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Comparative Study of the Normative Requirements for the Design of a Lattice Pylon: Case of A 225 kV Transmission Line

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ABSTRACT

It is undeniable that a correct estimate of the loads likely to affect a structure throughout its useful life is the key to any design. Moreover, a thorough knowledge of the parameters used to estimate these loads makes it possible to refine the calculations while giving a certain confidence to the designer. This is why this paper presents a comparative study of some standards directly affecting the wind loads applied to the components of electrical power transmission lines (in particular the standards NF EN 50341-1: 2012, DIN VDE 0210-2011 and IEC 60826 - 2003) and the resistance of the latter to the various forces which are transmitted in the bars (ASCE 10 and NF EN 50341-1:2001). To carry out this work, it was first a question of analyzing and understanding each dimensioning standard, then of visualizing the global environment of the different calculation rules, emphasizing the reason underlying the choice of a specific standard, and finally comparing these standards from the data of a specification. Regarding wind loads, it generally emerges that the DIN VDE 0210: 2011 standard is the most suitable for dimensioning because it gives the lowest load values. As for the verification of the stability of the structure, the comparison between the ASCE 10 and NF EN 50341-1:2001 standards for a triangle arming pylon of a 225 kV line showed that for the same work rate (97 %), the busiest bar has the dimensions 150 cm x 150 cm x 14 mm and 140 cm x 140 cm x 14 mm respectively for the ASCE 10 and NF EN 50341-1:2001 standards; which amounts to a saving of 13.44 kg in terms of mass and 8829.81 FCFA in terms of cost.

Keywords: Norm; charge; resistance; comparison; optimal.

1. Introduction

Access to sustainable electrical energy is an essential basis for the development of all countries. The means deployed in this sector are enormous and are constantly increasing, all this with the aim of covering all regions of the world. Since 2010, more than a billion people have been connected to electricity [1]. Thus, in 2019, 90% of the world's population had access to electricity [1]. This shows the quality of the efforts made by the various governments of the world to guarantee access to electricity for all populations and contribute to the achievement of the Sustainable Development Goals (SDGs).

However, despite these efforts, a large part of the world's population still does not have access to electricity. About 700 million people in the world do not have access to electricity and 600 million are sub-Saharan Africans [2]. Several reasons explain this delay, in particular the lack of infrastructure for the transport and distribution of this energy. Indeed, the transport of electricity from the source (hydroelectric dam, thermal power plant, solar power plant, etc.) to the population, requires a large network of pylons in the case of overhead transmission lines. The construction and commissioning of such infrastructures require not only colossal funds but also considerable experience and know-how in this area to ensure the stability, optimization and continuity of line service. The proof is that the interconnection of Mali and Guinea by a high-voltage line required more than 71 million euros [3]. This is how *Vinci Energies*, based on its experience in Morocco, has expanded its field of action in West Africa, particularly in sub-Saharan countries.

Thus, as part of Benin's Sustainable and Secure Access to Electricity Project (PADSBEE) [4], the company *Vinci Energies* designs and sizes several families of lattice towers. This hard work is done according to standards, which ensure the reliability of structures and compliance with regulations in the field. In the case of pylons, the application of standards makes it possible to guarantee better safety in the face of the most unfavorable climatic conditions, thus avoiding breakdowns on transmission lines which require very expensive maintenance following an accident like the one that killed 26 people in Kinshasa. following the fall of a high-voltage cable [5]. However, African countries have not yet established standards allowing them to frame the conditions for setting up such infrastructures. Indeed, the standards used for the design of the pylons are of European and American origins. This is why we have chosen to compare the normative requirements for the design of overhead electrical power transmission lines, based on different realities, to determine those which are the most suitable for the dimensioning of metal infrastructures such as pylons in the countries of West Africa.

2. Materials and methods

2.1. Materials

The main materials used to carry out this study are:

a) Standards NF EN 50341-1:2012, DIN VDE 0210:2011 and IEC 60826:2003
b) Excel from Microsoft Office and TOWER from Power Line Systems

Table 1 presents the units of measurement and their symbols.

