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Specific Issues on the Design and Expertise of Steel Columns for Overhead Lines

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Abstract

The article presents a study on the design and expertise of steel columns for overhead power lines for high voltage transportation. In our days is a matter of safety to verify and maybe redesign some component elements. The collapse of the columns in actual changing climate conditions can be eliminated by developing methods of structural upgrading, which has to be efficient from the implementation technology point of view, as well as costs.

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Keywords: steel columns for energy transportation; civil engineering; electrical engineering; optimization; specific loadings in design.

1. Introduction

The electro-energetic system includes the electrical part of the energetic system, starting with the electrical generators up to the electrical receptors. The producing installations, transport, distribution and utilization of the electrical energy are interconnected and have common and continuous conditions of employment for producing and consuming the electrical energy. Electrical overhead lines are an important part of this system, the main disadvantage being the fact that offers a lower safety in utilization, due to the direct meteorological factors on a long surface/distance.

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Nomenclature

m	reference state (started state)
n	corresponding state to a temperature value for which a traction p_{0m} is calculated
m	reference state (started state)
p_{0m}	horizontal component of the specific traction for the “m” state
p_{0n}	horizontal component of the specific traction for the”n” state
$\gamma_{(m)c}$	specific design loading for the reference state
$\gamma_{(n)n}$	specific norm loading , corresponding to the ”n” state
T_n	the temperature state for which the horizontal component of the traction is calculated
T_m	the reference temperature state
U	the medium bump factor
α_c	linear dilatation coefficient

2. Specific issues on design of electrical overhead columns

The design or verification of these types of columns needs knowledge both from the electrical and civil engineering expertise fields, as the loads that had to be taken into account are part of both fields. On the design of the overhead columns, in whole and in its components, the next hypotesis of combined loads must be taken into consideration:

- minimum temperature (no wind or frost);
- medium temperature (no wind or frost);
- medium temperature, wind speed of 10 m/s (no frost);
- medium temperature, maximum wind speed (no frost););
- maximum temperature (no wind or frost);
- frost temperature and frost deposits on the lines (no wind);
- frost temperature (wind with frost and frost deposit on the lines).

On the columns, the loads have different values and angles, depending also on the position of the electrical lines. Establishing the geometrical equation of an active conductor (active line), uniformly loaded, can be done by neglecting the rigidity of the material, assuming that the line is equivalent with a flexible and inextensible thread.

For a tensioned line into an opening, at a certain state of external medium, predetermination is required for the efforts and the deformations that appear when the external medium changes its state (growing of the frost layer, wind pressure, temperature as the lines are considered fixed in their suspension points, in the moment of these changing, variations of their lengths are produced, so, by consequence, variations of the internal efforts.

The equation that establishes the characteristic values of an opening between two columns (temperature, loads, length, specific deformations) is called state equation of the conductor and for a line with the suspensions points at the same level it can be brought to the following for:

$$u \cdot p_{0,n} - \frac{a_{med}^2 \cdot \gamma_{(n)n}^2}{24 \cdot p_{0,n}^{\;2}} \cdot E_c = u \cdot p_{0,m} - \frac{a_{med}^2 \cdot \gamma_{(m)c}^2}{24 \cdot p_{0,m}^{\;2}} \cdot E_c - \alpha_c \cdot E_c \cdot (T_n - T_m) \qquad (1)$$

3. Structural upgrading

In the past years, upgrading of the services offered by the electrical energy providers took place, by changing some of the components into the electrical line, introducing bigger conductors, thus resulting in bigger efforts on the columns. Also, the climate changing by meteorological extreme conditions on global level can have a negative influence on column behaviour. The cyclic loading and the vibrations induced by the wind can degrade some of the diagonals, usually very slender elements, and in time cracks may appear. The collapse can rapidly propagate along the lines (“the domino effect”) and cause serious injuries to the whole system of electric transportation. The estimate costs for repair and/or replacement for an alignment in double circuit of 40 km may cost 30 million dollars [3]. The collapse of the columns can be eliminated by developing methods of structural upgrading, efficient from the point of view of technology of implementation as well as costs.

