda}\sin(\theta)\right)}{\sin\left(\frac{\pi d}{\lambda}\sin(\theta)\right)}\right)^2$	$\langle P \rangle = \frac{\mu_0}{12\pi c} \cdot \omega^4 p_0^2$	$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$	 René Descartes (1596-1650) · John William Strutt Rayleigh (1842-1919) · Augustin Fresnel (1788-1827)

Examples of tallest structures throughout history



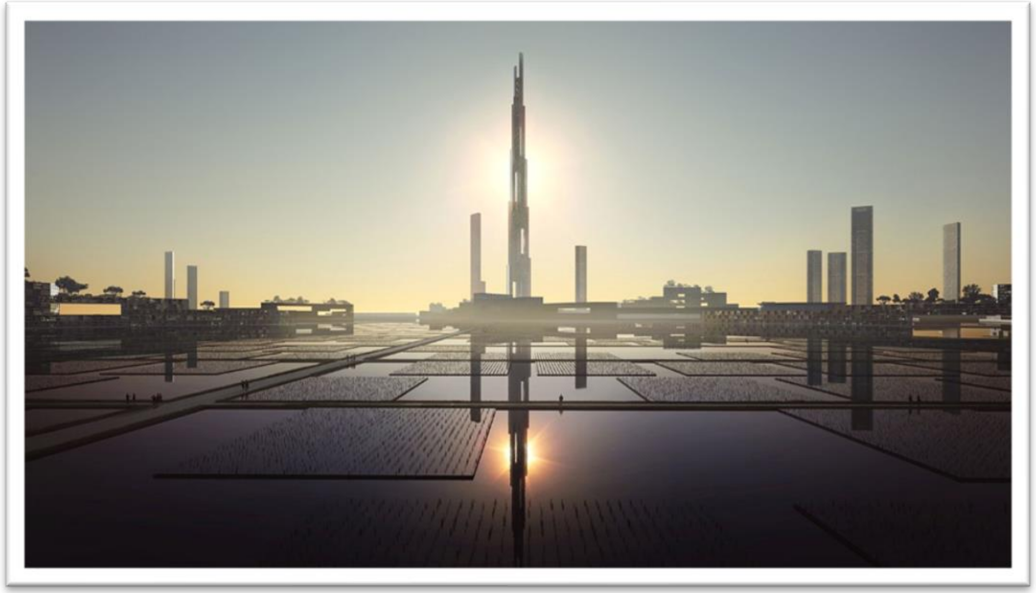
(*) Before Common Era

Examples of on going projects of mega-tall skyscrapers

Djeddah Tower 1007 m
(Saudi Arabia)

Oblisco Capitale 1000 m
(Egypt)

Sky Mile Tower 1700 m
Tokyo (Japan)



X-Seed 4000 (Tokyo, 1995)

130 *Journal of Urban Technology*

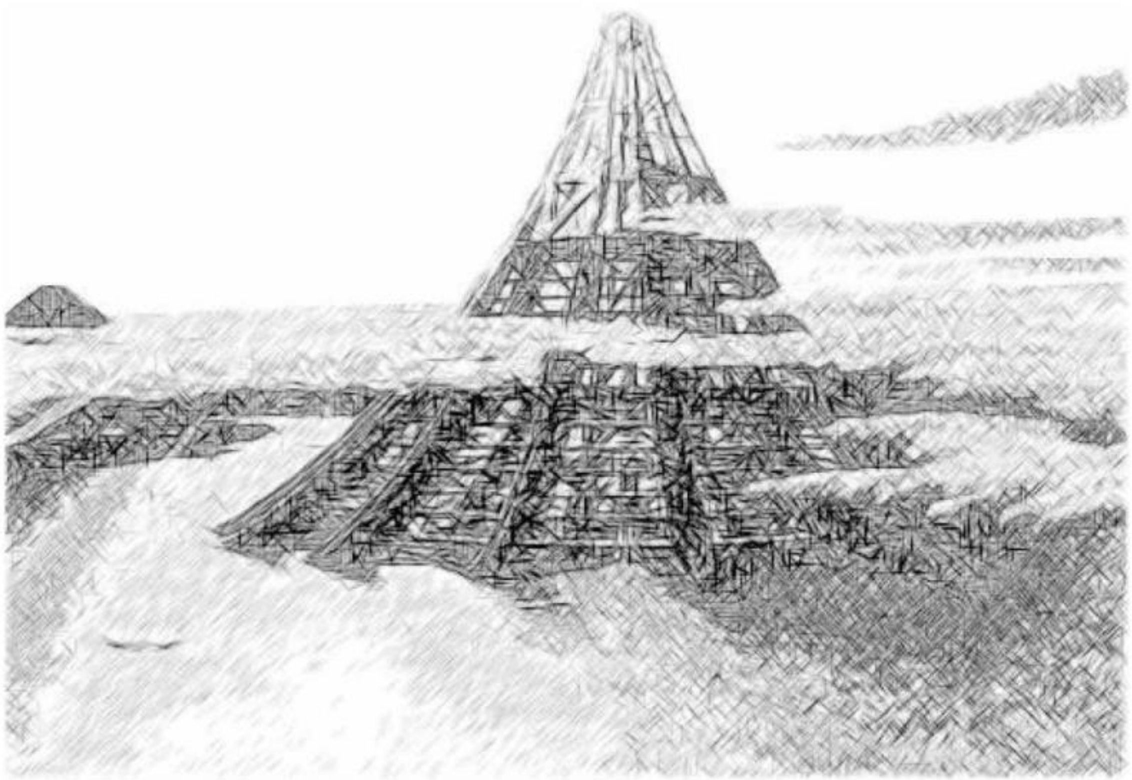


Figure 11. X-seed 4000, proposed by the Taisei Corporation, is a 4 km (2.485 miles) height, and 6 km (3.728 miles) wide sea-base structure. It contains 800 floors that could accommodate up to one million inhabitants.
Drawing by K. Al-Kodmany

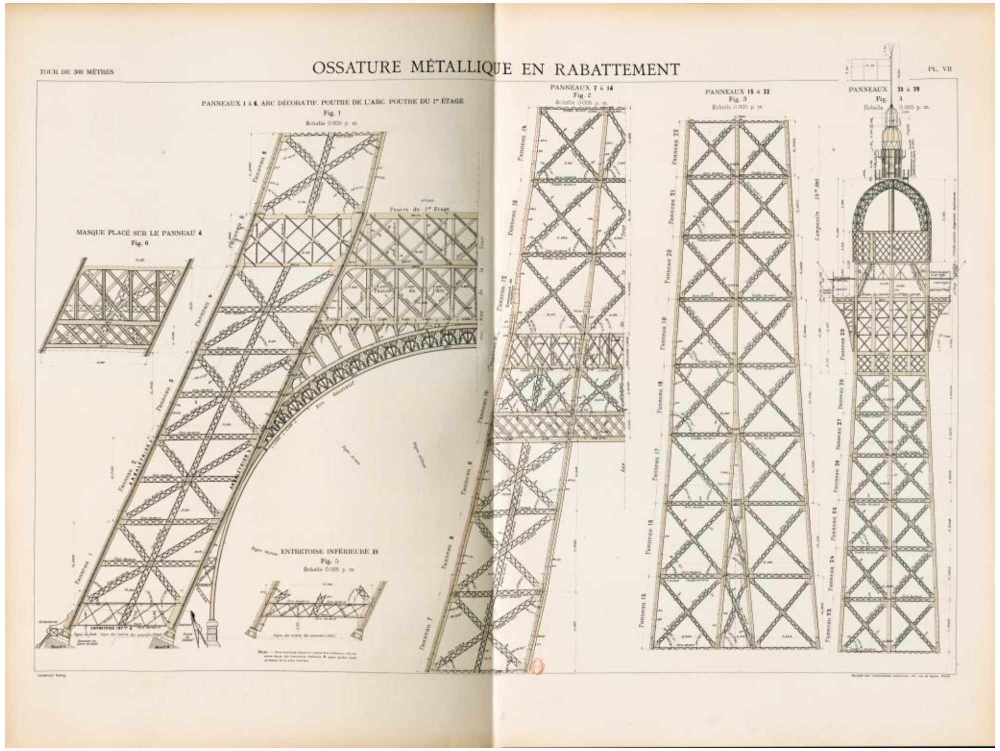
The « prototype » of the Eiffel Tower

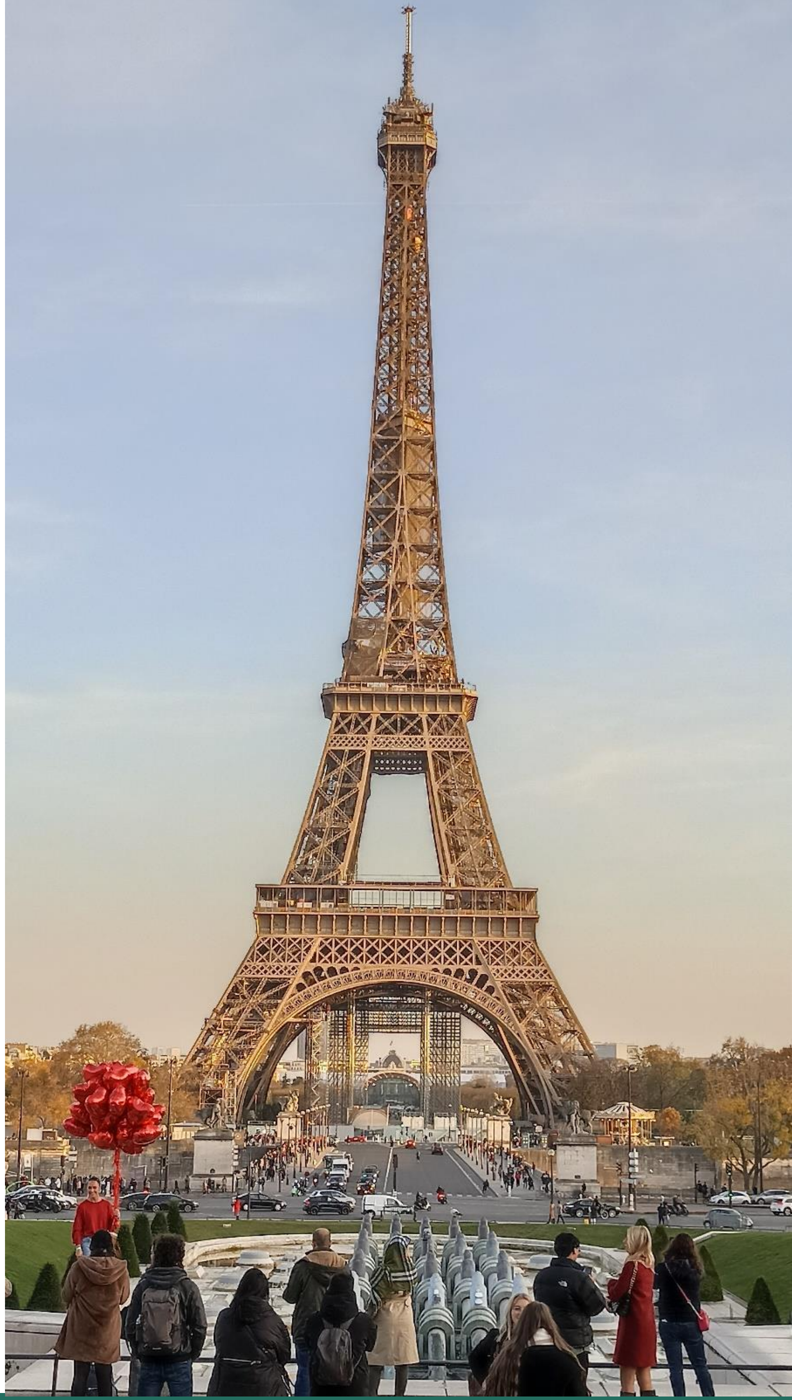
- Built in 1889 with equal angle steel, plates and rivets
- Designed without electricity or finite element modeling or computers
- Eurocodes : wind zone 2, seismic zone 1, snow zone A1