2.2. Methods

The design of any building is done on the basis of well-defined requirements which vary according to the standards. For the particular case of the pylons, the standards intervene at two levels of the design:

- for the evaluation of the loads caused by the action of the wind on the structure
- for checking the strength of the structure.

a) Comparison of wind load calculation standards

The calculation of the efforts on the pylon is one of the most important stages of the design because it makes it possible to know the various loads that this last must support throughout its lifespan. Among these loads, those caused by the action of the wind are those that depend on the standards. To compare them, three standards were studied: NF EN 50341-1:2012, DIN VDE 0210:2011 and IEC 60826:2003. The expressions of the loads presented by the three standards were first compared as indicated by expressions (1) to (11) [6-8] to highlight the similarities and differences in the calculation of the main parameters which are the dynamic wind pressure and the drag coefficient.

Then, the loads were evaluated for a 225 kV line with the three standards studied to identify those which give the lowest values.

b) Sizing and modelling of the pylon

After determining the standard that gives the lowest wind load values, the dimensions of the pylon were determined and the latter was modelled in the TOWER software.

c) Comparison of Structural Strength Verification Standards

Once the pylon has been modelled, its resistance to the various loads must be checked using the calculation codes of one of the standards implemented in the TOWER software. To choose the best standard at this stage of the design, a comparison was made between ASCE 10 and NF EN 50341-1:2001 with respect to the working rate of the chords and their dimensions.

d) Sizing and modelling of the pylon

After determining the standard that gives the lowest wind load values, the dimensions of the pylon were determined and the latter was modelled in the TOWER software.

e) Comparison of Structural Strength Verification Standards

Once the pylon has been modelled, its resistance to the various loads must be checked using the calculation codes of one of the standards implemented in the TOWER software. To choose the best standard at this stage of the design, a comparison was made between ASCE 10 and NF EN 50341-1:2001 with respect to the working rate of the chords and their dimensions.

3. Modelling

This part is dedicated to the identification of mathematical models related to the comparison of wind load calculation standards.

3.1. Expressions of wind loads on conductors according to standards NF EN 50341-1:2012, VDE 0210:2011 and IEC 60826:2003.

Standards	Wind loads on conductors	
NF EN 50341-1: 2012	$Q_{con} = q(h).G_{con}.C_{con}.d.L.cos^2(\phi)$	(1)
VDE 0210: 2011	$Q_{con} = q.G_{con}.C_{con}.d.L.cos^2(\vartheta)$	(2)
IEC 60826: 2003	$Q_{con} = q_o.G_{con}.G_{con}.C_{con}.d.L.sin^2(\theta)$	(3)

3.2. Expressions of wind loads on insulators according to standards NF EN 50341-1:2012, VDE 0210:2011 and IEC 60826:2003.

Standards	Wind loads on insulators	
NF EN 50341-1: 2012	$Q_{ins} = q(h).G_{ins}.C_{ins}.A_{ins}$	(4)
VDE 0210: 2011	$Q_{ins} = 1{,}2.q.A_{ins}$	(5)
IEC 60826: 2003	$Q_{ins} = q_o.C_{ins}.G_{ins}.A_{ins}$	(6)

3.3. Expressions of wind loads on the metal structure of the pylon according to standards NF EN 50341-1:2012, VDE 0210:2011 and IEC 60826:2003.

Standards	Wind loads on the steel structure	
NF EN 50341-1: 2012	Method 1 : $Q_{wt} = q(h).G_{wt}.(1+0{,}2.sin^2(2\phi))(C_{wt\,1}A_{wt\,1}cos^2(\phi) + C_{wt\,2}A_{wt\,2}sin^2(\phi)$	(7)
	Method 2: $Q_{wt} = q(h).G_{wt}.C_{wt}.A_{wt}.cos^2(\phi_m)$	(8)
VDE 0210: 2011	– $Q_{wTx} = q.(1+0{,}2.sin^2(2\phi))(A_{wt\,1}C_{wt\,1}cos^2(\phi) + A_{wt\,2}C_{wt\,2}sin^2(\phi))cos(\phi)$	(9)
	– $Q_{wTy} = q.(1+0{,}2.sin^2(2\phi))(A_{wt\,1}C_{wt\,1}cos^2(\phi) +$	(10)

$$A_{wt\,2}C_{wt\,2}sin^2(\phi))sin(\phi)$$

IEC 60826: 2003	$Q_{wt} = q_o.(1+0{,}2.sin^2(2\theta))(A_{t1}C_{t1}cos^2(\theta) + A_{t2}C_{t2}sin^2(\theta).G_{wt}$	(11)

