International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

STUDY OF A STRUCTURE SUSPENDED FROM A SYSTEM OF STEEL COLUMNS AND TRUSSES (SYSTEM AND STABILITY)

Kisalu Nzundu David
B.S. Civil Engineering, China Three Gorges University, Université Nouveaux Horizons Academic Assistant, Lubumbashi

DOI: https://doi.org/10.29121/ijesrt.v9.i9.2020.6

ABSTRACT

Throughout history, men always wanted to build structures that are each more impressive than the next, while rising higher in the air. In this process, men were not satisfied with making sure that these structures were beautiful, impressive and majestic, but that they could also be very useful, that they fulfilled a function, and that they were able to resist the various structural constraints that will be imposed on it, or that could be imposed on it.

With this in mind, we thought of creating a structure that could both inspire this side of wonder and structural beauty, while being useful and resistant to the loads imposed on it.

In this work, we are going to talk about a building suspended to its foundation, in the sense that the building does not rest directly on the ground, but is suspended nearly eight meters from the ground by each of the three columns which support the said building by a system of trusses. The structure is made of steel with reinforced concrete slabs, which gives it a significant advantage in terms of weight. Another advantage is that it reacts quite well to earthquakes, showing only very small deflections using the equivalent lateral force method.

In this work we will focus on the stability of the members of the system that carries the building and the stability of the building in general.

KEYWORDS: steel, suspended, structure, structural analysis.

1. INTRODUCTION

PRESENTATION OF THE STRUCTURE

1.1. Architecture

The first aspect to note about the architecture of the structure is that in plan view, it resembles a star, symbolic of emphasizing the fact of always aiming higher towards the stars. When standing at the foot of the building, the goal is to leave the observer in awe of this huge triangular suspended tube.

The building has ten floors including the ground floor. It is in all 48 m high. The three columns with a truss system that support the building are placed at a distance of 15 m from each other thus forming an equilateral triangle. The building is therefore inserted between the columns having the shape of an inverted equilateral triangle with respect to the columns. The building is also attached laterally to the columns by steel beams each 8 meters, which contributes to it's overall stability.

