Asociación Argentina
de Mecánica Computacional

Mecánica Computacional Vol XXX, págs. 1133-1142 (artículo completo)
Oscar Möller, Javier W. Signorelli, Mario A. Storti (Eds.)
Rosario, Argentina, 1-4 Noviembre 2011

REINFORCEMENT OF LATTICE STRUCTURES WITH APPLICATIONS TO COMMUNICATION TOWERS RETROFITTING

Claudia A. Egidi[a], **María D. Rey Saravia**[a], **Jorge S. Ballaben**[a,b] **and Marta B. Rosales**[a,b]

[a]*Departamento de Ingeniería, Universidad Nacional del Sur, Av. Alem 1253,8000 Bahía Blanca, Argentina,cegidi@uns.edu.ar,doloreysaravia@hotmail.com*

[b]*CONICET, Argentina, jorgeballaben@gmail.com, mrosales@criba.edu.ar*

Keywords: Lattice tower, Retrofit, Lateral loads, computational model.

Abstract. The extensive use of wire-less communication demand structures to support the antennas. The most common types are self-supported towers or guyed towers, depending on various factors as the height, terrain availability, etc. Also, due to economical reasons, lattice towers are used in both typologies. The design of these structures is, in general, carried out following the standard codes and simplified models. Moreover, as a result of changes in design code requirements and the increasing demand of the communication industry, the retrofitting of existing steel lattice has become a common practice. Sometimes due to environmental reasons, new structures are not accepted and the new communication requirements must be satisfied by installing the antennas on existing towers (named co-localizations) that should be strengthened so as to meet increased loads. A reinforcing method used in practice in our country is through leg strengthening. A previous study addressed the behavior of reinforcing members in a one-panel reinforced single leg and a portion of the tower (legs and diagonals) under compressive load with small eccentricity. In the present work, the study is extended to lateral static and dynamic loads. The analysis is carried out with a standard finite element software and different configurations of the reinforcement connections are considered. The connections are made with bolts and fasteners and the effectiveness of the reinforcement is analyzed mainly through the force distributions between the existing leg and the reinforcing member. Also, the behavior of the joint is studied in detail through for two configurations. Finally, these results will be useful to design a physical experiment to be carried out in the future.

1 INTRODUCTION

Existing steel lattice towers are frequently subjected to retrofitting and this area has become important for structural engineers. Both power transmission and communications demand more towers and due to environmental reasons or limitations in the space, it is frequently not possible to install new structures to support the conductors or the antennas and existing towers should support additional elements. Additionally, new standard codes, sometimes impose higher loads which may result in exceeding the material strength. On the other hand, modern communication standards require very precise signal broadcasting which leads to severe restrictions on the stiffness of the structure. All these reasons lead to need of improvement of the structural capacity of the towers to satisfy the requirements.

Although the whole reinforced structure is not frequently subject of detailed analysis, two interesting articles regarding transmission towers can be mentioned. A thorough study on the retrofitting of transmission towers is reported in Tongkasame, 2008. In this Ph.D. thesis the author developed an experimental study of a reinforced one-panel leg specimen, a finite element model to simulate it and an extension of the latter to a multi-panel leg-reinforced tower model. The author shows that the use of bolted angles is an effective method to increase the load capacity up to 100 %. More recently, Zhuge and Mills (2010) analyze the effectiveness of leg reinforcement in multi-panels with various bracing patterns. On the other hand, detailed studies on the connections are more frequent. Some of them include finite element simulation with different configurations of the joints and material descriptions (Citipitioglu *et al*, 2002, Foces y Garrido, 2007 and Jiménez Pérez, 2008).

There is little knowledge on the real behavior of these reinforced structures and their joints. Analytical methods fail to address such complex problems. Therefore, the best alternatives appear to be the physical experiments and the computational simulations. The latter can be achieved through a finite element model which may also serve as a reference to design the physical model. The authors of the present study reported preliminary results in (Egidi *et al.*, 2010).

The aim of this study is to analyze the behavior of reinforced lattice towers typically employed in the communication industry. The legs are arranged in a triangular cross-section and joined with three planes with diagonals. The data employed correspond to an existing reinforced tower in operation. To follow the analysis, a simplified model was assumed. The study comprehends several stages. First, an isolated leg (a cold-formed 60° angle) with and without reinforcement are subjected to vertical loads. A finite element model is constructed and then extended to a panel comprising the three legs and diagonal planes. Then, some detailed studies on the joints are reported, using either a cylinder or a simplified bolt model. Finally, lateral loads are added to the single reinforced legs model to analyze the effect of a linear or bilinear steel material. A dynamic load is also included. The analysis of the results allow to draw some preliminary conclusions and the design of a future experimental study.