3.4. Expressions of dynamic wind pressure according to standards NF EN 50341-1:2012, VDE 0210:2011 and IEC 60826:2003.

Standards	Dynamic wind pressure	
NF EN 50341-1: 2012	$q_h(h) = \frac{1}{2}.\rho.[1+7.I_v](V_{b,0}.C_{dir}.C_0.k_r.\ln\left(h/z_0\right))^2$	(12)
VDE 0210: 2011	$q_b = 1{,}5 * (\frac{1}{2}.\rho.{V_b}^2)$ If $h \leq 7$m	(13)
	$q_b = 1{,}7 * (\frac{h}{10})^{0{,}37} * (\frac{1}{2}.\rho.{V_b}^2)$ If 7m $< h \leq$ 50m	(14)
	$q_b = 2{,}1 * (\frac{h}{10})^{0{,}24} * (\frac{1}{2}.\rho.{V_b}^2)$ If 50m $< h \leq$ 300m	(15)
IEC 60826: 2003	$q_0 = \frac{1}{2}.\tau.\mu.(K_R.V_{RB})^2$	(16)

4. Results and analysis

4.1. Results

All the results of the comparison of wind load calculation standards, the sizing and modelling of the pylon, and the comparison of structural strength verification are recorded in tables 2 to 6 and figures 1 to 5.

4.2. Analysis of the results

4.2.1. Results of the comparison of wind load calculation standards

a) Results of the comparison of standards according to dynamic wind pressure

From the relations **(12) to (16)**, we can see an important difference in the way the wind pressure is determined according to the three standards. The NF and VDE standards take into account in the calculations the height of the components of the line under study. In fact, we can see in Figure 1 that wind speed increases with ground height logarithmically. It is therefore easy to deduce that for greater heights of the support, the load due to the action of the wind on the pylon becomes significant.

To appreciate the difference between these normative requirements, it is interesting to observe the evolution of the dynamic pressure of the wind for low height (from 1 to 7m) and for great height (from 7 to 50 m). The results of this analysis are shown in Fig.2.

We note on these graphs that for heights above ground ranging from 1 to 7 m from the supports, the difference in value between the pressures in accordance with the three standards is of the order of 200

N/m. However, for higher values, the difference becomes even more significant (average difference of about 700 N/m). Theoretically, we can say that the wind pressure is more restrictive for the pylon according to the standards NF EN 50341-1 and VDE 0210.

b) Results of the comparison of standards according to the drag coefficient

The drag coefficient is a dimensionless coefficient that describes the resistance to the flow of a body when a fluid flows around it (air in this specific case). This coefficient is a function of the shape of the body in question. In the case of the design of a line, its determination depends on the type of component under study. The requirements of the three standards, i.e. NF EN 50341-1, VDE 0210 and IEC 60826 concerning this coefficient are summarized in Table 3.

According to Table 3, it can be seen in general that the drag coefficient is included in the standards without allocating any particular attention to it. This stems from the difficulty of assigning a valid coefficient allowing the components to be characterized as a whole, in particular the conductor cables and the angles of the pylon. Thus, this factor is almost identical for all standards and does not cause a difference in the calculation of the load to be applied. However, it would be interesting to deepen the research on the variations of the shape coefficient of the angles as a function of the Reynolds number in order to base our choice on the airflow regime.

c) Evaluation of loads in real time

The calculation of the wind loads with the three standards for the 225 kV line led to the results in Table 4.

Table 4 therefore shows that the IEC 60826 standard gives the highest wind load values and the DIN VDE 0210 standard gives the lowest loads. Therefore, for the calculation of wind loads, the most suitable standard is DIN VDE 0210:2011.

4.2.2. **Results of the sizing and modelling of the pylon.**

The dimensions of our tower are summarized in Table 5.

The modeling of the pylon was done with the software TOWER and the results obtained before simulation are presented under several views in figure 3 below.

4.2.3. **Results of Comparison of Structural Strength Verification Standards**

By running the TOWER software in structure verification mode, the support is analyzed according to a load tree designated according to the specifications. After simulation, we obtain the work rates in each member of the pylon which is represented by a colour chosen by the user or by a number displayed next to the component. The deformations of our alignment pylon according to two (02) different standards (ASCE 10 and NF EN 50341-1:2001) are shown in Figure 4.