4. Case study: overhead column of 400kV, double circuit.

The analyzed model corresponds to a model presented and tested by N. Prasad Rao et. al. [1],[2]. The analysed model dimensions, corresponded to the tested column, can be seen in the Fig. 1. The configuration of the column and the scale of 1 to 1 “in situ” tested model are presented in figure 2 and 3. For the model validation, a comparison calculus between our own model (made with Scia 15) and the tested model [2] was made. The collapse for the tested column took place first in the principal element of the eccentric bracing, and the same happened in our model. The value of the critical loading coefficient, that led to the collapse of the indicated diagonal, has the value of 0.96 (96% of the forces indicated in figure 1), according to the analytical studies made by de N. Prasad Rao et. al. [2].
Our analyses provide the same coefficient to the value of 0.983 (98.3% of the forces from Fig. 1.).

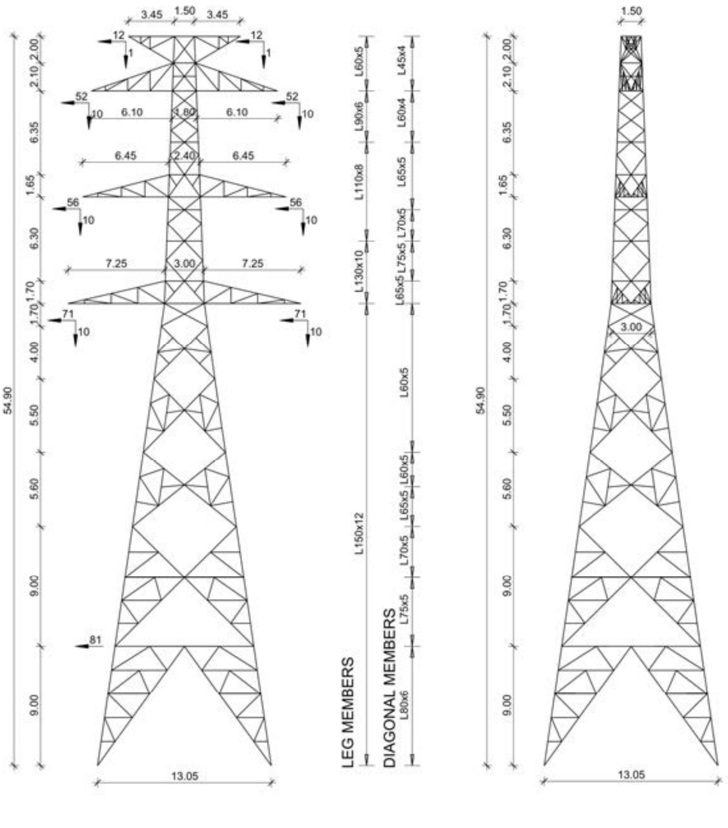

Fig. 1.Configuration of the column

In parallel, the deformations obtained on the analyses we made, and the deformations from the mentioned article are presented in the Fig. 3.

As it can be seen, the structure is intact above the first section in which the diagonal collapse took place.

Even if the loads on the experimental column were applied separately, in the analytical analyses the loadings were applied simultaneous as well as in the ones made by N. Prasad Rao et. al. [2].

For studying an improved behaviour of the structure, horizontal bracing systems are proposed (Fig. 4), taken from Albermani et. al [3], who tested in the laboratory many types of horizontal bracing systems. The types indicated in Fig. 4, named 2ac) and 3ac) were introduced in our tower.