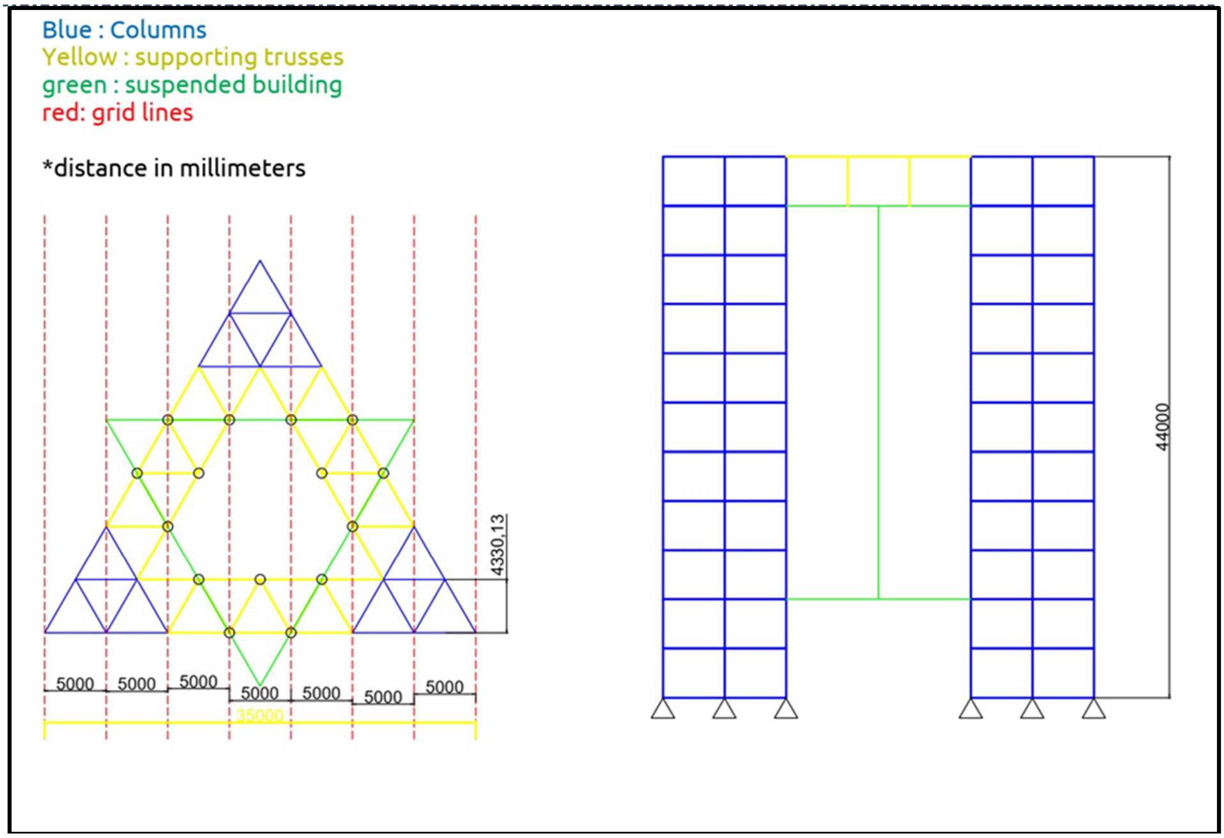


Fig. 1. Plan view and facade of the building

Although we have focused on the structural aspect of the building, we can already show that the vertical circulation in the building will be positioned in the columns thus avoiding any contact between the ground and the building. In each column there will be an elevator shaft and a stairwell.

The external aspect will consist mainly of plexiglass, the entire building will be covered with it around its perimeter. The columns will be bare, except for the parts containing the stairwell and the elevator shaft.

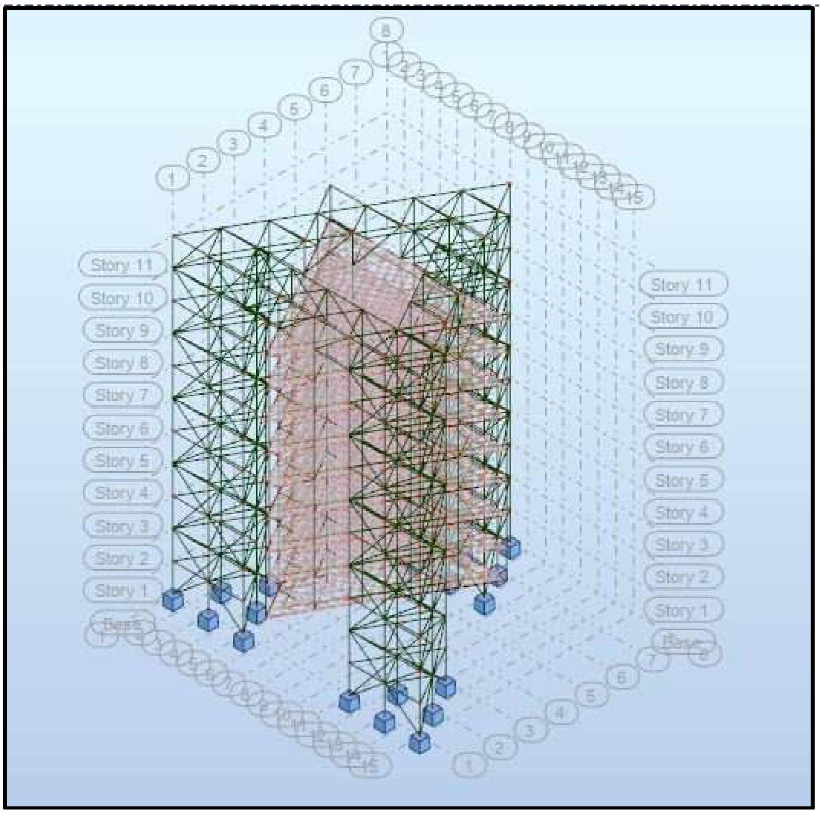


Fig 2. 3D view of the building

1.2 Structure

Materials

Steel is extremely strong; it is a hard material. It has great flexibility and can undergo significant deformations before breaking. Steel can also withstand high weights. Another important feature is that it is very shock resistant. Following all these qualities that steel can have, adding that it can also carry loads over greater distances than concrete and that it will be lighter since its sections will be smaller, the reason for the use of said material is rather obvious when it comes to suspending a building.

For slabs and stairs, we will opt for reinforced concrete. The reason we preferred concrete for the slabs is simple, its weight has an advantage when it comes to resisting lateral loads (wind, earthquakes), without however adding weight to the building.