1	**2**	3	4

1	2	3	4	5

A1	A2	B1	B2	C1	C2	D	E



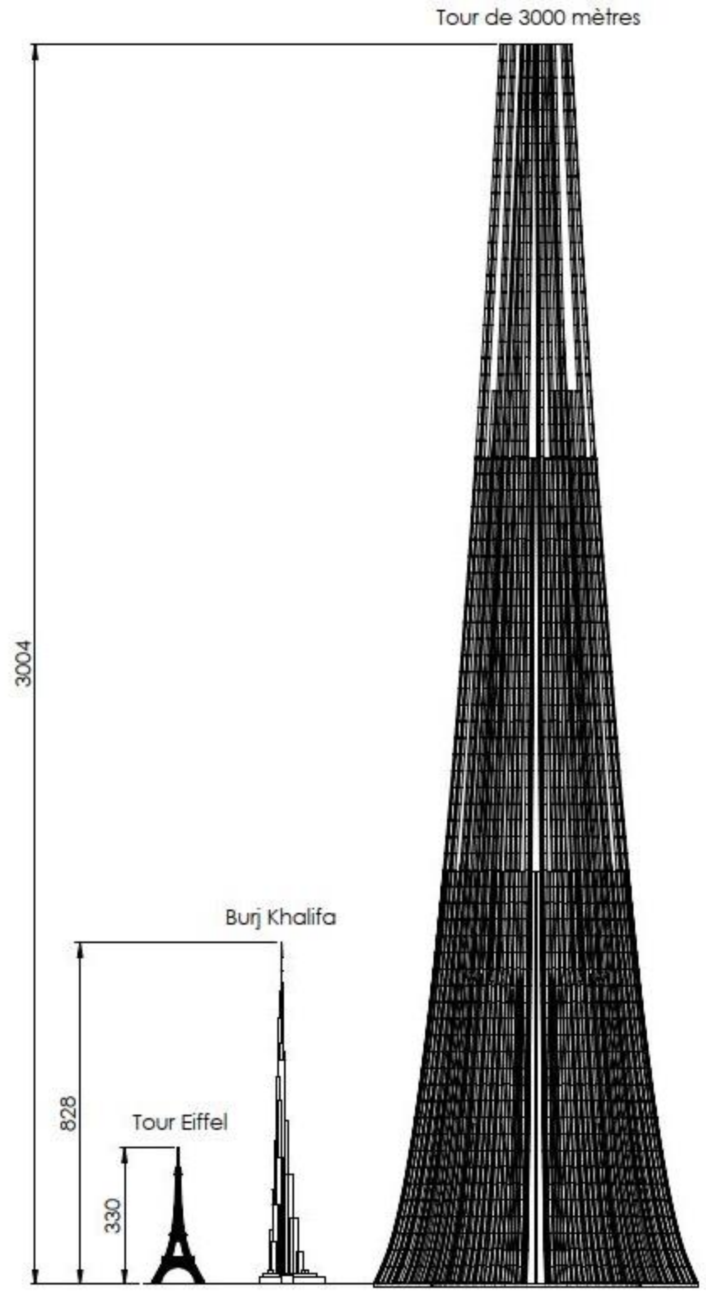


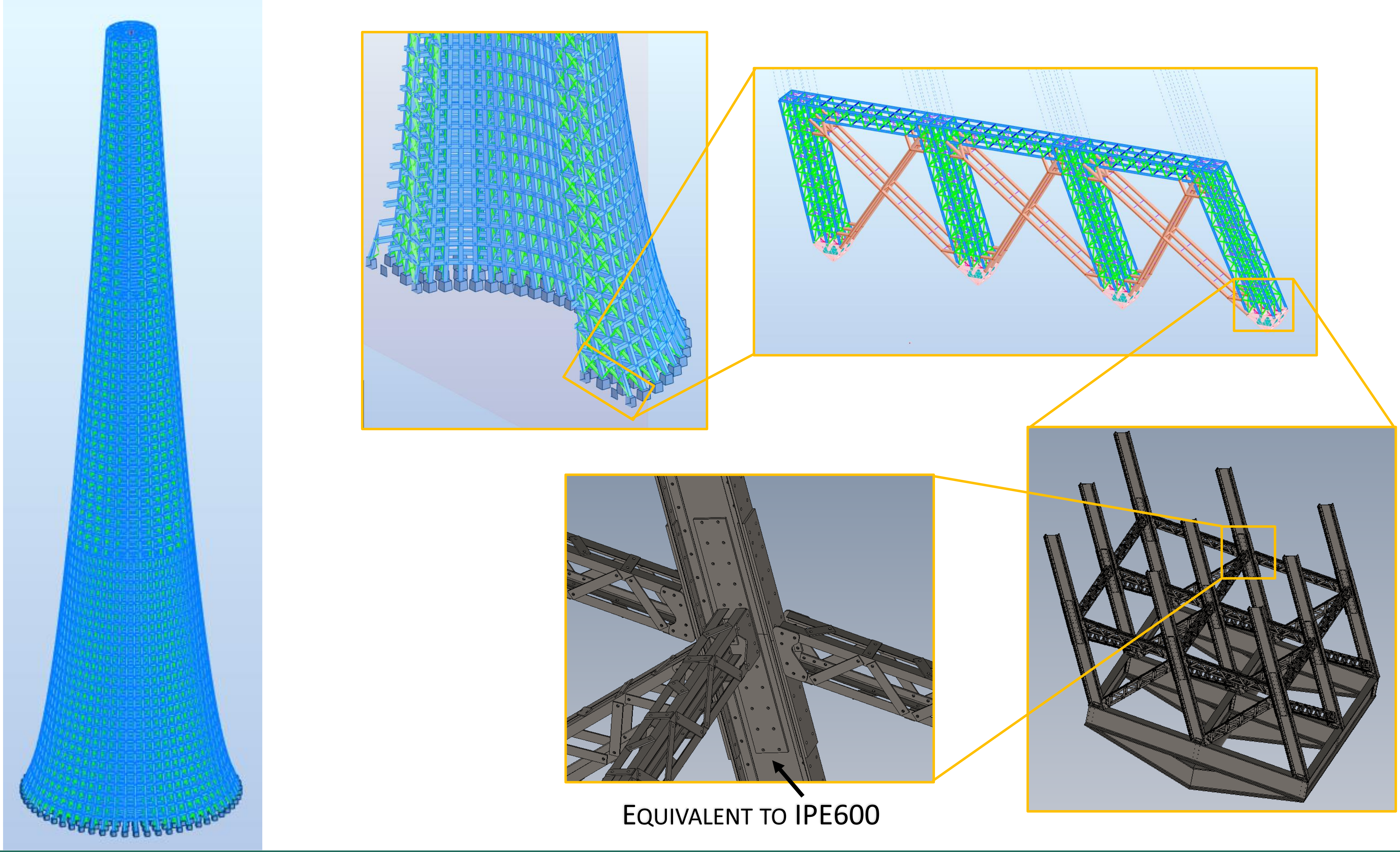
Why a 3000 meter tower is not built in 2024 ?

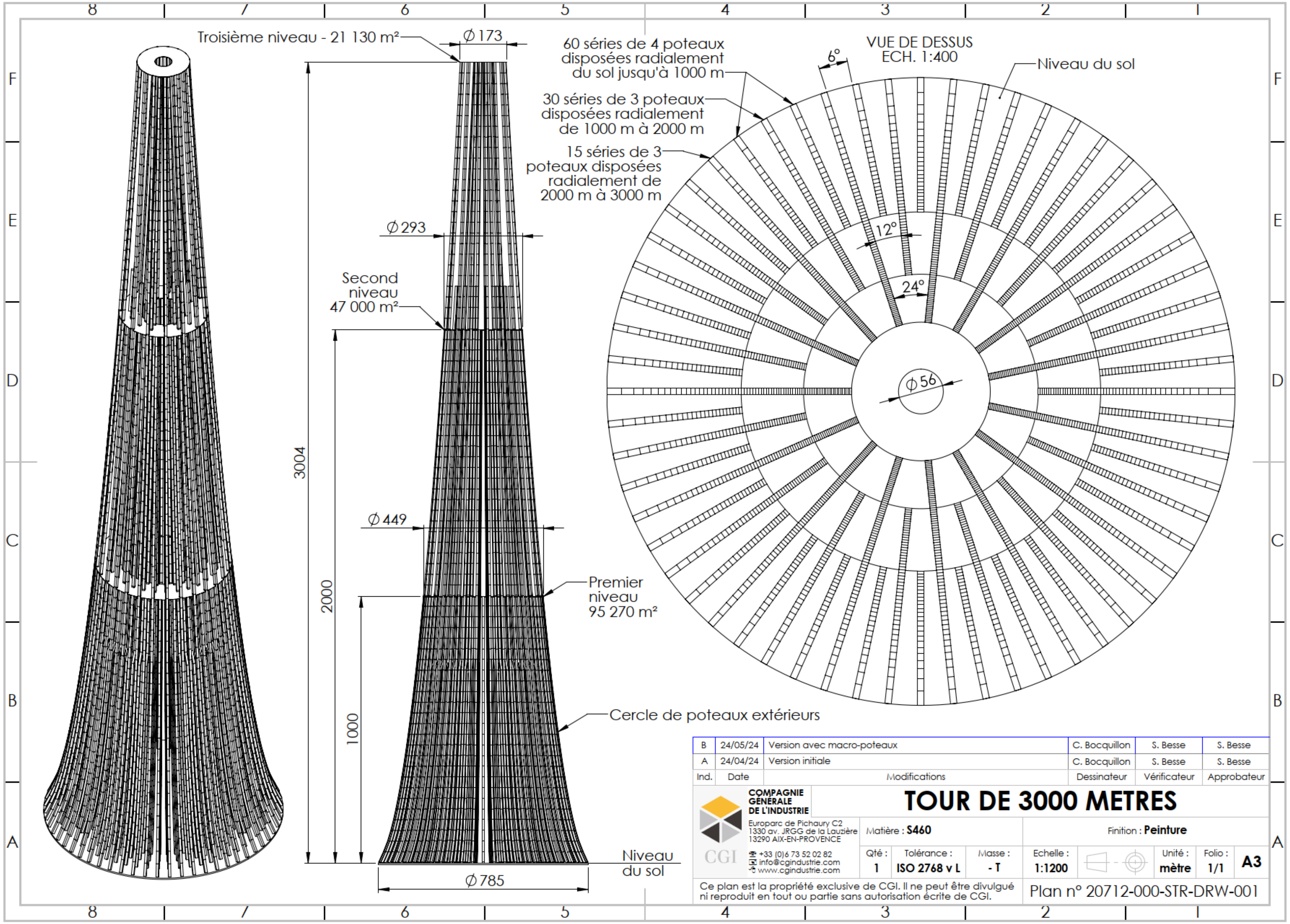
- Building a 3000 meter high tower poses many technical challenges, economic, environmental and logistical. Here are some main reasons for which such a structure has never been built.
- Technical problems and engineering
  - Structural stability including wind resistance and earthquake resistance
  - Compressive load on ground columns and risk of buckling
  - Materials
  - Elevators
- Cost
- Environmental issues
- Logistics and accessibility
- Human limits and comfort

The 3000 meter tower

- Height : 3000 meters
- Function : commercial center (70%) + tourism (30%)
- Floors : 4 (ground, 1000, 2000, 3000 meters)
- Opened structure to reduce wind loads
- Weight : 750 000 tons (excluding foundations)
- Material : carbon steel S460
- Social utility :
  - Firefighting observation center
  - Astronomical observatory at 3000 meters
  - Population gathering area in the event of flooding
  - Base jump center
  - Glass floor