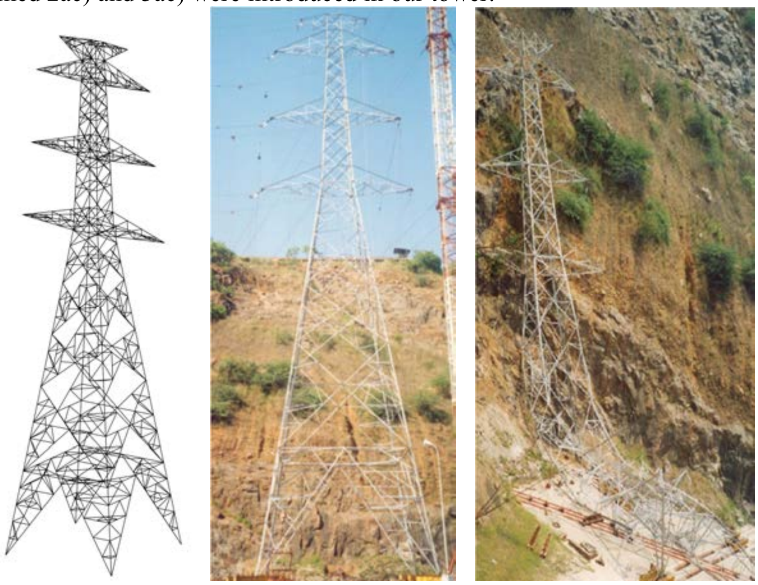

Fig.2. 3D configuration and tested specimen before and after the test [2]

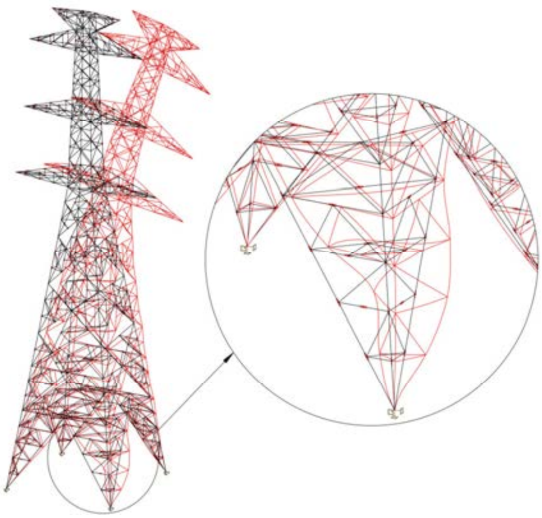

Fig. 3. Collapse in the model of the column, the same as in the tested column

To be in accordance to the obtained results after studying the first section of the columns (first substructure, at the base of the column), the position of these bracing horizontal systems is proposed to be positioned as close as possible to the middle of the analyzed substructures. The horizontal systems were mounted directly on the existing elements for avoiding supplementary efforts due to the eccentric implementation. The exact position can be seen in Fig. 5, in total a number of 9 horizontal bracing systems, on each vertical section of the column under the first cantilever, and the structure was analyzed in two variants.

The same loads were introduced on the columns for the normal configuration as well as for the upgraded configuration, including horizontal and vertical loads, applied incremental.