Tab 1. Materials

	Material	E (MPa)	G (MPa)	NI	LX (1/°C)	RO (kN/m3)	Re (MPa)
1	S 355	210000,00	81000,00	0,30	0,00	77,01	355,00
2	C25/30	31000,00	12916,67	0,20	0,00	24,53	25,00
3	B500C						500,00

Members sections

Two types of sections were mainly used, round sections and H sections. Round sections were used to act as diagonals in truss systems, but also for probably easier assembly at the connections. The HEB 300 sections were mainly used in the columns, the HEB 800 mainly used in the trusses supporting the building, and also the building itself on the edges.

Tab 2. Members sections

Section name	Bar list
ROUND 200	592to789 1207to1228
HEB 800	790to793 795to799 806to814 821to829 836to844 851to859 866to874 881to889 896to904 911to919 1057to1062 1229to1252
HEB 300	2to505 507to559 561to591 800to805 815to820 830to835 845to850 860to865 875to880 890to895 905to910 934to1056 1063to1206

Section name	AX (cm2)
ROUND 200	314,16
HEB 800	334,18
HEB 300	149,08

Section name	AY (cm2)	AZ (cm2)	IX (cm4)	IY (cm4)	IZ (cm4)
ROND 200	265,07	265,07	15708,00	7853,98	7853,98
HEB 800	192,93	139,73	946,02	359084,00	14903,70
HEB 300	109,30	35,15	186,00	25165,70	8562,83

Loads on the structure

The various loads are the self-weight of the building and all the fixed charges, the live loads corresponding in this case to those of an office building, the wind loads blowing along the x and y axes greater than 50 m / s, and finally earthquakes in a high-risk area classified A.

Tab 3. Loads on building Vertical distribution of seismic forces

Case	Load type	List	Load values
1	self-weight	2to505 507to559 561to793 795to919 934to1261	PZ Negative Factor=1,00
2	uniform load	905to908 911to917 1152 1153 1181 1182	PZ=-10,00(kN/m)
2	nodal force	1136 1137 1140	FX=0,0(kN) FY=0,0(kN)
2	uniform load	815to895 897to904 909 910 918 919 1080to1082 1092to1094 1098to1170By12 1104to1106 1116to1118 1128to1130 1140to1142 1154 1163to1178By3 1164 1167 1173 1176 1179	PZ=-10,00(kN/m)
3	(FE) uniform	1253	PZ=-3,00(kN/m2)
4	(FE) uniform	1254	PZ=-3,00(kN/m2)
5	(FE) uniform	1255	PZ=-3,00(kN/m2)
6	(FE) uniform	1256	PZ=-3,00(kN/m2)
7	(FE) uniform	1257	PZ=-3,00(kN/m2)
8	(FE) uniform	1258	PZ=-3,00(kN/m2)
9	(FE) uniform	1259	PZ=-3,00(kN/m2)
10	(FE) uniform	1260	PZ=-3,00(kN/m2)
11	(FE) uniform	1261	PZ=-3,00(kN/m2)

Tab 4. Seismic load

Story	Height (m)	Mass (kg)	F(kN)	M(kN*m)
Story 1	4,00	52667,36	5,82	0,00
Story 2	4,00	178311,30	39,39	0,00
Story 3	4,00	194612,92	64,48	0,00
Story 4	4,00	186740,23	82,50	0,00
Story 5	4,00	194612,92	107,47	0,00
Story 6	4,00	186740,23	123,75	0,00
Story 7	4,00	194612,92	150,46	0,00
Story 8	4,00	186740,23	165,00	0,00

Story 9	4,00	194612,92	193,45	0,00
Story 10	4,00	197276,39	217,88	0,00
Story 11	4,00	126550,22	153,74	0,00

Trusses system

The system of trusses used to support the load of the suspended building and transmit the forces to the columns, was designed specifically to form a whole with the trusses of the three columns. The result of this arrangement is that the burdens are distributed evenly among all members up to the foundation. And as it was pointed out earlier, the round sections were used as a diagonal to avoid possible assembly difficulties.

Further study is required to accurately determine the type of connections appropriate for arranging the members together, although the ball connections may already be opted for.