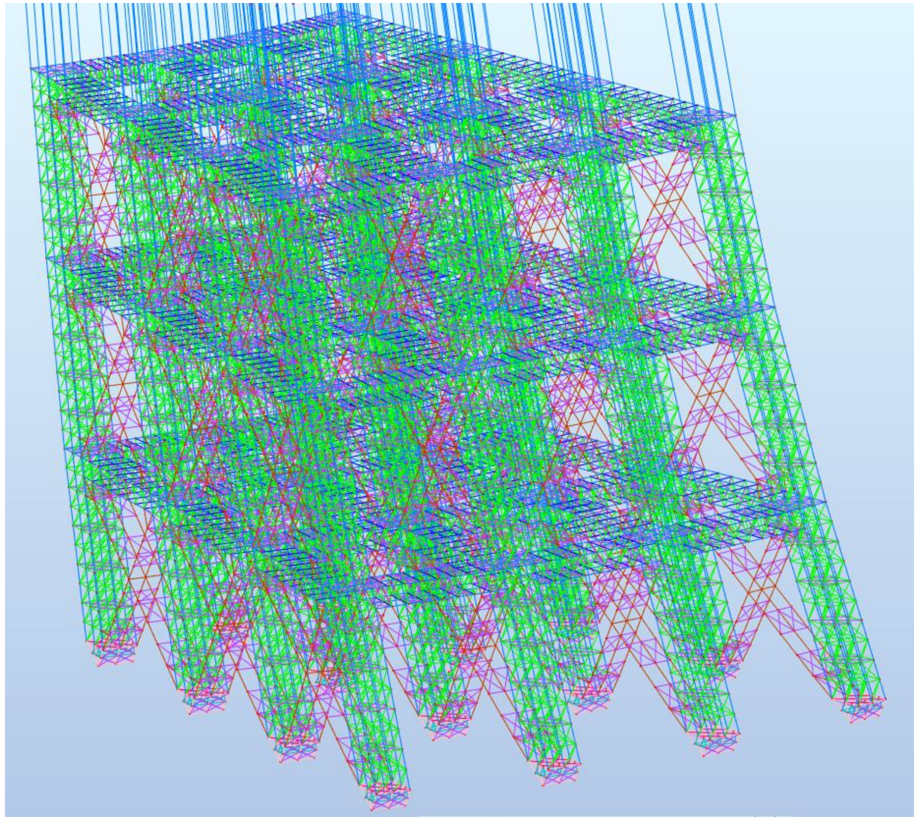

EQUIVALENT TO IPE600

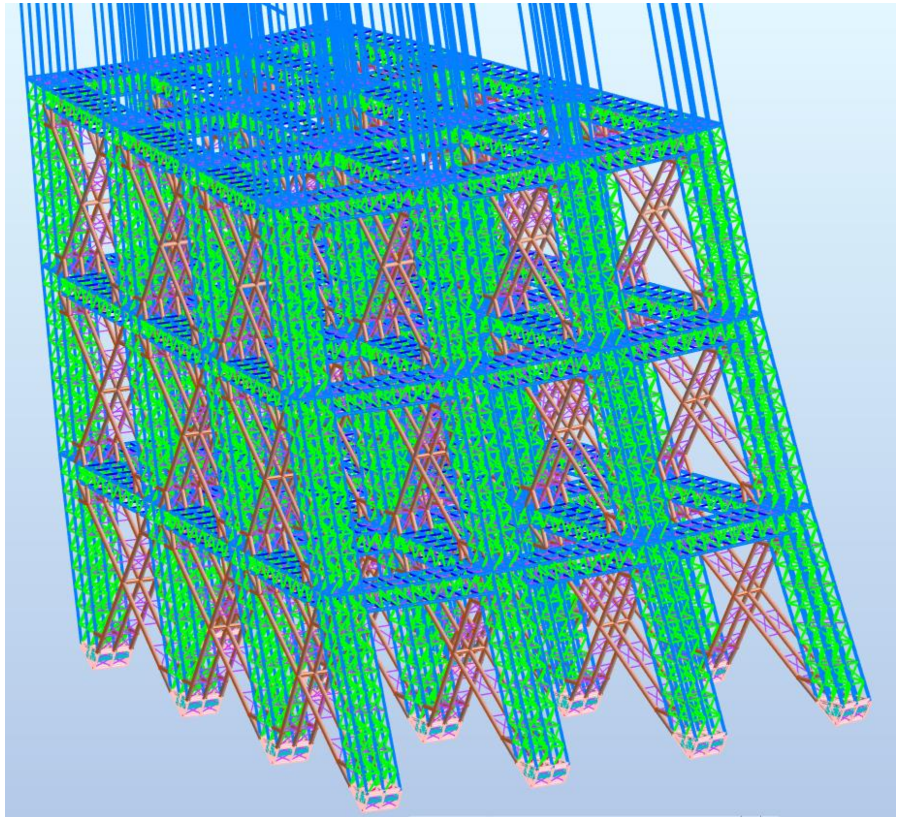


Troisième niveau - 21 130 m²
∅173
60 séries de 4 poteaux disposées radialement du sol jusqu'à 1000 m
30 séries de 3 poteaux disposées radialement de 1000 m à 2000 m
15 séries de 3 poteaux disposées radialement de 2000 m à 3000 m
VUE DE DESSUS
ECH. 1:400
6°
Niveau du sol
∅293
12°
24°
Second niveau 47 000 m²
∅56
3004
∅449
2000
Premier niveau 95 270 m²
1000
Cercle de poteaux extérieurs
Niveau du sol
∅785
B | 24/05/24 | Version avec macro-poteaux | C. Bocquillon | S. Besse | S. Besse
A | 24/04/24 | Version initiale | C. Bocquillon | S. Besse | S. Besse
Ind. | Date | Modifications | Dessinateur | Vérificateur | Approbateur
COMPAGNIE GÉNÉRALE DE L'INDUSTRIE
Europarc de Pichaury C2
1330 av. JRGG de la Lauzière
13290 AIX-EN-PROVENCE
CGI
+33 (0)6 73 52 02 82
info@cgindustrie.com
www.cgindustrie.com
TOUR DE 3000 METRES
Matière : S460
Finition : Peinture
Qté : 1
Tolérance : ISO 2768 v L
Masse : - T
Echelle : 1:1200
Unité : mètre
Folio : 1/1
A3
Ce plan est la propriété exclusive de CGI. Il ne peut être divulgué ni reproduit en tout ou partie sans autorisation écrite de CGI.
Plan n° 20712-000-STR-DRW-001

3D view (from 0 to 18°, from z = 0 to 120 m)

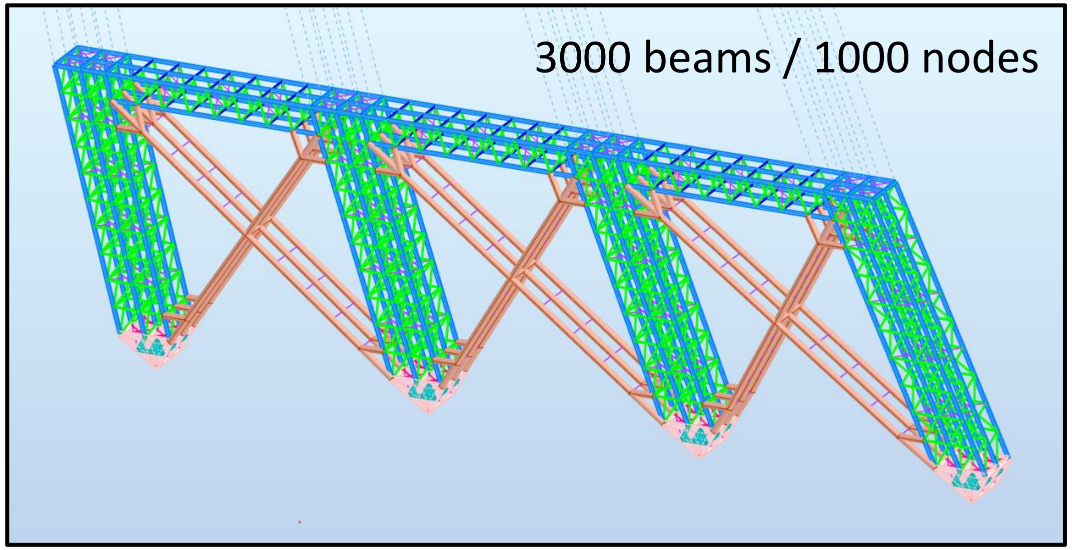
- 26 000 beam elements / 12 000 nodes





Software and hardware

- More than 30 million beams
- Not suitable for a full 3D realistic model on a computer in 2024 even with 1-D beam elements
- Calculations performed using the software ANSYS Mechanical 2024 R1 - 4CAD
- Modeling ground and 1st floor
- Calculation code : Eurocodes 0, 1, 3, 8
- Finite element method using ANSYS Mechanical
- Solve millions of degrees of freedom in seconds
- Should be justified with linear elasticity
  and linear material
- Cylindrical symmetry
- Buckling length : 1 meter



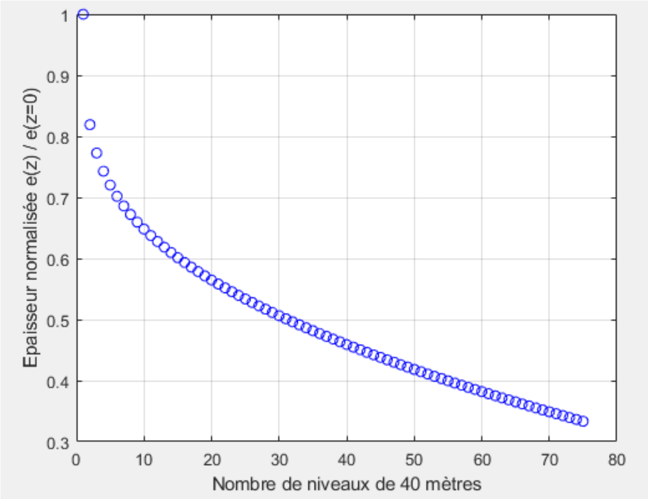
Method for global design

- Total weight

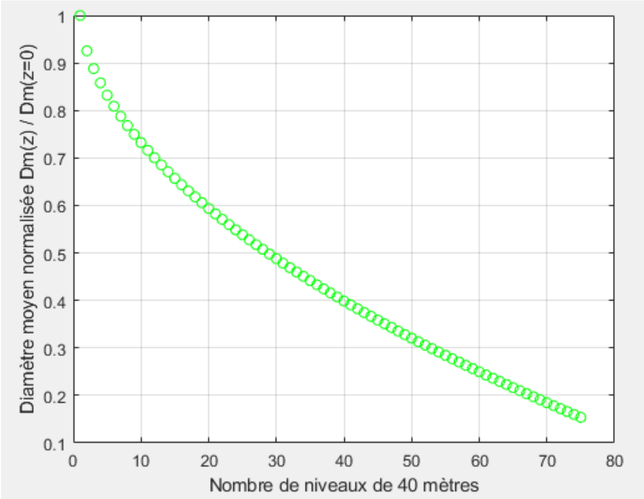
$$P_{tot} = \alpha P_1 = P_1 \sum_{i=1}^{N} \prod_{k=0}^{i-1} (1 - t_k)^k$$

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

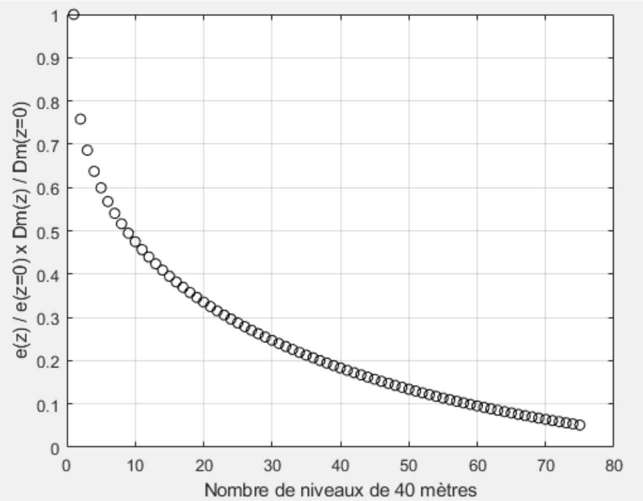
$Facteur\ \alpha$
N *the number of levels of the tower*
P_1 *weight of the first level* $(z = 0$ *to* 40 *meters*$)$
t_k *reduction rate from level* $k-1$ *to level* k
$e(z)$ *apparent thickness of the tower along* z
$D_m(z)$ *mean diameter of the tower along* z



X



=

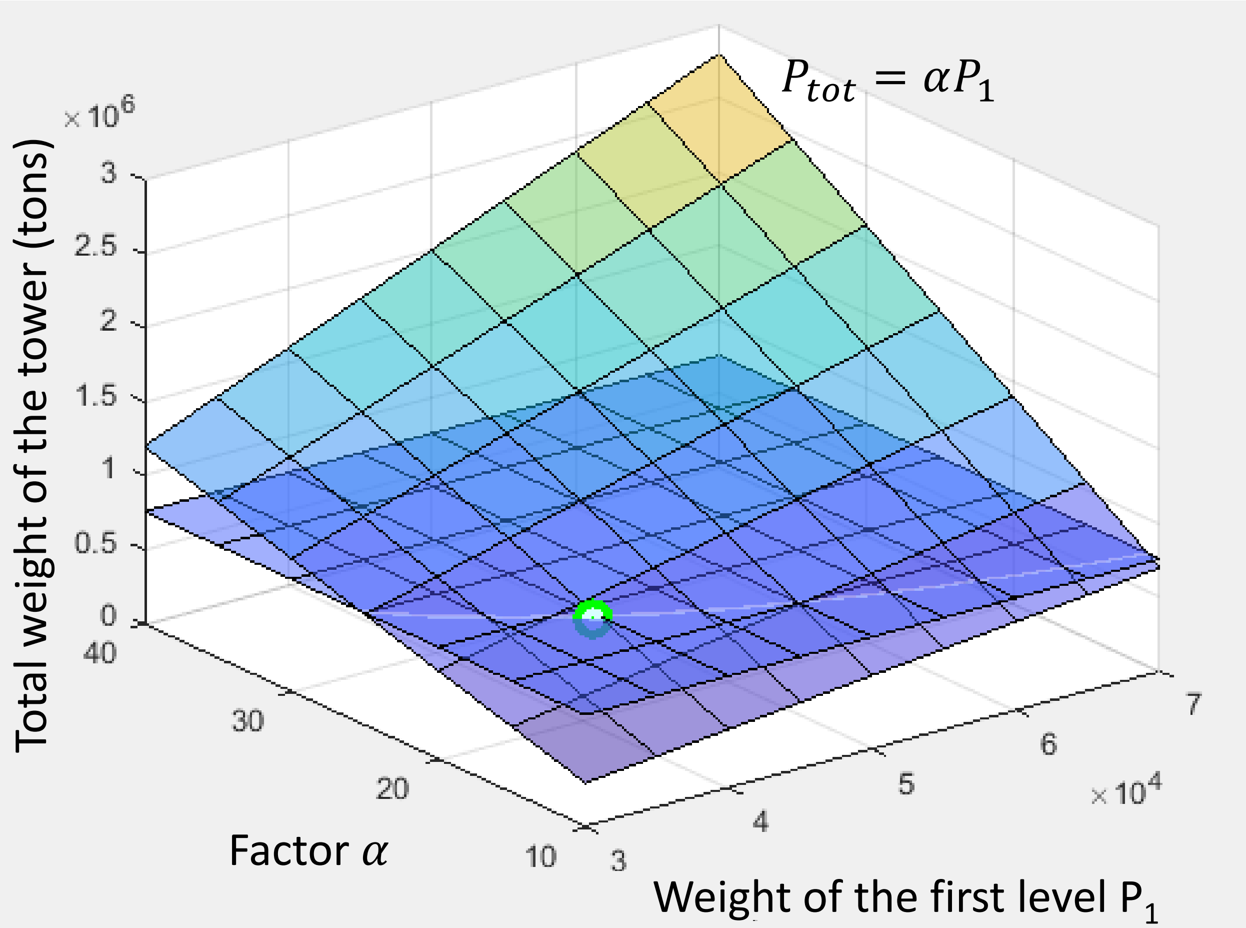


Method for global design

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

- Surface of total weight

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



(P_1, α, P_{tot}) =

(39 612 tons, 18.866, 747 320 tons)

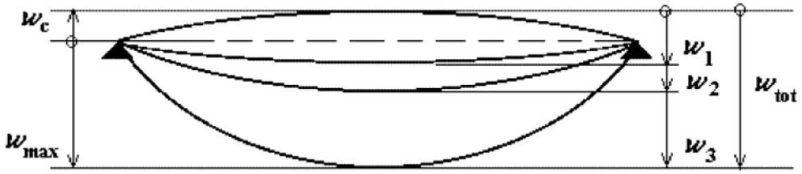
Ultimate Limit State (ULS)