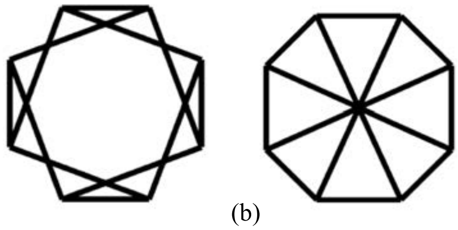

Fig. 4. Horizontal bracing system (a) the 2ac system . (b) the 3ac system

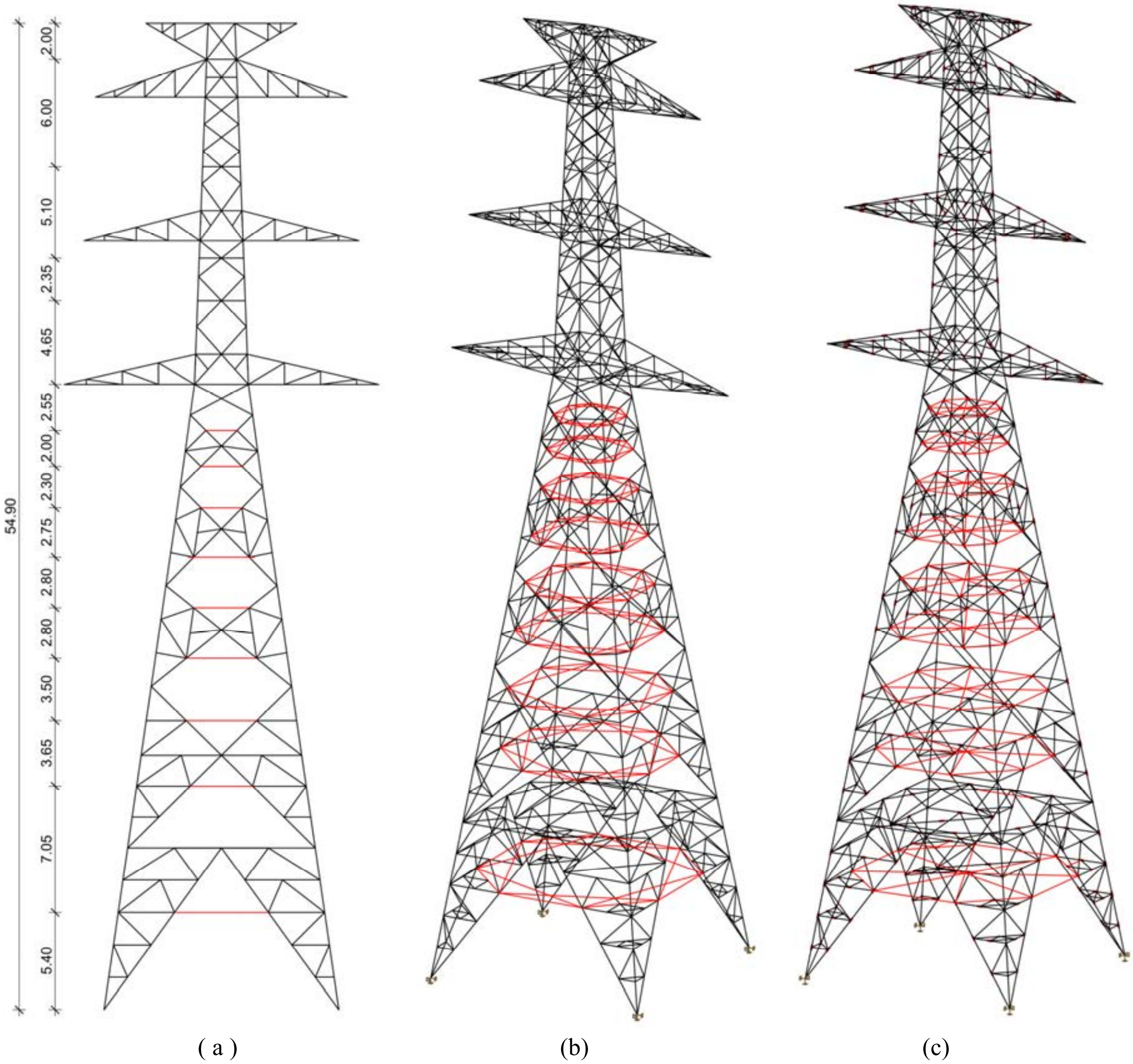

Fig. 5. Position of the horizontal bracings systems (a) position on the length of the column; (b) the 2ac system; (c) the 3c system

The comparison between the real structure and the improved one is represented in the Fig. 6. The results show a growth of the critical load coefficient from 0.938 to 1.36 for the improved structure with 2ac) type of bracings, meaning an improvement of 44.98%.

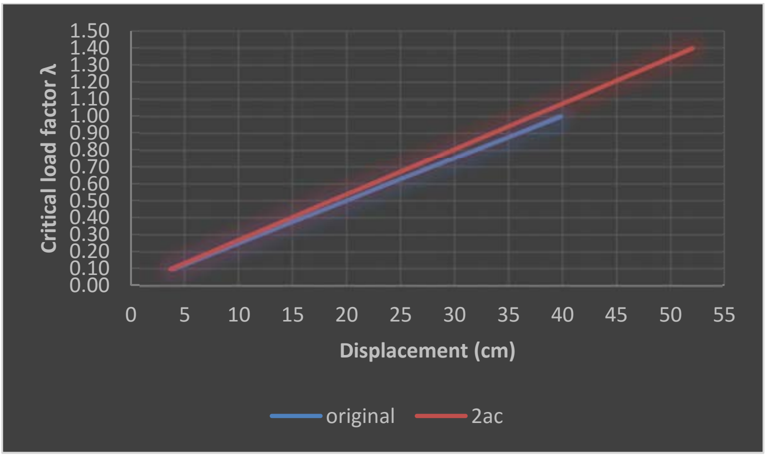

Fig. 6. Critical load factor for original structure and 2ac) horizontal bracings system