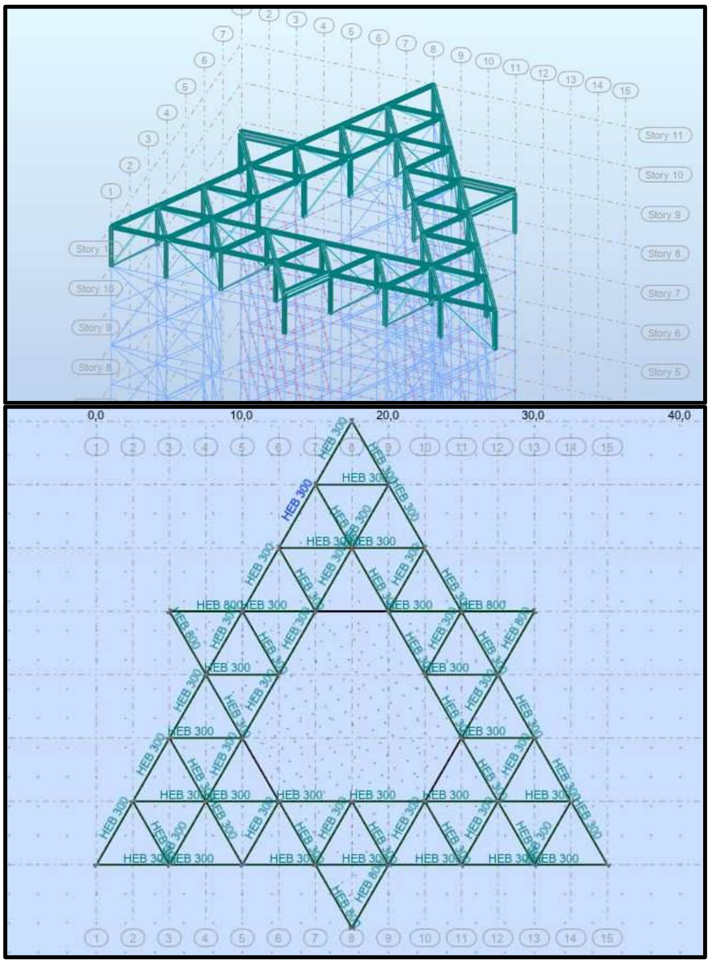


Fig 3. a and b Supporting truss

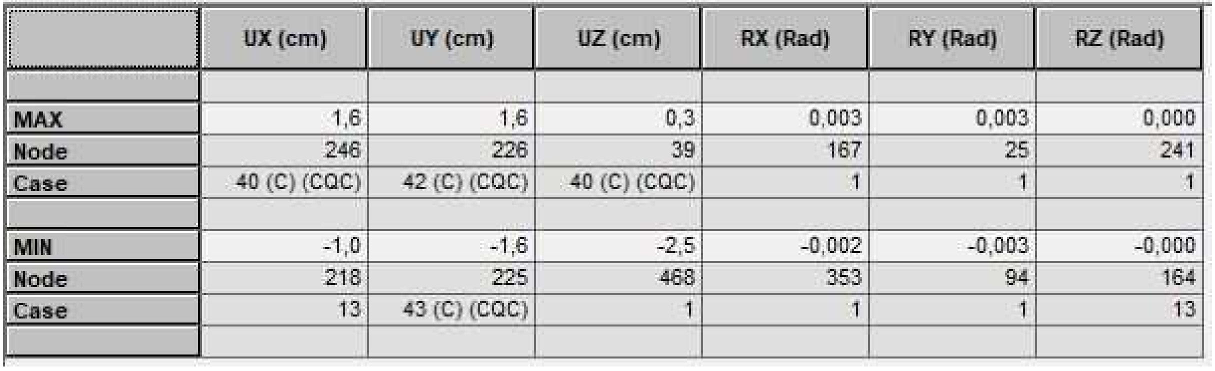
2. STRUCTURAL ANALYSIS RESULTS

2.1 General stability

After having carried out the analysis of the structure taking to also involve the combinations at the ultimate limit states and at the service limit states, we note a maximum displacement due to the self-weight of the building of 2.5 cm in the vertical direction, which remains quite reasonable as no exaggerated displacement has been observed in any of the members individually as we will see shortly.

This is a beneficial effect of the type of trusses chosen and the way it has been put together. Creating several triangles gives a fair transfer of forces, and provides general stability to the building, which can even be improved.