- ▸ Steel S460
- ▸ Maximal ratio : 99 %
- ▸ Maximal stress : 454 MPa

(< 460 MPa)

Pièce	Profil	Matériau	Lay	Laz	Ratio	Cas
479	OK IPE 600	S 460 M	2.06	10.73	0.99	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
529	OK IPE 600	S 460 M	2.06	10.73	0.99	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
321	OK IPE 600	S 460 M	2.06	10.73	0.98	110 ACC:SEI/4=1*1.00 + 2*0.30 + 8*-1.00
519	OK IPE 600	S 460 M	2.06	10.73	0.97	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
550	OK IPE 600	S 460 M	2.06	10.73	0.95	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
410	OK IPE 600	S 460 M	2.06	10.73	0.95	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
509	OK IPE 600	S 460 M	2.06	10.73	0.93	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
311	OK IPE 600	S 460 M	2.06	10.73	0.93	110 ACC:SEI/4=1*1.00 + 2*0.30 + 8*-1.00
272	OK IPE 600	S 460 M	2.06	10.73	0.92	47 ELU/21=1*1.35 + 2*1.05 + 5*1.50
301	OK IPE 600	S 460 M	2.06	10.73	0.91	110 ACC:SEI/4=1*1.00 + 2*0.30 + 8*-1.00
551	OK IPE 600	S 460 M	2.06	10.73	0.90	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
282	OK IPE 600	S 460 M	2.06	10.73	0.90	47 ELU/21=1*1.35 + 2*1.05 + 5*1.50
400	OK IPE 600	S 460 M	2.06	10.73	0.89	110 ACC:SEI/4=1*1.00 + 2*0.30 + 8*-1.00
262	OK IPE 600	S 460 M	2.06	10.73	0.89	47 ELU/21=1*1.35 + 2*1.05 + 5*1.50
390	OK IPE 600	S 460 M	2.06	10.73	0.88	110 ACC:SEI/4=1*1.00 + 2*0.30 + 8*-1.00
548	OK IPE 600	S 460 M	2.06	10.73	0.87	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
558	OK IPE 600	S 460 M	2.06	10.73	0.87	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
539	OK IPE 600	S 460 M	2.06	10.73	0.86	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
461	OK IPE 600	S 460 M	2.06	10.73	0.84	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
552	OK IPE 600	S 460 M	2.06	10.73	0.84	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
9	OK IPE 600	S 460 M	2.06	10.73	0.83	51 ELU/25=1*1.35 + 2*1.05 + 6*1.50
273	OK IPE 600	S 460 M	2.06	10.73	0.82	110 ACC:SEI/4=1*1.00 + 2*0.30 + 8*-1.00
553	OK IPE 600	S 460 M	2.06	10.73	0.81	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
372	OK IPE 600	S 460 M	2.06	10.73	0.81	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
263	OK IPE 600	S 460 M	2.06	10.73	0.80	47 ELU/21=1*1.35 + 2*1.05 + 5*1.50
540	OK IPE 600	S 460 M	2.06	10.73	0.80	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
520	OK IPE 600	S 460 M	2.06	10.73	0.79	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
541	OK IPE 600	S 460 M	2.06	10.73	0.78	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
521	OK IPE 600	S 460 M	2.06	10.73	0.77	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
274	OK IPE 600	S 460 M	2.06	10.73	0.77	110 ACC:SEI/4=1*1.00 + 2*0.30 + 8*-1.00
554	OK IPE 600	S 460 M	2.06	10.73	0.76	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
542	OK IPE 600	S 460 M	2.06	10.73	0.76	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
469	OK IPE 600	S 460 M	2.06	10.73	0.76	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
522	OK IPE 600	S 460 M	2.06	10.73	0.76	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
528	OK IPE 600	S 460 M	2.06	10.73	0.75	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
283	OK IPE 600	S 460 M	2.06	10.73	0.75	51 ELU/25=1*1.35 + 2*1.05 + 6*1.50
264	OK IPE 600	S 460 M	2.06	10.73	0.75	110 ACC:SEI/4=1*1.00 + 2*0.30 + 8*-1.00
380	OK 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	OK IPE 200	S 460 M	48.43	178.90	0.74	51 ELU/25=1*1.35 + 2*1.05 + 6*1.50
543	OK IPE 600	S 460 M	2.06	10.73	0.74	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
265	OK 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	OK IPE 200	S 460 M	48.43	178.90	0.74	47 ELU/21=1*1.35 + 2*1.05 + 5*1.50
518	OK IPE 600	S 460 M	2.06	10.73	0.74	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
547	OK IPE 600	S 460 M	2.06	10.73	0.74	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
523	OK IPE 600	S 460 M	2.06	10.73	0.74	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50
557	OK IPE 600	S 460 M	2.06	10.73	0.74	39 ELU/13=1*1.35 + 2*1.05 + 3*1.50

Serviceability Limit State (SLS)



Légende

w_c Contreflèche dans l'élément structural non chargé

w_1 Partie initiale de la flèche sous les charges permanentes de la combinaison d'actions correspondante selon les expressions (6.14a) à (6.16b).

w_2 Partie à long terme de la flèche sous les charges permanentes.

w_3 Partie additionnelle de la flèche due aux actions variables de la combinaison d'actions correspondante d'après les expressions (6.14a) à (6.16b).

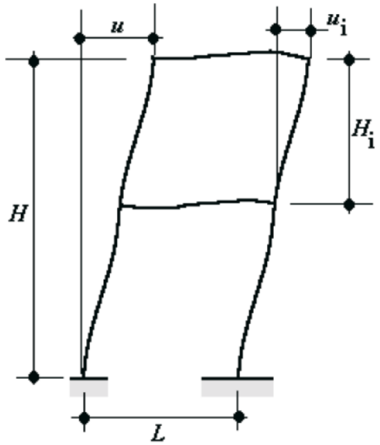
w_{tot} Flèche totale, soit somme de w_1, w_2, w_3.

w_{max} Flèche résiduelle totale compte tenu de la contreflèche.

Pièce	Profil	Matériau	Ratio(uy)	Cas (uy)	Ratio(uz)	Cas (uz)
1045	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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	OK 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

Serviceability Limit State (SLS)

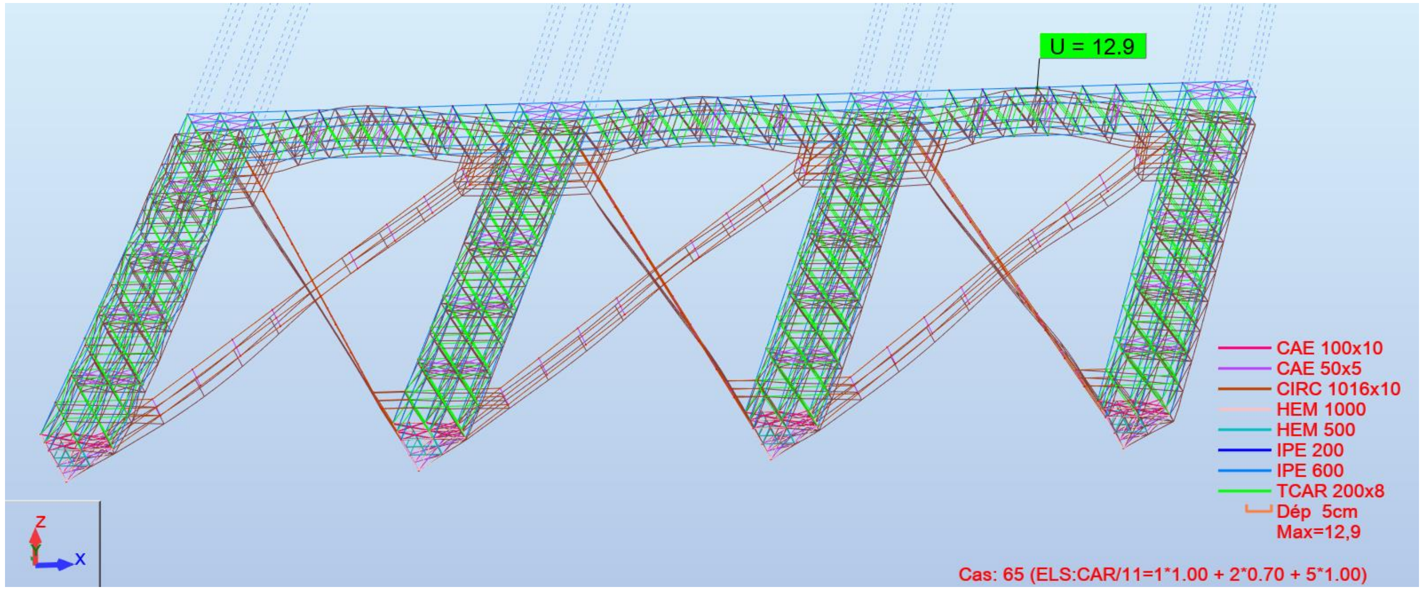
130 mm



Légende

u Déplacement horizontal général sur la hauteur H du bâtiment

u_i Déplacement horizontal sur la hauteur H_i d'un étage



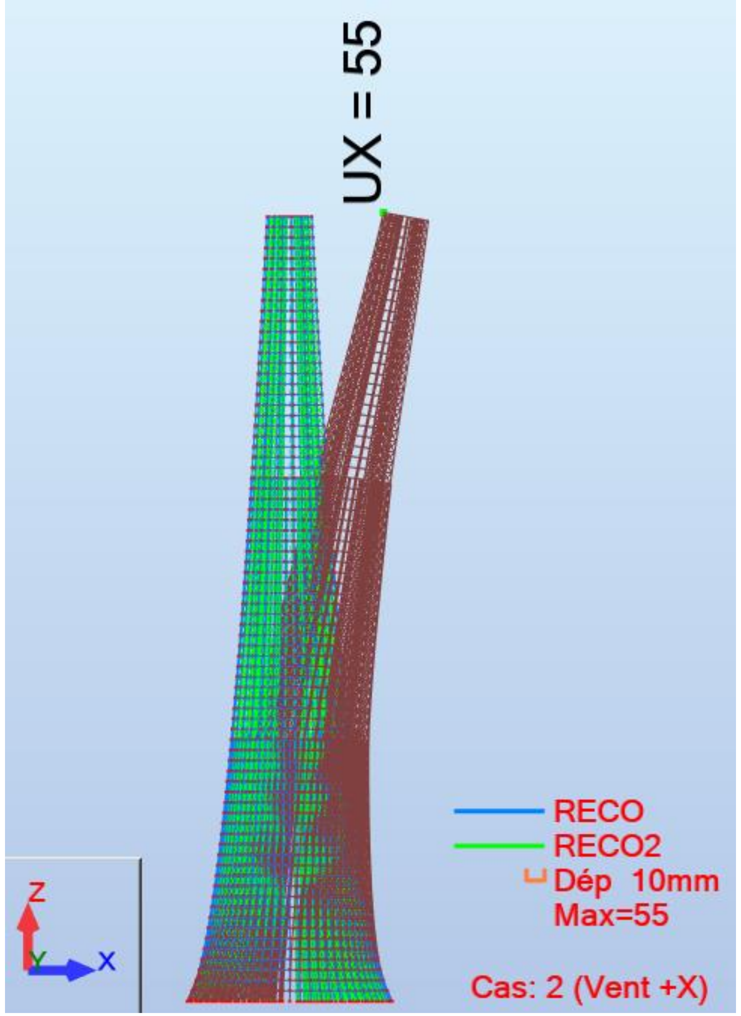
Pièce		Profil	Matériau	Ratio(vx)	Cas (vx)	Ratio(vy)	Cas (vy)
267	OK	IPE 600	S 460 M	0.07	61 ELS:CAR/7=1*1.00 + 2*0.70 + 3*1.00	0.18	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
232	OK	IPE 600	S 460 M	0.11	63 ELS:CAR/9=1*1.00 + 2*0.70 + 4*1.00	0.17	65 ELS:CAR/11=1*1.00 + 2*0.70 + 5*1.00
282	OK	IPE 600	S 460 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	OK	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	OK	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	OK	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	OK	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	OK	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	OK	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	OK	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	OK	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	OK	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	OK	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

Horizontal wind deflection at z = 3000 m

- Wind deflection based on 300 daN/m²

- For Eiffel Tower, Eurocode : H / 150
  - H / 150 = 300 000 mm / 150 = 2 meters
  - Experimental : max 130 mm (storm, 1999)
  - Eiffel tower respects a criteria H / 2300