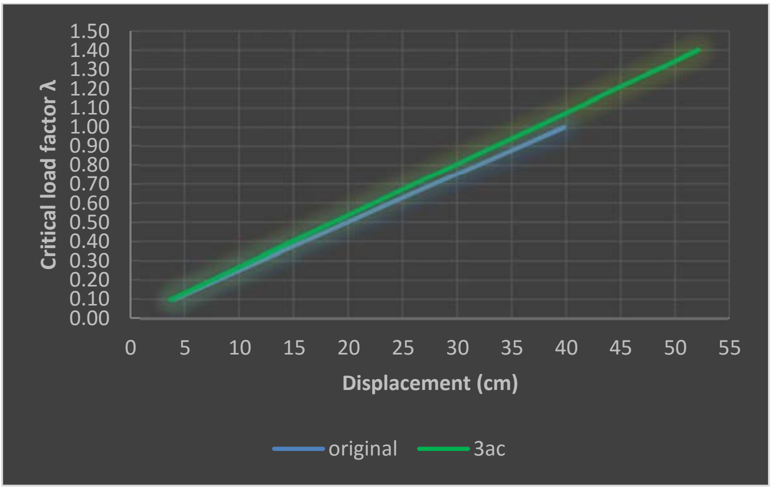

Fig. 7. Critical load factor for original structure and 3ac) horizontal bracings system

The displacement at which the instability occurs, for the original structure, is 39.1cm, and after upgrading with 2ac) type of bracing systems, the value is 52.6cm. In the case of 3ac) type of bracing, the loading critical coefficient goes up from 0.938 to 1.35. In percentage terms, the growth is almost the same as in the 2ac) type, of 43.92%. Similarly, the displacement associate to collapse for the improved column is of 52.1cm.

5. Conclusions

Electrical overhead lines are an important part in the energetic-electrical system of a country. The design/maintenance of these types of columns needs knowledge both in the field of electrical engineering and civil engineering. In the actual condition of very brutal climatic changing conditions, that leads to modifications in the values of the loads, the behaviour of overhead columns lines can be improved by using simple horizontal bracing systems.

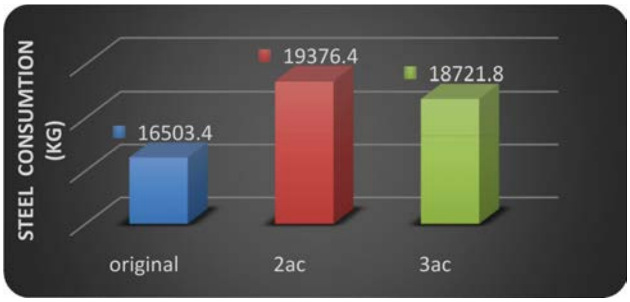

Fig. 8. Steel consumption for the original and the upgraded columns

The paper analyses the specific loads that need to be taken into account in a very appropriate form for the design of the columns, proposing a very simple method of positioning horizontal bracing systems on the length of the column. The specific bracing systems lead to a growth of the loading coefficient factor of more the 40%, for both the proposed substructures, stability-wise.

From the point of view of steel consumption, the best results were obtained in the 3ac) systems. The original struture has a 16,503.4kg of steel,for the 2ac) systems the value grwoth to 19,376.4kg, or in perecentage, 17.4%. For the 3ac) systems, the steel quantity is only of 18,721.8kg, or 13.44%.

Certanly, the 2ac). system leads to a better structural behaviour in parallel to the easiest mounting, but the 3ac) system has the advantage of a lower steel consumption.

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