Tab 5. Maximum and minimum displacements



	UX (cm)	UY (cm)	UZ (cm)	RX (Rad)	RY (Rad)	RZ (Rad)
MAX	1,6	1,6	0,3	0,003	0,003	0,000
Node	246	226	39	167	25	241
Case	40 (C) (CQC)	42 (C) (CQC)	40 (C) (CQC)	1	1	1
MIN	-1,0	-1,6	-2,5	-0,002	-0,003	-0,000
Node	218	225	468	353	94	164
Case	13	43 (C) (CQC)	1	1	1	13

We will therefore have as details of the loads for the analysis, the following*:*
Autodesk Robot Structural Analysis Professional 2020
Characteristics of analysis example:

Structure type: Shell and steel frame

Structure geometrical center coordinates:
X = 17.500 *(m)*
Y = 12.990 *(m)*
Z = 22.000 *(m)*

Structure gravity center coordinates:
X = 17.497 *(m)*
Y = 10.115 *(m)*
Z = 24.396 *(m)*

Central moments of inertia of a structure:
Ix = 360551282.431 *(kg*m2)*
Iy = 359930156.033 *(kg*m2)*
Iz = 216227342.045 *(kg*m2)*
Mass = 1893477.638 *(kg)*

Structure description

Number of nodes:	3017
Number of bars:	1234
Bar finite elements:	2315
Planar finite elements:	2916
Volumetric finite elements:	0
Rigid links:	0
Releases:	0
Unidirectional releases:	0
Non-linear releases:	0
Compatibilities:	0
Elastic compatibilities:	0
Non-linear compatibilities:	0
Supports:	18
Elastic supports:	0

Unidirectional supports: 0
Non-linear supports: 0
Non-linear hinges: 0
Cases: 20
Combinations: 4

Calculation summary

Solution method - Multi-threaded solver
No of static degr. of freedom: 17994

Stiffness matrix diagonal elements
Min/Max after decomposition: 3.338462e+05 2.078375e+10
Precision: 10

Table of load cases / analysis types

Case 1 : DL1
Analysis type: Static - Linear

Potential energy : 1.35186e+02 (kN*m)
Precision : 6.63273e-06

Case 2 : DL2
Analysis type: Static - Linear

Potential energy : 3.76834e+01 (kN*m)
Precision : 9.72949e-06

Case 3 to case 11 : Live loads
Analysis type: Static - Linear

Potential energy (per load) : 6.80411e-01 (kN*m)
Precision (per load) : 2.80289e-06

Case 12 : Wind Simulation Y+ 51,05 m/s
Analysis type: Static - Linear

Potential energy : 5.31373e+00 (kN*m)
Precision : 8.64546e-07

Data:
Wind pressure : 1.57 (kPa)
Terrain level : 0.00 (m)
Wind profile : Constant
Exposed elements : Whole structure
Openings : Closed for the wind flow
Stop criterion : Manual

Sum of main forces : 1491.502 (kN)
Sum of perpendicular forces : 4.758 (kN)
Sum of vertical forces : 48.244 (kN)
Precision : 1.33 (%)

Sum of forces may differ due to model simplification (forces on panel/cladding sidewalls and bar top/bottom side are neglected)

Case 13 : Wind Simulation X-Y- 51,05 m/s
Analysis type: Static - Linear

Potential energy : 5.41267e+00 (kN*m)
Precision : 4.89894e-06

Data:
Wind pressure : 1.57 (kPa)
Terrain level : 0.00 (m)
Wind profile : Constant
Exposed elements : Whole structure
Openings : Closed for the wind flow
Stop criterion : Manual

Sum of main forces : 1367.416 (kN)
Sum of perpendicular forces : 367.007 (kN)
Sum of vertical forces : 53.329 (kN)
Precision : 1.07 (%)
Sum of forces may differ due to model simplification (forces on panel/cladding sidewalls and bar top/bottom side are neglected)

Case 14 : Wind Simulation X+Y- 51,05 m/s
Analysis type: Static - Linear

Potential energy : 5.76359e+00 (kN*m)
Precision : 4.13093e-06

Data:
Wind pressure : 1.57 (kPa)
Terrain level : 0.00 (m)
Wind profile : Constant
Exposed elements : Whole structure
Openings : Closed for the wind flow
Stop criterion : Manual

Sum of main forces : 1417.315 (kN)
Sum of perpendicular forces : -304.213 (kN)
Sum of vertical forces : 22.932 (kN)
Precision : 4.65 (%)
Sum of forces may differ due to model simplification (forces on panel/cladding sidewalls and bar top/bottom side are neglected)

Case 38 : EN 1998-1:2004 Direction_X
Analysis type: Static - Seismic
Excitation direction:
X = 1.000
Y = 0.000
Z = 0.000
Data:
Site : A

Spectrum type : 1
Behavior factor : 1,00

Spectrum parameters:
Acceleration : a_g = 1,00
S = 1,00 b = 0,20 T_B = 0,15 T_C = 0,40 T_D = 2,00