The maximum work rate found is 99.23% with ASCE 10 and 97% with NF EN 50341-1 and corresponds to the work rate of the "Fg1373X" element which is a bar located at the foot of the pylon. We can therefore already deduce that our pylon resists the efforts because the maximum work rate is less than 100%. Moreover, there is a difference of approximately 2% between the results obtained for the two standards. To verify this discrepancy, we varied the wind loads on our pylon according to its height. The results are shown in Figure 5.

We can notice on this graph that whatever the force applied on the pylon, the work rate in compression of the bar given by the ASCE 10 standard is always higher than that of NF EN 50341-1, and this with an average difference of 2%. This difference is appreciable all the more since it is a question of standards in force and is justified by the way of determining the compressive force on the bars. However, this difference still has an influence on the metal structure, in particular on the cost of construction.

We consider one of the bars used for the design of the feet of our pylon. The starting dimensions are 14 cm x 14 cm x 14 mm. By simulating the behaviour of our pylon on the TOWER software, we obtained a work rate of 97% according to standard NF EN 50341-1 and 99% according to ASCE 10. To obtain the same work rate as that given by the NF EN 50341- with the ASCE 10, it will be necessary to increase the section of the angle iron which now goes to 15 cm x 15 cm x 14 mm.

Based on the catalogue of angles presented in the appendix, we were able to determine the weight and the price of each of the angles for a length of 6 m which is presented in Table 6.

We can notice from the previous table that for the verification of the structure in the TOWER software, the NF EN 50341-1 standard offers an advantage of 13.44 kg in terms of weight and 12.34 euros (which corresponds to 8829 81 FCFA) in terms of price compared to the ASECE 10 standard. It is easy to deduce that of the two standards studied, the NF EN 50341-1 standard is the most optimal.

5. Conclusion

Any company that wants to be efficient and competitive must ensure that the cost price of its products and/or services is reduced as much as possible while guaranteeing the quality of its service. In this sense, this comparative study of standards related to the field of power lines has identified some important aspects:

1. The importance of wind loads and its relative importance to other types of loading. Numerous studies have been carried out over time to explain the behavior of the wind and means have been developed to qualify and quantify it;
2. How different countries, including France, Germany and Canada, deal with wind in their national codes;
3. The basic wind speed considered in the calculation of the dynamic wind pressure;
4. The influence of the distance between the ground and the conductors on the wind speed profile;
5. The procedure followed to calculate the wind load.
6. Differences in standards on the calculation of forces on the structure of a pylon
7. The influence of standards on the choice of angles

Then, each of these standards was analyzed in relation to the different aspects identified. Each of the standards was analyzed for comparison purposes. A parametric study was needed to compare the few aspects included in the calculation of wind loads, which do not necessarily treat the different parameters in the same way. In the light of the data collected and analyzed during this study, certain points were noted and here are the details:

- Further studies are needed to better characterize the drag coefficient of the components of an overhead line, in particular the conductors and the angles. It would indeed be very interesting to base the choice of angles to be used on the wind flow regime, especially since studies have shown that the wind speed profile varies according to altitude;
- The comparative study must be done with other mechanical dimensioning standards to determine those which best optimize the weight and design cost of the lattice towers;
- It would probably be preferable for the electric power transmission industry to harmonize their design criteria related to the calculation of wind loads as well as the verification of the structure.

Furthermore, it would also be interesting to compare the results of the mechanical dimensioning according to the standards with respect to the nature of the terrain and the structural coefficient which were mentioned to complete the study which was carried out.

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TABLES & FIGURES

Table 1: Units of measurement and their symbols

Nomenclature

Symbols	Meanings	Units
U	Rated voltage value	V
q_{v}, q, q_{0}	Dynamic wind pressure	$N.m^{-2}$
Q	Force exerted by the wind	N
$q(h)$	Gust wind pressure	$N.m^{-2}$
G	Structural coefficient of line components	-
VS	Drag coefficient of line components	-
C_{dir}	Wind direction coefficient	-
$C0_{\_}$	Orography coefficient	-
L	Medium range	m
ρ, μ	Air density	kg/m^{3}
$V_{b,0}, V_{b}, V_{RB}$	Reference wind speed	m/s
h	Component height above ground	m
z_{0}	roughness length	m
I_{V}	Turbulence intensity	-
τ	Air density correction factor	-
K_{R}	Roughness factor	-
χ	Compactness ratio	-
$\Phi, \boldsymbol{\vartheta}$	Angle between the direction of the wind and the perpendicular to the conductor	-
A	Effective area of components	m^{2}
D	Reynolds number	-
m	Overload coefficient applied to cables and strings of insulators	-
ω	Cable linear weight	$N.m^{-1}$
T	Cable tension	N
Pi	Weight of insulators	N
a_{1}, a_{2}	Spans adjacent to tower	m
h_{1}, h_{2}	Pylon elevation relative to adjacent pylons	m
H	Lower under-console height	m
f_{max}	Maximum deflection	m
G_{ground}	Ground clearance	m
P_{equi}	Equivalent weight	$Nm-^{1}$
F	Linear force of the wind on the cable	$Nm-^{1}$
P	Net linear weight of the cable	$Nm-^{1}$
P_{c}	Critical range	m
α	Cable Thermal Expansion Coefficient	$°C^{-1}$
E	Young's modulus	$N/^{mm2}$