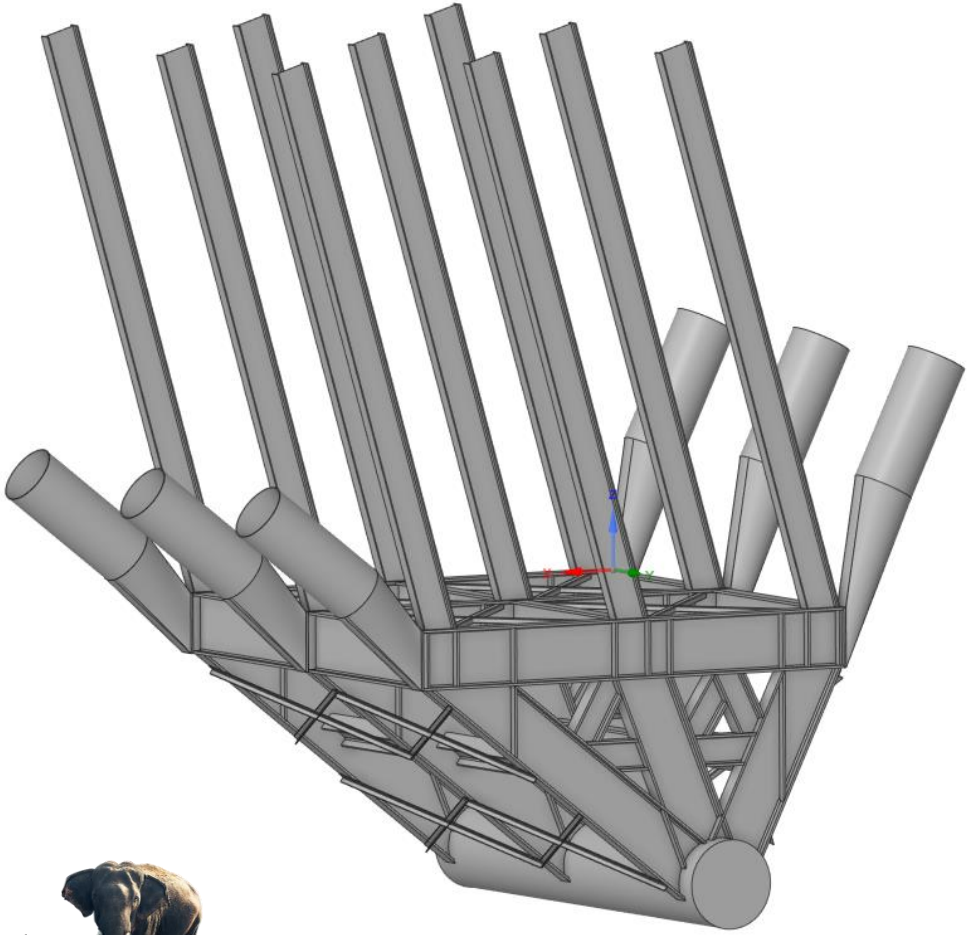
- The Tower respects a criteria H / 54 000

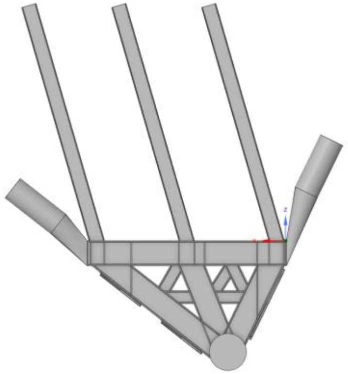


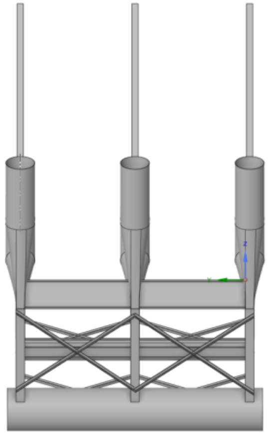
Hinged support (160 tons x 240 supports)

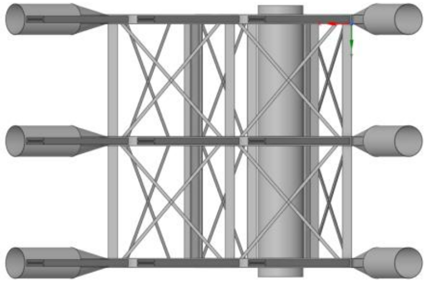
- IPE600
- HEM 1000
- HEM 500
- CAE 100x10
- BAR 1500
- DN1000

- Steel S460





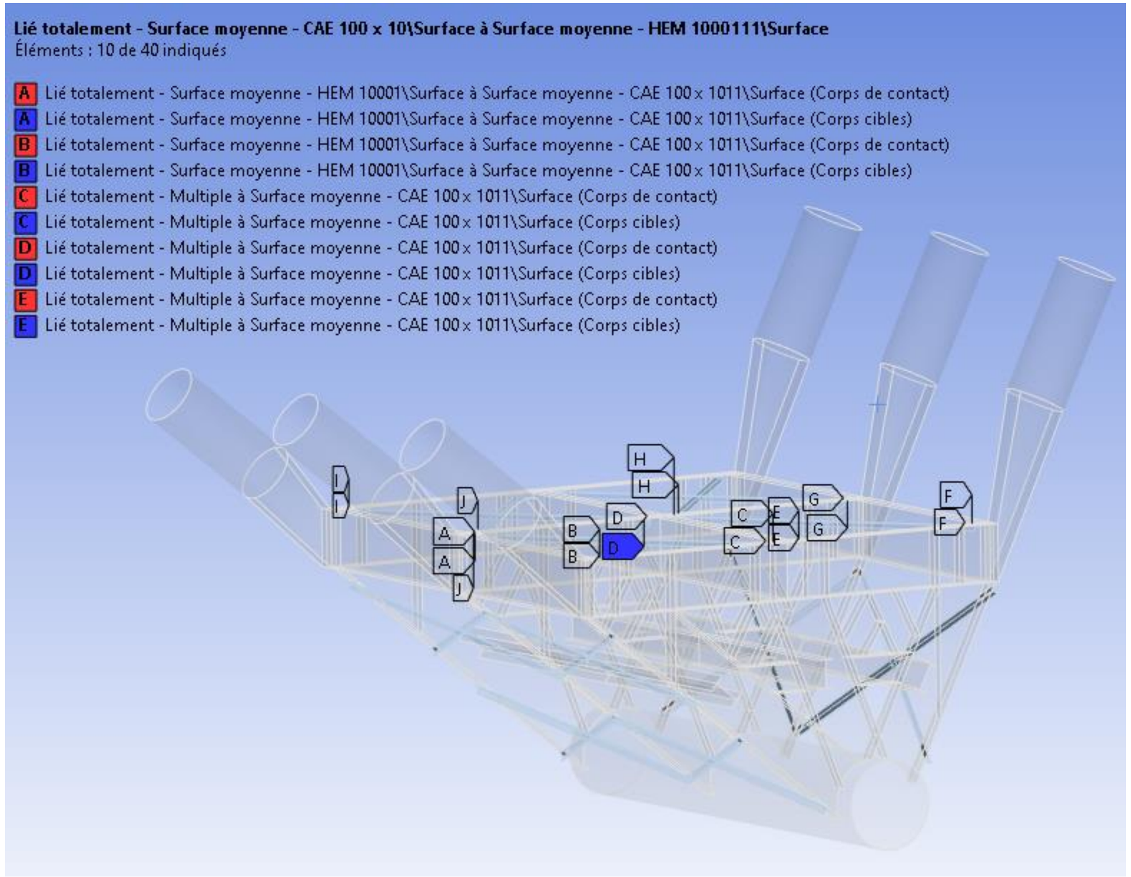




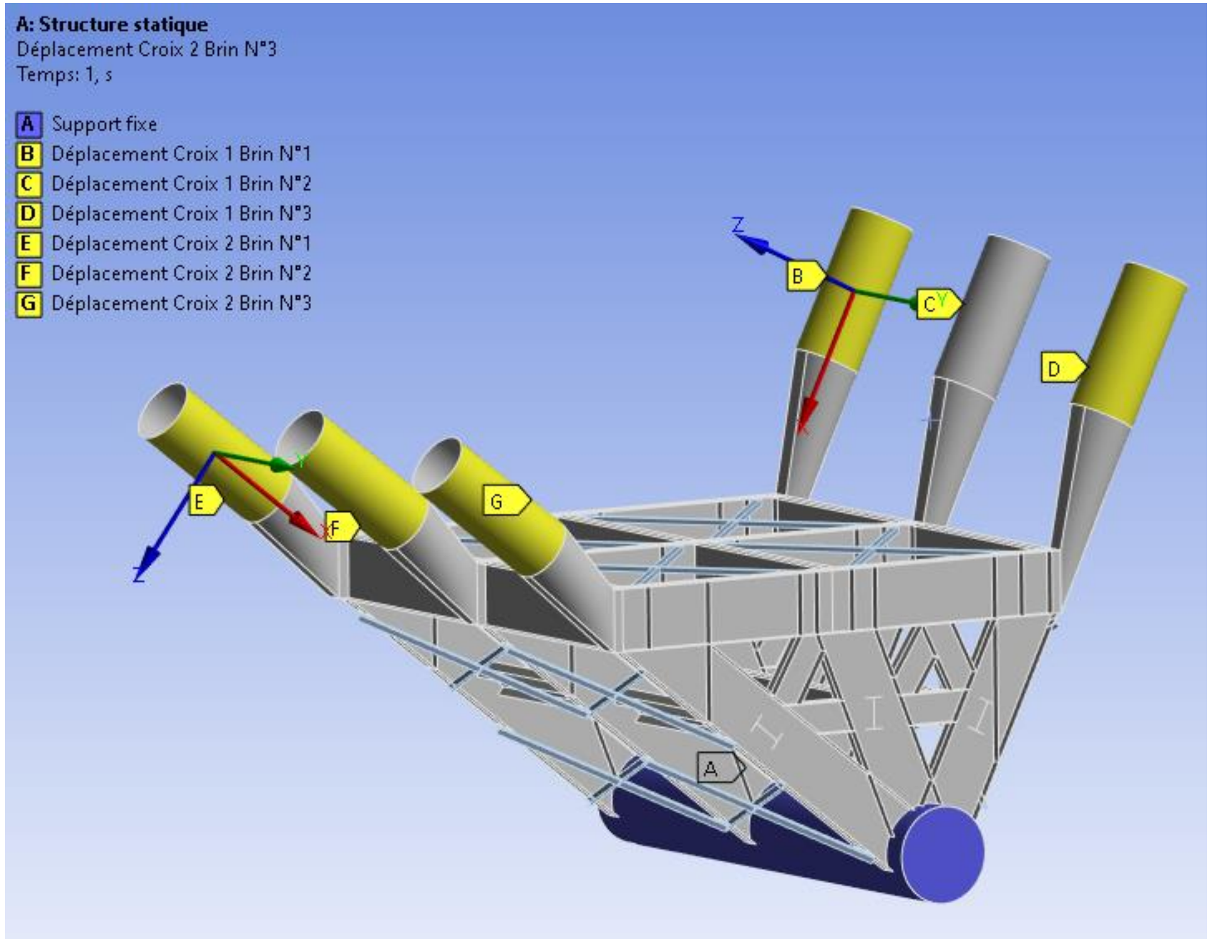
(tonnage of all the supports ≈ 6500 elephants)