Fundamental period:
Approximated method T = 1,45 (s)
Steel frames C_t = 0.085

Structure range:
Top story Story 11
Bottom story Story 1

Effective height H_n = 44,00(m)

Base shear
$S_d(T_1)$ = 0,69
m = 1893477,64 (kg)
l = 1,00
Shear force V = 1303,92(kN)

Vertical distribution of seismic forces

Story	Height (m)	Mass (kg)	F(kN)	M(kN*m)
Story 1	4,00	52667,36	5,82	0,00
Story 2	4,00	178311,30	39,39	0,00
Story 3	4,00	194612,92	64,48	0,00
Story 4	4,00	186740,23	82,50	0,00
Story 5	4,00	194612,92	107,47	0,00
Story 6	4,00	186740,23	123,75	0,00
Story 7	4,00	194612,92	150,46	0,00
Story 8	4,00	186740,23	165,00	0,00
Story 9	4,00	194612,92	193,45	0,00
Story 10	4,00	197276,39	217,88	0,00
Story 11	4,00	126550,22	153,74	0,00

Case 39 : EN 1998-1:2004 Direction_Y
Analysis type: Static - Seismic
Excitation direction:
X = 0.000
Y = 1.000
Z = 0.000

Data:
Site : A
Spectrum type : 1
Behavior factor : 1,00

Spectrum parameters:
Acceleration : a_g = 1,00
S = 1,00 b = 0,20 T_B = 0,15 T_C = 0,40 T_D = 2,00

Fundamental period:

Approximated method T = 1,45 (s)
Steel frames C_t = 0.085

Structure range:

Top story	Story 11
Bottom story	Story 1

Effective height H_n = 44,00(m)

Base shear

$S_d(T_1)$ = 0,69
m = 1893477,64 (kg)
l = 1,00
Shear force V = 1303,92(kN)

Vertical distribution of seismic forces

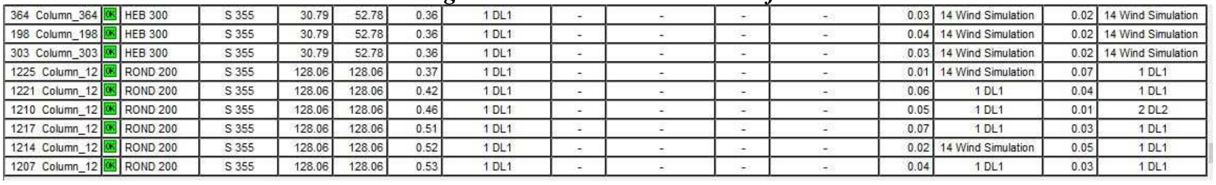
Story	Height (m)	Mass (kg)	F(kN)	M(kN*m)
Story 1	4,00	52667,36	5,82	0,00
Story 2	4,00	178311,30	39,39	0,00
Story 3	4,00	194612,92	64,48	0,00
Story 4	4,00	186740,23	82,50	0,00
Story 5	4,00	194612,92	107,47	0,00
Story 6	4,00	186740,23	123,75	0,00
Story 7	4,00	194612,92	150,46	0,00
Story 8	4,00	186740,23	165,00	0,00
Story 9	4,00	194612,92	193,45	0,00
Story 10	4,00	197276,39	217,88	0,00
Story 11	4,00	126550,22	153,74	0,00

Case 40 to 43 :
Analysis type: Linear combination

2.2 Members stability

Using the various analysis parameters above, we performed the design and verification of each member. We have found that in the majority of cases the governing load is the self-weight of the structure as can also be seen in the image Fig 4. This can be explained in the sense that the building does not rest directly on the ground, and therefore its own weight due to gravity becomes very important. In the following image you can see the ten most loaded members, their section and the safety ratio. You can easily see that the "ok" highlighted in green indicates that all the standards in terms of deformation, deflection and stability have been met.