S	Cable section	mm2
θ	Cable temperature	°C
D	Distance between console	m
D_{pp}	Electrical insulation distance between phase	m
D_t	working distance	m
l_{ch}	Insulator string length	m
ds	Safety distance	m
Del	Electrical isolation distance between phase and earth	m
D_b	Cable swing distance	m
C	Driver's console length	m
L_c	Bridge length	m
L_g	Guard wire console length	m

Table 1**: 225 kV line data. [9]**

line type	225 kV line
Equivalent range	400m
Reference height above ground	33m
Diameter of conductors	31.05mm
Diameter of ground wires	15.6mm
Type of land	Type II
load case	Wind only
Reference speed	24m/s
Driver type	Stranded conductor

Table 2: Comparison of drag coefficient calculation methods according to the three standards.

drag coefficient	EN 50341-1	VDE 0210	IEC 60826
Drivers	Method 1: For stranded conductors, the drag coefficient is equal to 1; Method 2: Deduction of wind tunnel tests; Method 3: The drag coefficient is a function of the Reynolds number $\boldsymbol{C_x = 1,2}$ if Re $\leq 6.10^{4}$ $\boldsymbol{C_x = 0,9}$if Re $\geq 10^{5}$	The values of the drag coefficient are given by table 4.3.2 of the normative document according to the type of line component under study.	Method 1: For stranded conductors, the drag coefficient is equal to 1; Method 2: Deduction of wind tunnel tests;
Insulators	The recommended value is 1.2		The drag coefficient of the insulators is considered to be equal to 1
Metal structure of the pylon	With the first method, the drag coefficient is a function of the filling rate which is equal to the ratio of the section of the section considered to the total surface of the pylon. With the second method, the standard considers that the angles have a drag coefficient of 1.6.		This standard joins NF EN 50341-1 on the calculation of the drag coefficient according to the filling rate.

Table 43**: Comparative values of wind loads.**

type of load	Standards		
	EN 50341-1	**DIN VDE 0210**	**IEC 60826**
On conductors (N)	**9277**	**7093.71**	**9896.58**
On ground wires (N)	**4661**	**3563.99**	**4972.72**

Table 4: Dimensions of the pylon.

Dimensions	Values
Height under lower console (m)	**26.8**
Distance between console (m)	**6,318**
Bracket length (m)	**4.6**
Easel length (m)	**3.7**
Guard wire console length (m)	**3.54**

Table5**: Mass and price of angles L140*140*14 and L150*150*14. [11]**

angles	**140x140x14**	**150x150x14**
Mass (kg)	**178.8**	**192.24**
Price (euro)	**163.23**	**175.57**
Mass difference (kg)	**13.44**	
Price differences (euros)	**12.34**	

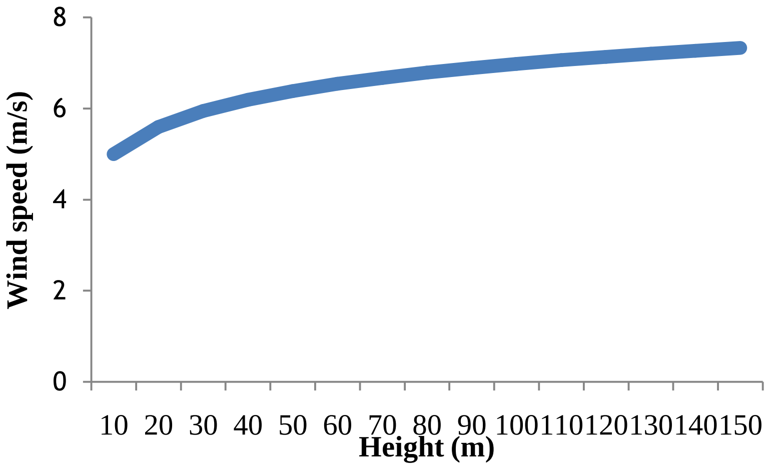


Figure 1*: Evolution of wind speed as a function of height.* [10]