Hinged support

40 contacts from welded CAE 100 x 10

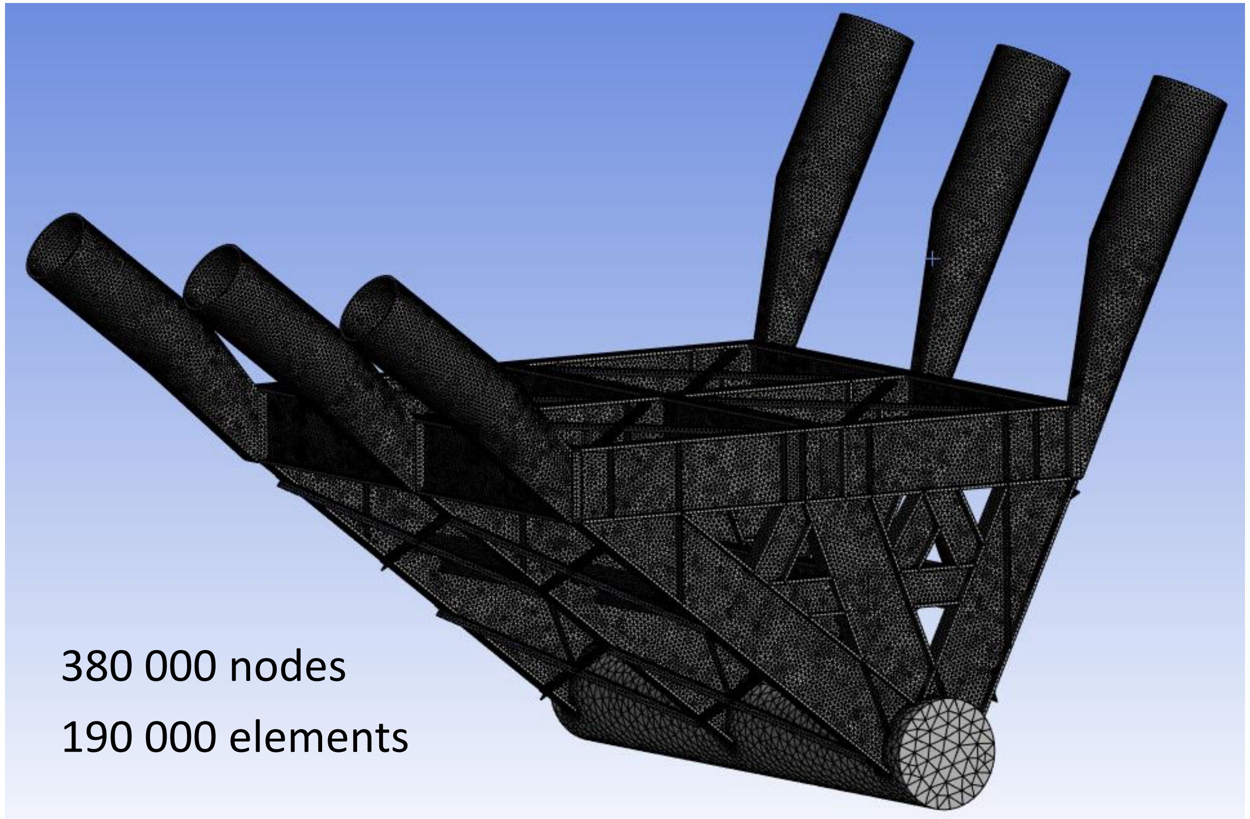


Boundary conditions

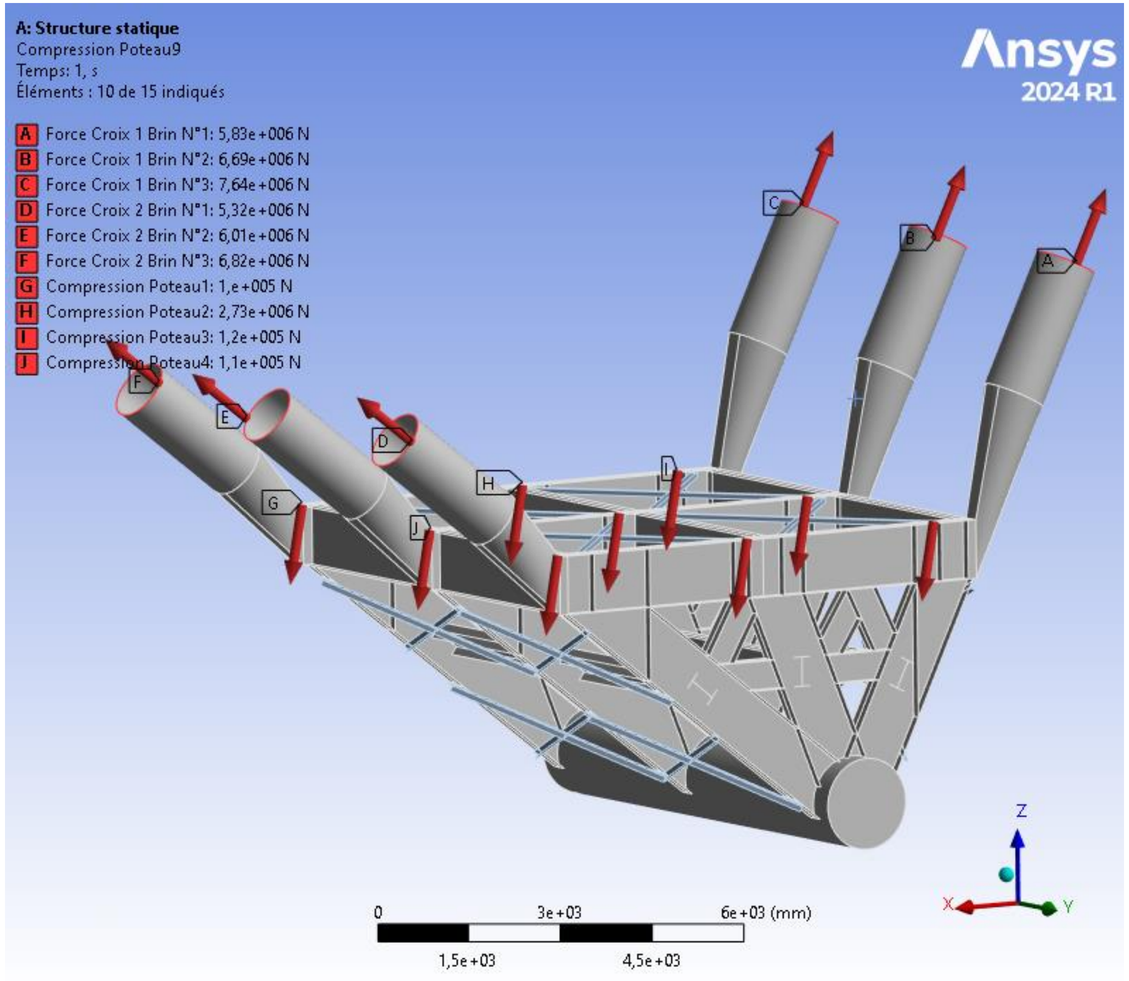


Hinged support

Mesh (triangular quadratic mesh SHELL281)

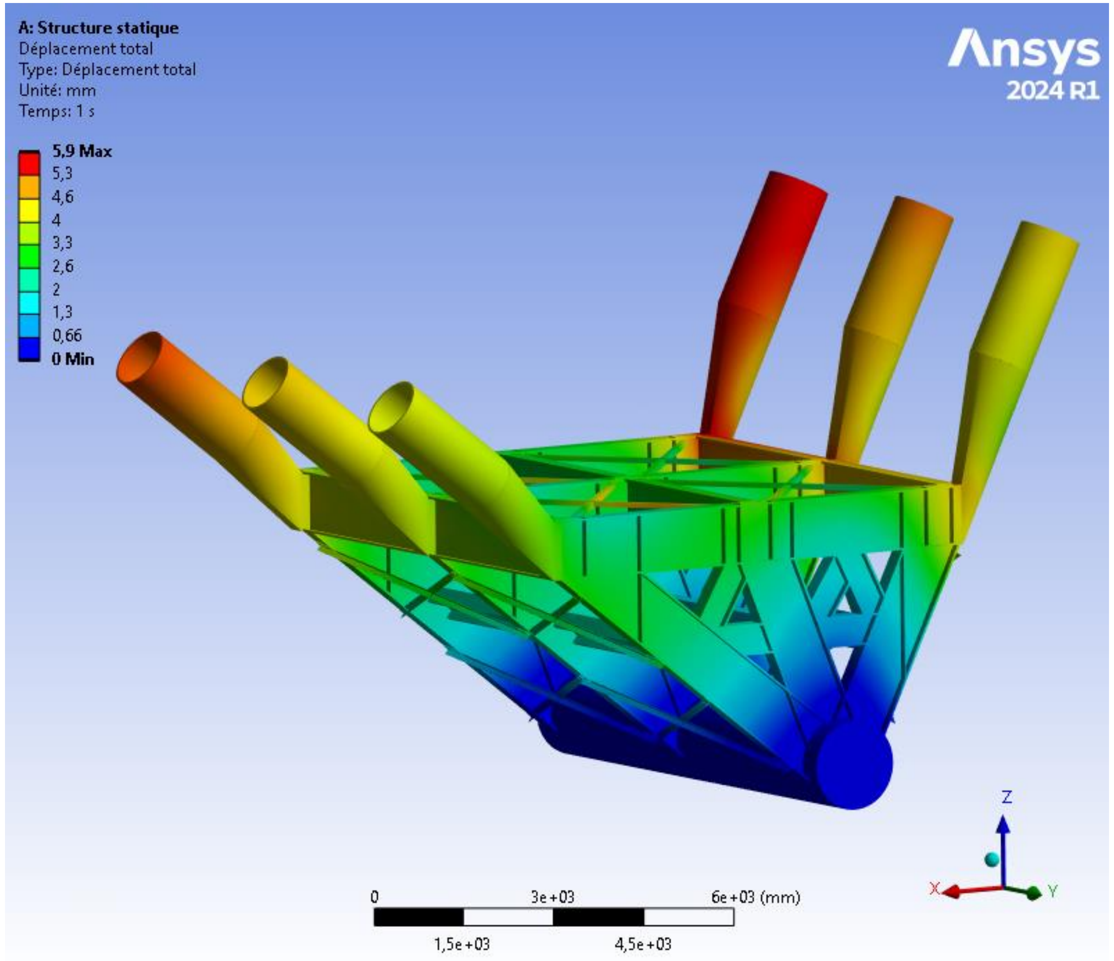


Loads coming from the 3D beam model



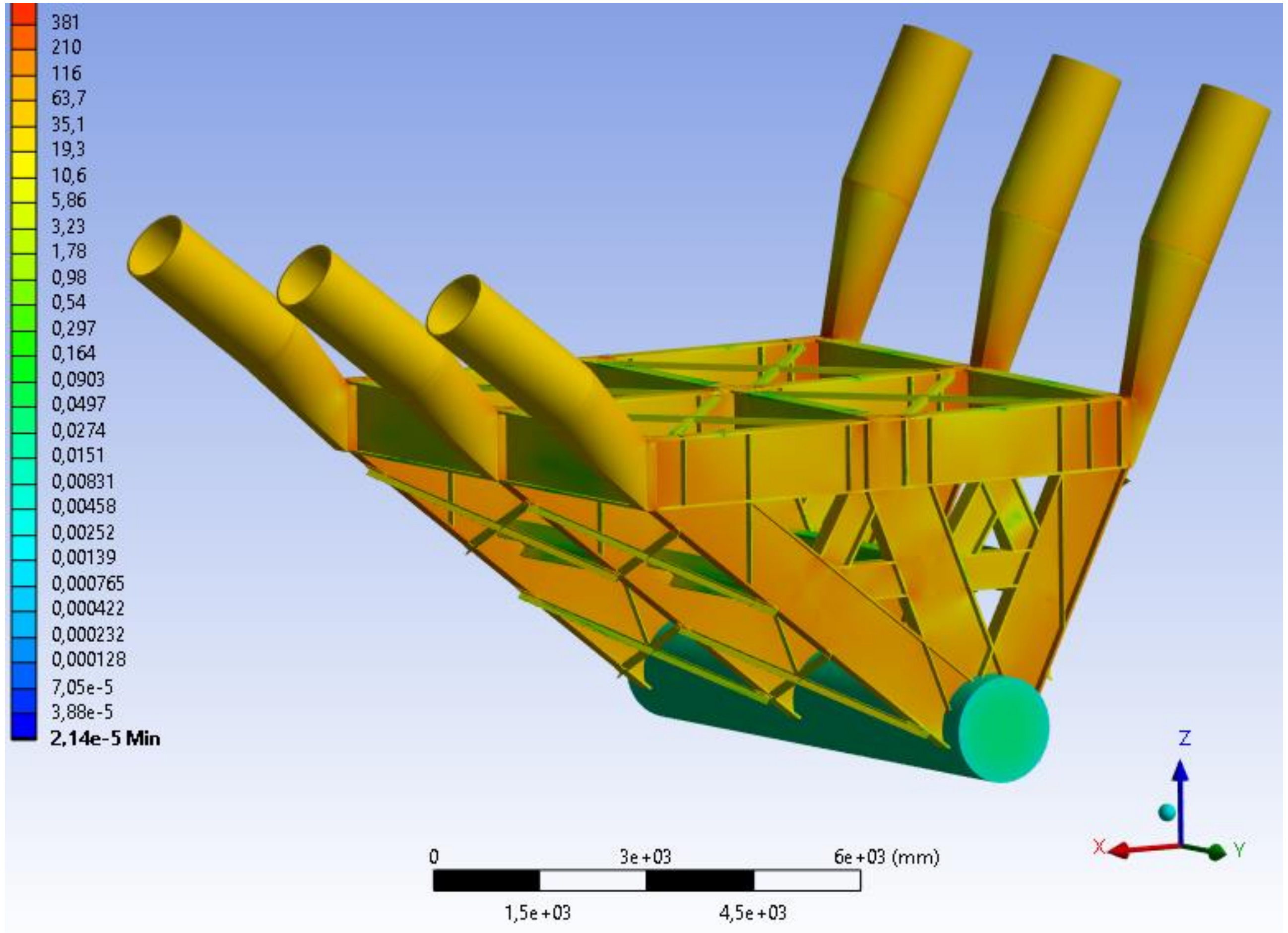
Hinged support

Total displacement

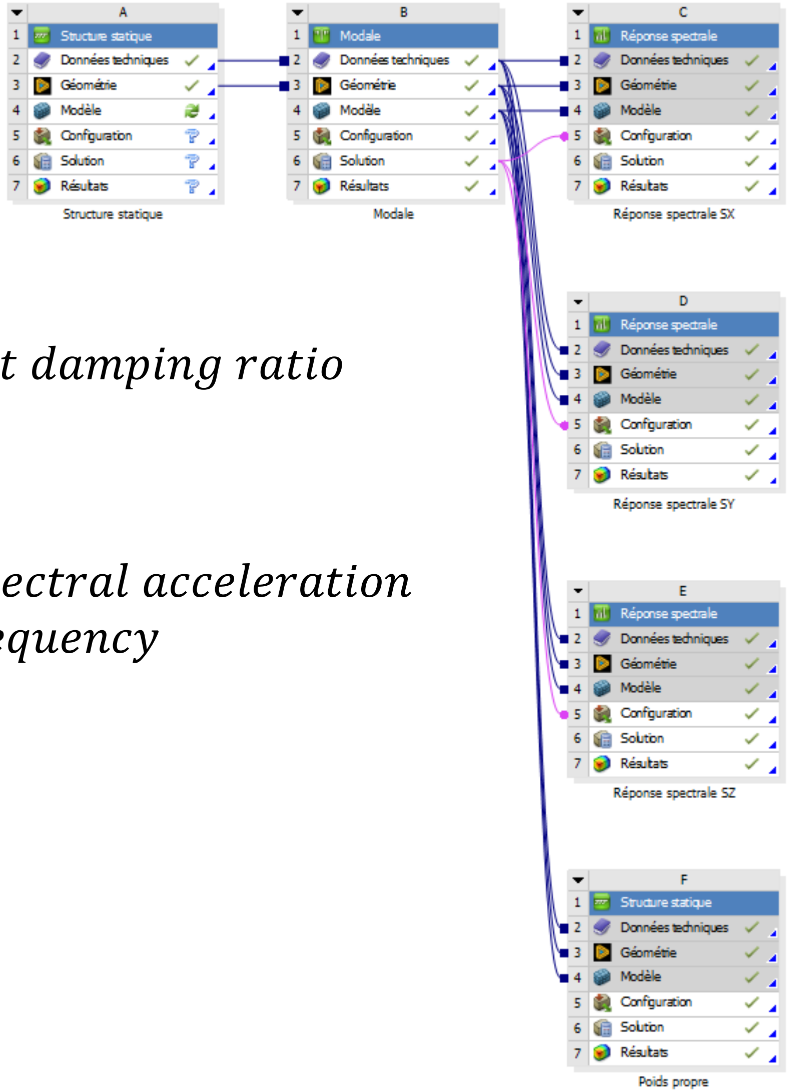


Von Mises stress (nodal values without averages)