Fig 4. Most loaded members are safe



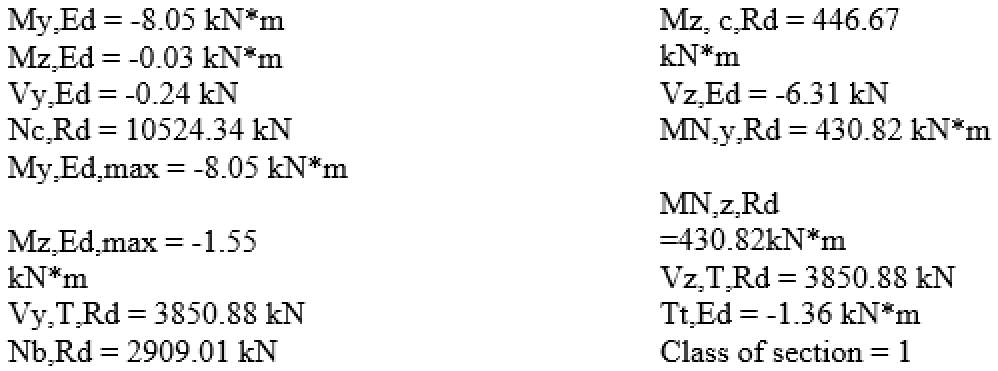
364 Column_364	OK	HEB 300	S 355	30.79	52.78	0.36	1 DL1	-	-	-	-	0.03	14 Wind Simulation	0.02	14 Wind Simulation
198 Column_198	OK	HEB 300	S 355	30.79	52.78	0.36	1 DL1	-	-	-	-	0.04	14 Wind Simulation	0.02	14 Wind Simulation
303 Column_303	OK	HEB 300	S 355	30.79	52.78	0.36	1 DL1	-	-	-	-	0.03	14 Wind Simulation	0.02	14 Wind Simulation
1225 Column_12	OK	ROND 200	S 355	128.06	128.06	0.37	1 DL1	-	-	-	-	0.01	14 Wind Simulation	0.07	1 DL1
1221 Column_12	OK	ROND 200	S 355	128.06	128.06	0.42	1 DL1	-	-	-	-	0.06	1 DL1	0.04	1 DL1
1210 Column_12	OK	ROND 200	S 355	128.06	128.06	0.46	1 DL1	-	-	-	-	0.05	1 DL1	0.01	2 DL2
1217 Column_12	OK	ROND 200	S 355	128.06	128.06	0.51	1 DL1	-	-	-	-	0.07	1 DL1	0.03	1 DL1
1214 Column_12	OK	ROND 200	S 355	128.06	128.06	0.52	1 DL1	-	-	-	-	0.02	14 Wind Simulation	0.05	1 DL1
1207 Column_12	OK	ROND 200	S 355	128.06	128.06	0.53	1 DL1	-	-	-	-	0.04	1 DL1	0.03	1 DL1

Here are the results of the analysis of the most loaded member:
LOADS:
Governing Load Case: 1 DL1

MATERIAL:
S 355 (S 355) fy = 335.00 MPa

SECTION PARAMETERS: ROND 200
h=20.0 cm gM0=1.00 gM1=1.00
Ay=200.00 cm2 Az=200.00 cm2 Ax=314.16 cm2
tw=10.0 cm Iy=7853.98 cm4 Iz=7853.98 cm4 Ix=15708.00 cm4
Wply=1333.33 cm3 Wplz=1333.33 cm3

INTERNAL FORCES AND CAPACITIES:



N,Ed = 1476.66 kN
My,Ed = -8.05 kN*m
Mz,Ed = -0.03 kN*m
Vy,Ed = -0.24 kN
Nc,Rd = 10524.34 kN
My,Ed,max = -8.05 kN*m
Mz,Ed,max = -1.55 kN*m
Vy,T,Rd = 3850.88 kN
Nb,Rd = 2909.01 kN

My,c,Rd = 446.67 KN*m
Mz, c,Rd = 446.67 kN*m
Vz,Ed = -6.31 kN
MN,y,Rd = 430.82 kN*m
MN,z,Rd =430.82kN*m
Vz,T,Rd = 3850.88 kN
Tt,Ed = -1.36 kN*m
Class of section = 1

LATERAL BUCKLING PARAMETERS:
BUCKLING PARAMETERS:
About y axis: About z axis:
Ly = 6.40 m Lam_y = 1.63 Lz = 6.40 m Lam_z = 1.63
Lcr,y = 6.40 m Xy = 0.28 Lcr,z = 6.40 m Xz = 0.28
Lamy = 128.06 kyy = 1.40 Lamz = 128.06 kyz = 0.53