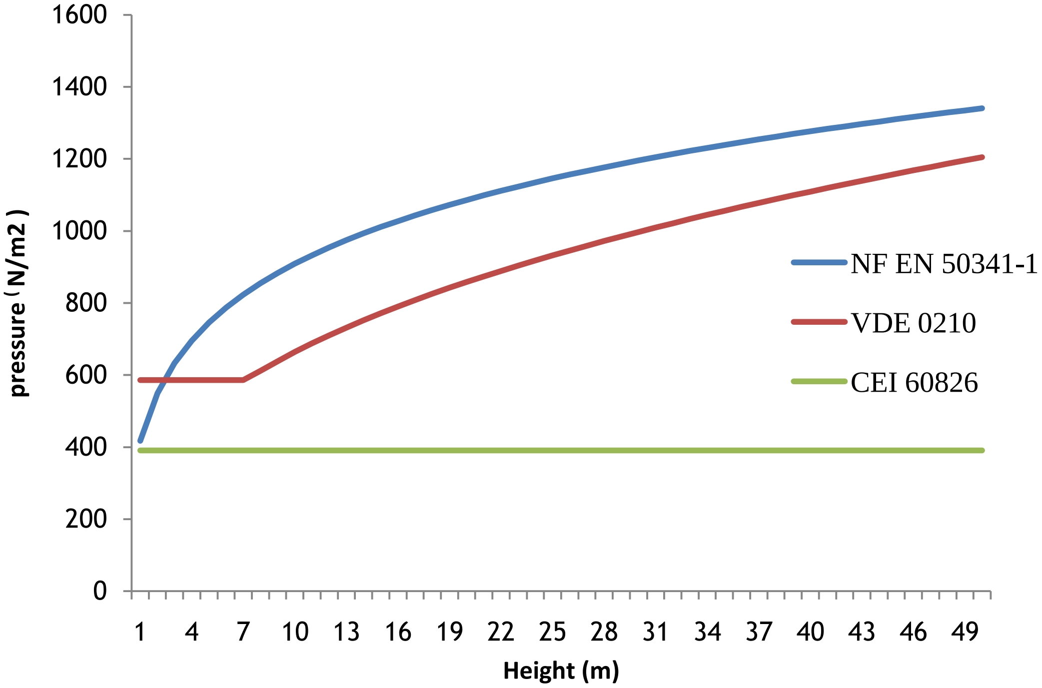


Figure 2: Evolution of dynamic wind pressure as a function of height.