Logarithmic scale



Modal analysis and Response Spectrum Method (RSM)



- Mode superposition method
- 15 modes
- Combination of modal response including Complete Quadratic Combination (CQC) method

$$R = \sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N}\left(R_i R_j \frac{\left(\omega_i + \omega_j\right)^2 \xi^2}{\left(\omega_i - \omega_j\right)^2 + \left(\omega_i - \omega_j\right)^2 \xi^2}\right)}$$

ξ *constant damping ratio*

- Missing mass correction : force due to missing mass

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

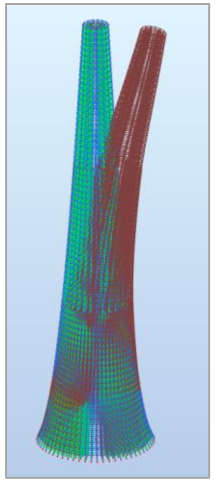
M *total mass*

$S_{A\,max}$ *highest spectral acceleration at the cutoff frequency*

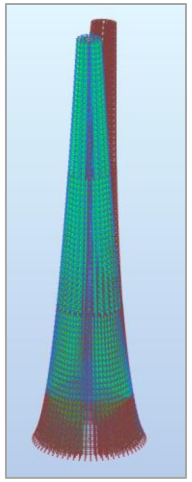
- Spatial combination (triaxial dynamic response)
  - Maximum response due to earthquake will be highest of three as given :