VERIFICATION FORMULAS:
Section strength check:
N,Ed/Nc,Rd = 0.14 < 1.00 (6.2.4.(1))
My,Ed/MN,y,Rd = 0.02 < 1.00 (6.2.9.1.(2))
Mz,Ed/MN,z,Rd = 0.00 < 1.00 (6.2.9.1.(2))
(My,Ed/MN,y,Rd)^ 2.00 + (Mz,Ed/MN,z,Rd)^2.00 = 0.00 < 1.00 (6.2.9.1.(6))
Vy,Ed/Vy,T,Rd = 0.00 < 1.00 (6.2.6-7)
Vz,Ed/Vz,T,Rd = 0.00 < 1.00 (6.2.6-7)
Tau,ty,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)
Tau,tz,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)

Global stability check of member:
Lambda,y = 128.06 < Lambda,max = 210.00 Lambda,z = 128.06 < Lambda,max = 210.00 STABLE
N,Ed/(Xy*N,Rk/gM1) + kyy*My,Ed,max/(XLT*My,Rk/gM1) + kyz*Mz,Ed,max/(Mz,Rk/gM1) = 0.53 < 1.00 (6.3.3.(4))
N,Ed/(Xz*N,Rk/gM1) + kzy*My,Ed,max/(XLT*My,Rk/gM1) + kzz*Mz,Ed,max/(Mz,Rk/gM1) = 0.53 < 1.00 (6.3.3.(4))

LIMIT DISPLACEMENTS
Deflections (LOCAL SYSTEM): *Not analyzed*
Displacements (GLOBAL SYSTEM):
vx = 0.2 cm < vx max = L/150.00 = 4.3 cm Verified
Governing Load Case: 1 DL1
vy = 0.1 cm < vy max = L/150.00 = 4.3 cm Verified
Governing Load Case: 1 DL1
Section OK !!!

2.3 Earthquake resistance

As we discussed previously, a structure organized in this way, that is, by creating triangles in our trusses and in its general shape, efficiently and fairly transmits the forces in the structure. The method used is that of equivalent lateral loads, which is an approximate one but which has nevertheless proven its worth over the years. As we can see in Table Tab 5 the displacements due to the seismic loads do not exceed a maximum of 1.5 cm, which is a more than satisfactory response.
Further analysis is still necessary to obtain more detailed results for the seismic analysis.

3. CONCLUSIONS

In conclusion, here is what we can take away from this study:

- Building a suspended building is possible, as long as one takes into account important parameters such as the cost, the mass of the building, the ultimate limit states and the service limit states which must not be reached, and it is by taking into account all these data that we were able to propose a steel model, this one conferring non-negligible advantages in terms of resistance, span and weight, organized in trusses to distribute evenly the constraints in the supporting structure ;
- The advantages facing the equivalent lateral and lateral loads (wind and earthquakes) are very encouraging in the sense that the deflections induced by these loads are very minimal. Although an in-depth seismic study is necessary, the preliminary results obtained are encouraging;
- Although the architecture has not been worked on in depth on this building, it has potential for innovation, some improvements are obviously possible, hoping to pave the way for work of the same kind much more elaborate.

REFERENCES

[1] Matadi Bridge (Le Pont Maréchal) Construction Project, http://www.jsce.or.jp/e/archive/project/pj02.html (1979)
[2] Matadi Suspension Bridge, https://structurae.net/structures/matadi-suspension-bridge (1979)
[3] Ito, M. / Yachida, M. / Naruse, T., Matadi Bridge over the Zaire River (1979)
[4] Democratic Republic of the Congo, https://en.wikipedia.org/wiki/Democratic_Republic_of_the_Congo#Mining
[5] NEHRP Recommended Provisions: Design Examples (2006)
[6] Dr. Seshu Adluri, Structural Steel Design Beam-Columns (2017)

[7] AMERICAN INSTITUTE OF STEEL CONSTRUCTION, Specification for Structural Steel Buildings, July 7, (2016)
[8] Transportation Research Board. 1991. p. 130., Bridge Aesthetics Around the World (1991)
[9] Xu Huahua, Architectural Design & Construction (2016)
[10] G.A.R. Parke, B. Young, R. Ziemian, Journal of Constructional Steel Research
[11] R. Bjorhovde, Structural steel research and design: Where are we headed? (2007)
[12] N. Trahair, M. Bradford, D. Nethercot, L. Gardner, The Behaviour and Design of Steel Structures to EC3 - 4th Edition (2007)
[13] Crios Do Remedios, The Value of Fundamental Research (Article) (2006)
[14] Leet, fundamentals of structural analysis (1988)
[15] Chris Grimley, the interior design: reference and specifications book (2013)
[16] Browns, Iles, Yandzio, steel building design : medium rise braced frame in accordance with the Eurocodes and the UK national annexes (2008)