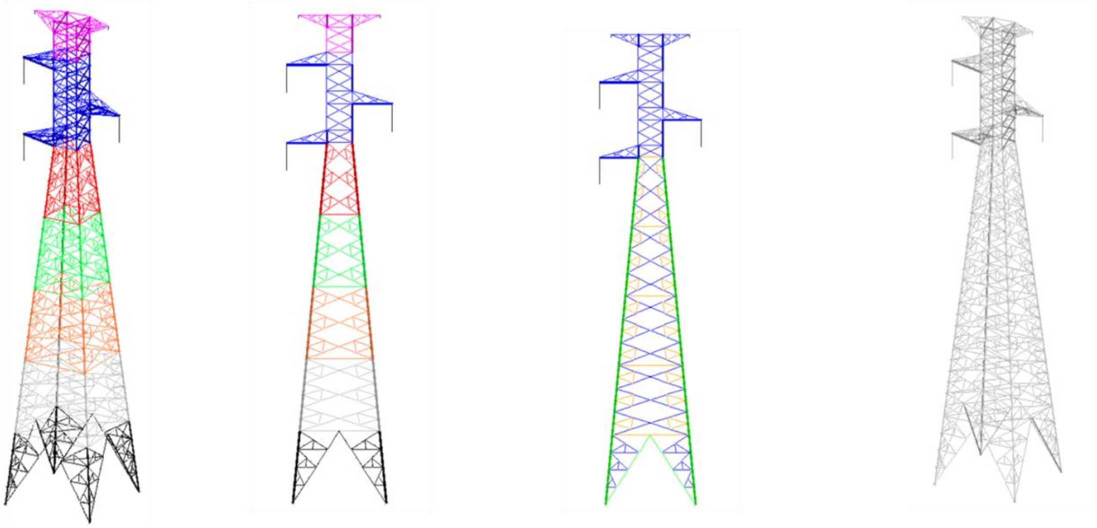
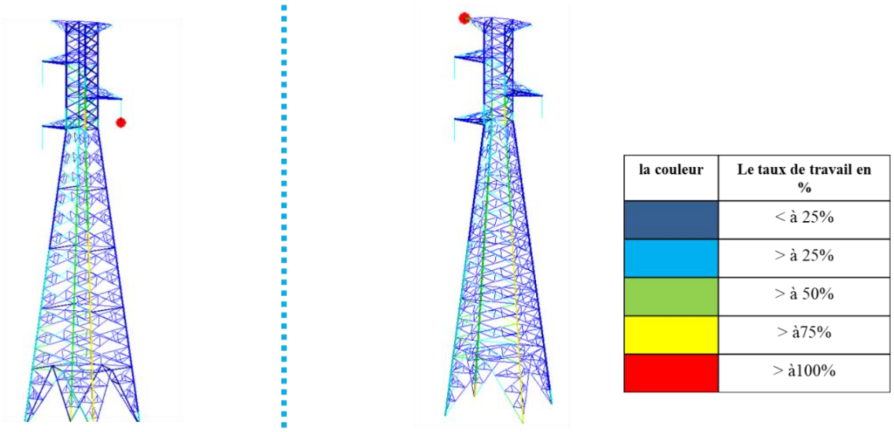


Figure 3: Different views of the pylon before simulation.



la couleur	Le taux de travail en %
🟦	< à 25%
🟦	> à 25%
🟩	> à 50%
🟨	> à75%
🟥	> à100%

Maximum usage (ASCE 10): 99,23 %

Maximum usage (NF EN 50341-1): 97,00 %

Figure 4: Deformations and working rate of the pylon according to ASCE 10 and NF EN 50341-1.

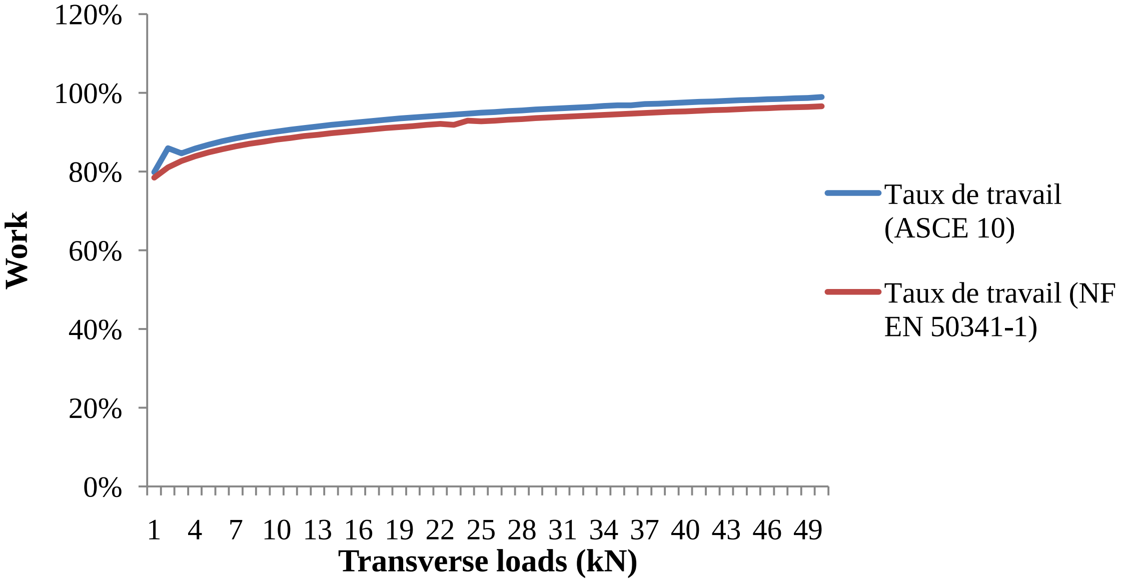


Figure 5: Evolution of the work rate according to the transverse load.