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

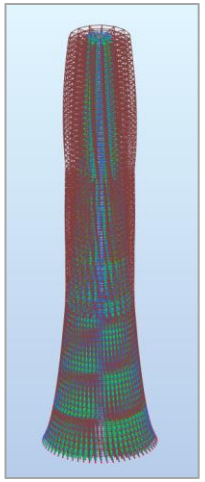
Modal analysis : preliminary results



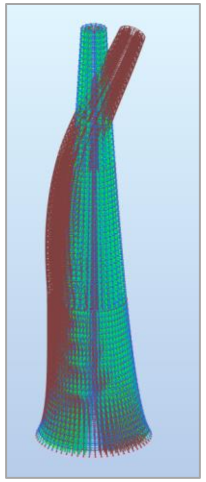
N°1 : 0.05 Hz



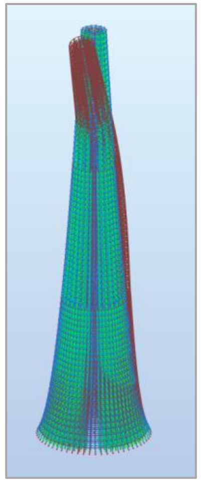
N°2 : 0.05 Hz



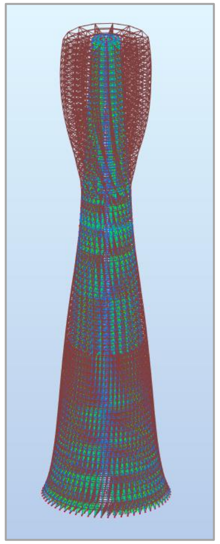
N°3 : 0.11 Hz



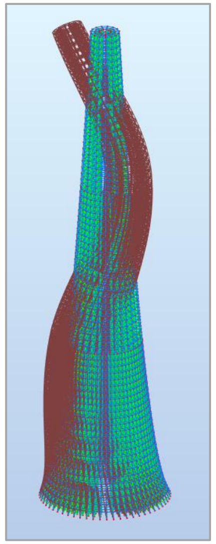
N°4 : 0.11 Hz



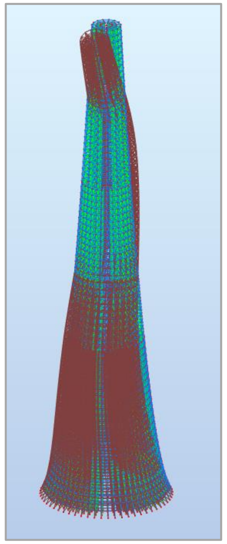
N°5 : 0.11 Hz



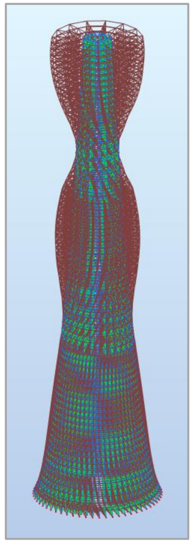
N°6 : 0.17 Hz



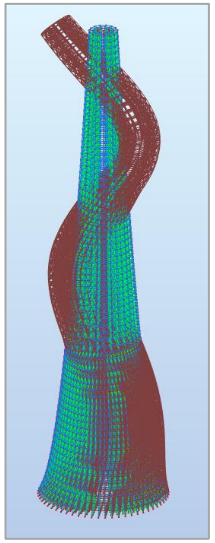
N°7 : 0.18 Hz



N°8 : 0.18 Hz



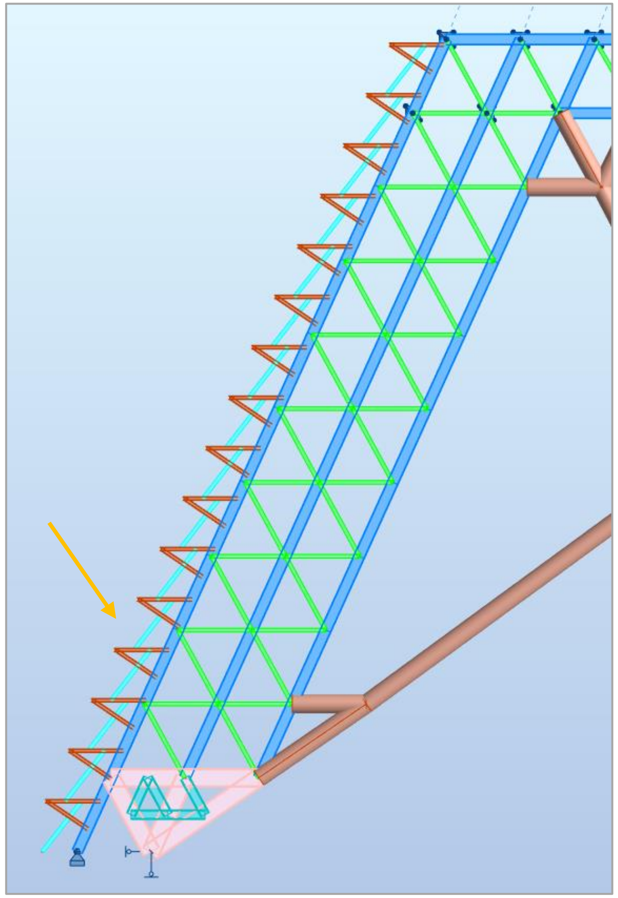
N°9 : 0.24 Hz



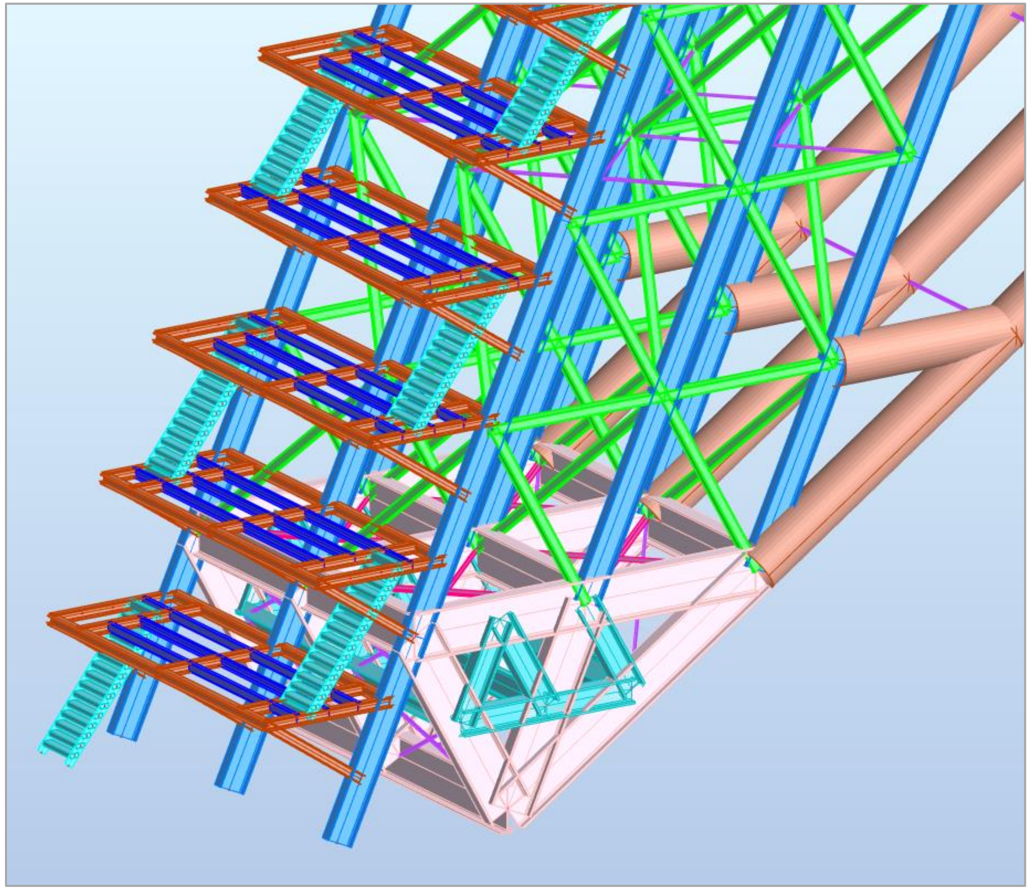
N°10 : 0.28 Hz

Stairs and walkways

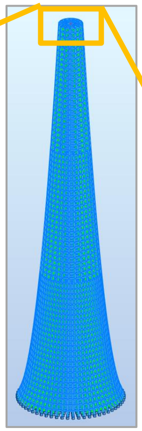
Side view



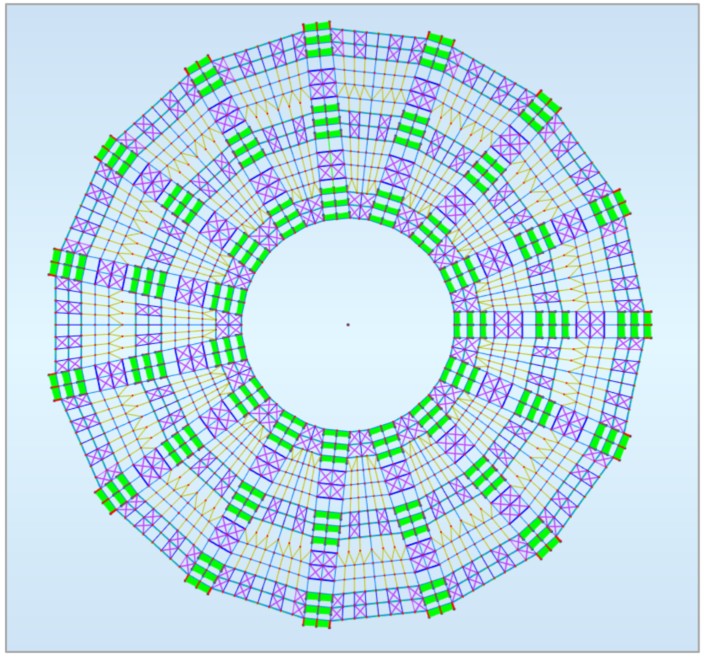
Perspective view



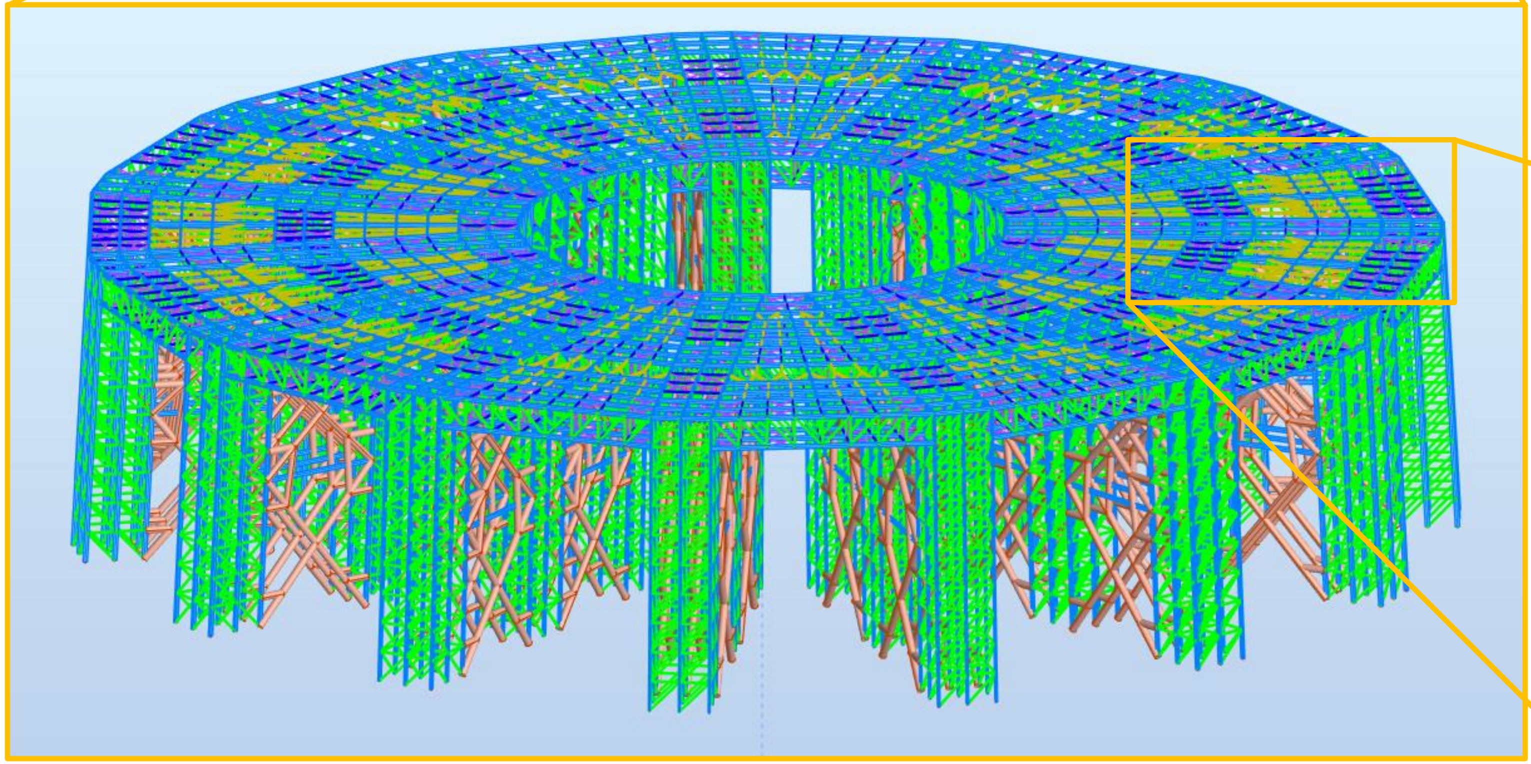
Floor z = +3000 m
(10 300 tons)

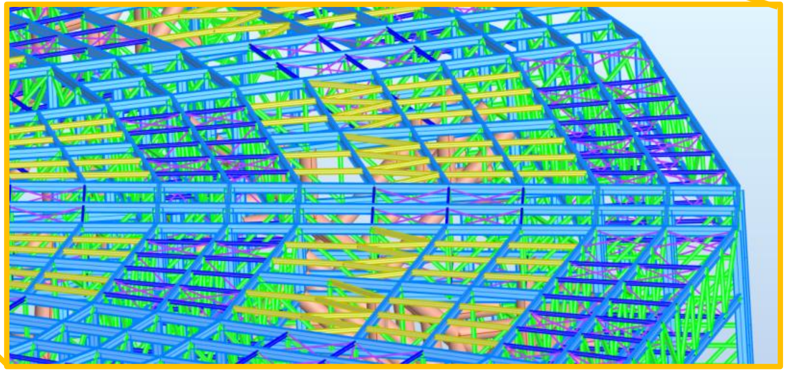


Aerial view



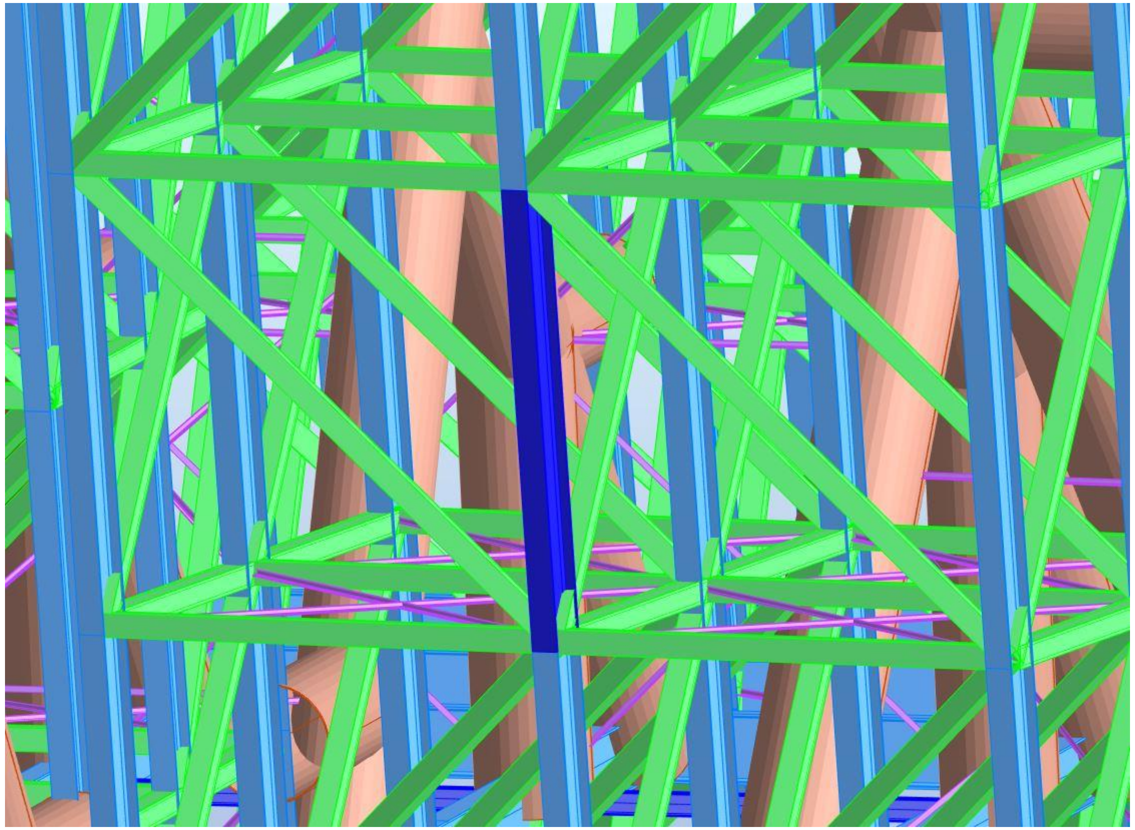
Perspective view (23 000 beam elements, 8 000 nodes)



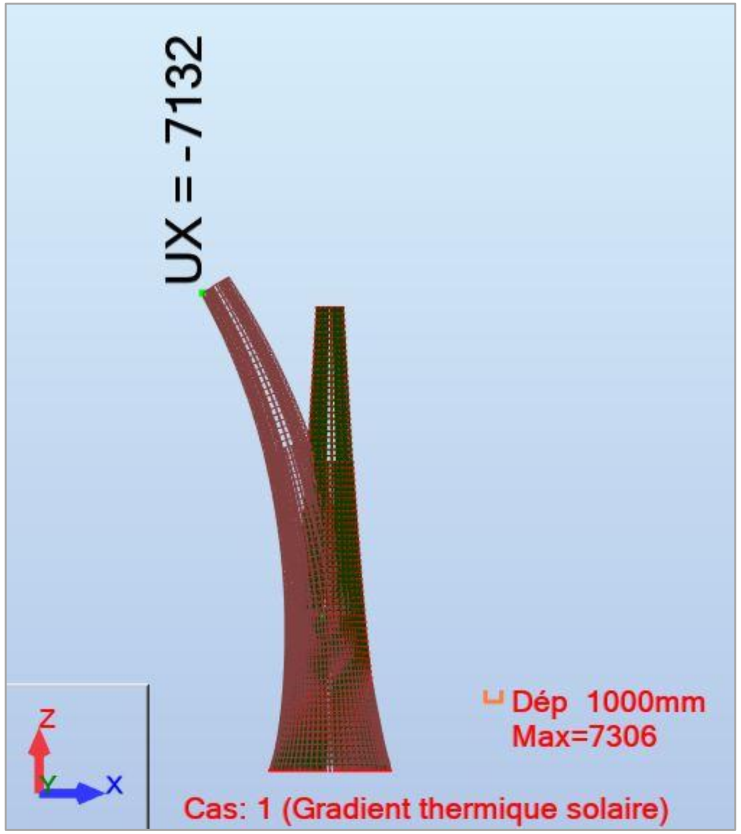


Thermal gradient from the sun

- Shadows from the beams significantly limit the thermal gradient caused by the sun



25°C/60°C thermal gradient
(never happens)



I will leave you with this question

- How can this structure be integrated into socio-ecological needs and sustainability of the future ?

Thank You!

sebastien.besse@cgindustrie.com
+33 (0)6 73 52 02 82

References

1. Baker, W.F., Korista, S., & Novak, L., Structural Design and Construction of the Burj Khalifa. Council on Tall Buildings and Urban Habitat, 2007.
2. Ali, M.M., & Moon, K. S., The Role of Structural Engineering in the Design of Tall Buildings. Architectural Science Review, 2007. 50(3): p. 205-223.
3. Smith, B.S., & Coull, A., Case Study: The Structural Design of the Jin Mao Tower. International Journal of High-Rise Buildings, 1991.
4. Charnish, B., & McNamara, R., Seismic Design of High-Rise Steel Buildings: A Case Study of the Petronas Towers. Structural Design of Tall and Special Buildings, 2002. 11(4): p. 243-260.
5. Slavid, R. Structural Challenges in the Design of the Shard, London. in Proceedings of the Institution of Civil Engineers - Structures and Buildings. 2012.
6. Smith, R.J., & Gill, P., Design and Construction of the Kingdom Tower. Structural Design of Tall and Special Buildings, 2014. 23(12): p. 897-911.
7. Klemencic, R., & Fry, J., Advanced Structural Systems for Tall Buildings: A Case Study of the Willis Tower. Journal of Structural Engineering, 2001. 127(5): p. 573-582.
8. Thornton, C.H., & DeCastro, F., Innovative Design and Construction Techniques for the Shanghai World Financial Center. CTBUH Journal, 2008. 3: p. 34-41.
9. Imai, K., & Yoshimoto, S., Structural Analysis and Design of the Tokyo Skytree. Journal of Structural Engineering, 2011. 137(12): p. 1529-1539.
10. Irwin, P., & Kilpatrick, J., Wind Engineering Challenges in the Design of the Guangzhou International Finance Center. Journal of Wind Engineering and Industrial Aerodynamics, 2010. 98(12): p. 863-876.
11. Salmon, C.G., Johnson, J. E., Steel Structures: Design and Behavior. 1996: Prentice Hall.
12. Chen, W.F., Toma, S., Advanced Analysis and Design of Steel Frames. 1994: CRC Press.
13. McCormac, J.C., Nelson, J. K., Structural Steel Design: A Practice-Oriented Approach. 2006: Prentice Hall.
14. (CEN), C.E.d.N., Eurocode 3: Design of Steel Structures. EN 1993-1-1. 2005.
15. André, J., Simões da Silva, L., Guide des Eurocodes : Introduction aux Eurocodes structurels et utilisation en France. 2010: Eyrolles.
16. Bouchair, A., Godart, B. , Application des Eurocodes aux Structures en Acier. 2012: Presses des Ponts.
17. Martin, L., Leblois, T., Conception et Calcul des Structures Métalliques selon l'Eurocode 3. 2014: Dunod.
18. Zienkiewicz, O.C., Taylor, R. L., Zhu, J. Z., The Finite Element Method: Its Basis and Fundamentals. 2005: Butterworth-Heinemann.
19. Gallagher, R.H., Zienkiewicz, O. C., The Finite Element Method in Engineering Science. 1973: McGraw-Hill.
20. Ghali, A., Neville, A. M., Brown, T. G., Structural Analysis: A Unified Classical and Matrix Approach. 2009: CRC Press.
21. Bathe, K.J., Finite Element Procedures. 1996: Prentice Hall.
22. Chandrupatla, T.R., Belegundu, A. D., Introduction to Finite Elements in Engineering. 2011: Prentice Hall.
23. Cook, R.D., Malkus, D. S., Plesha, M. E., Witt, R. J., Concepts and Applications of Finite Element Analysis. 2002: John Wiley & Sons.
24. Lagaros, N.D., Tsompanakis, Y. Structural Optimization: Proceedings of the International Conference on Engineering Optimization. 2007.
25. Arora, J.S., Introduction to Optimum Design. 2011: Academic Press.
26. Grama, L., & Saka, M. P. , Design Optimization of Steel Structures. 2016: CRC Press.
27. Bendsoe, M.P., Sigmund, O. , Topology Optimization: Theory, Methods, and Applications. 2004: Springer.
28. Timoshenko, S.P., Gere, J. M., Theory of Elastic Stability. 1961: McGraw-Hill.
29. Bazant, Z.P., Cedolin, L., Stability of Structures: Elastic, Inelastic, Fracture, and Damage Theories. 1991: Oxford University Pres.
30. Galambos, T.V., Structural Stability of Steel: Concepts and Applications for Structural Engineers. 1998: John Wiley & Sons.
31. Singer, J., Arbocz, J., Weller, T., Buckling Experiments: Experimental Methods in Buckling of Thin-Walled Structures, Volume 1: Basic Concepts, Columns, Beams, and Plates. 2002: John Wiley & Sons.
32. Besse, S., Note de calculs de la tour de 3000 mètres, C.G.d.l.I. (CGI), Editor. 2024.