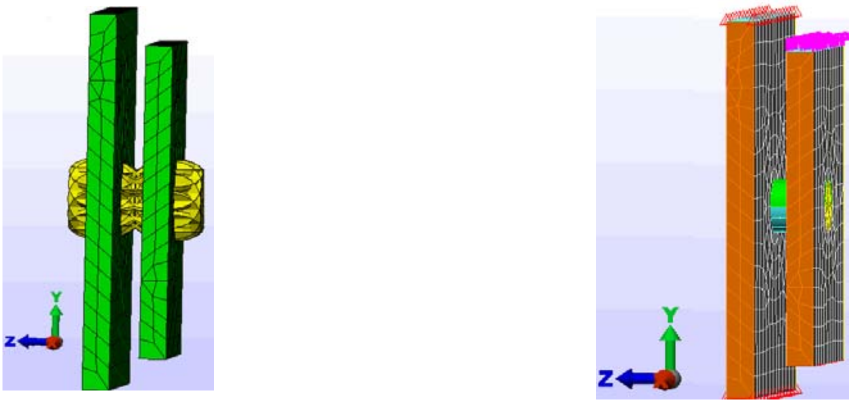
2 JOINT ANALYSIS

In the first place, a typical arrangement used to join the reinforcement, the leg and the clamps (connections) is analyzed with a finite element software. There are different types of schemes for the reinforcements and the joints (see two examples in Figure 1). A simplified configuration composed of two plates with the fastener modeled in two ways, i.e. as a perfectly assembled cylinder and as a beam subjected to the plates surfaces (bolt), was modeled with finite elements (Figure 2). Both cases were subjected to concentrated and distributed loads. The Mechanic Event Simulation (MES) of the ALGOR software (Algor,

2009) was employed to perform the simulation. Although this study is static, a time-dependent load with slow variation was employed so as to take into consideration some features of the software only present in this modulus.

Figure 1. Examples of joints for a reinforced tower.

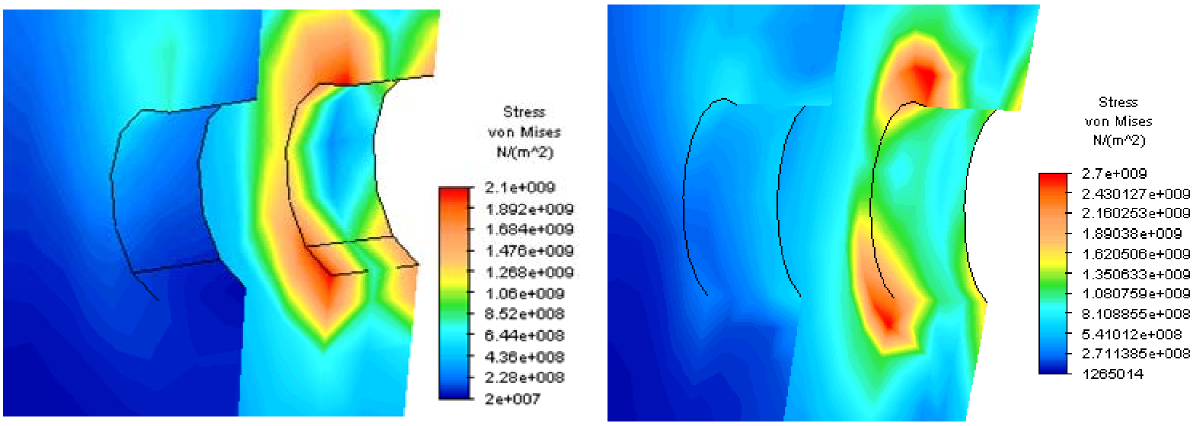
The data was taken from an existing guyed tower. The plates material is AISI 1045 hot rolled steel. The large plate is 0.09 m high, 0.07 m wide and 0.0064m thick and the small plate, 0.075 m high, 0.050 m wide and 0.0064 m thick, with a gap between them of 0.0064 m. The large plate is fixed at top and at the bottom surfaces. The cylinder is 0.0127 m of diameter and 0.192 long, without any backlash with the plate. The bolt is assumed of the same diameter with head and nut of 0.015 m. Some of the results of this study are reported in Figures 3 to 5.



a) b)

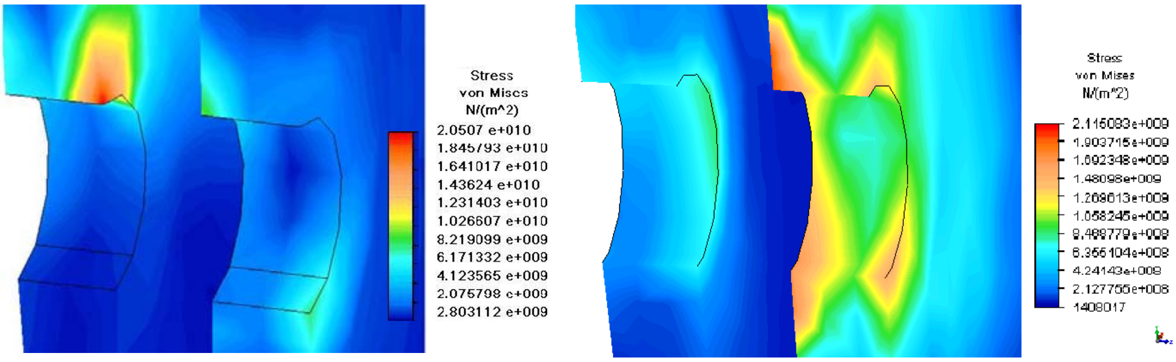
Figure 2. Two configurations of joints. Finite element model. a) bolt modeled as beam; b) perfectly assembled cylinder with distributed load.

Figure 3 shows the von Mises stresses in an enlarged view of the joint when a concentrated vertical load of 63 kN is applied on the small plate. The stress magnitudes are similar though the bolt model exhibits a more gradual distributions on the plates and the cylinder model, small regions of concentrated stress. Figure 4 depicts also the stresses but for the case of a distributed vertical load of the same resultant force. Here, a different stress distribution is observed. When the beam model is chosen for the bolt, some stress concentrations are present in the loaded plate. If one observes the whole joint picture (Figure 5) of the deformed state, the bolt model exhibits more significant flexibility.



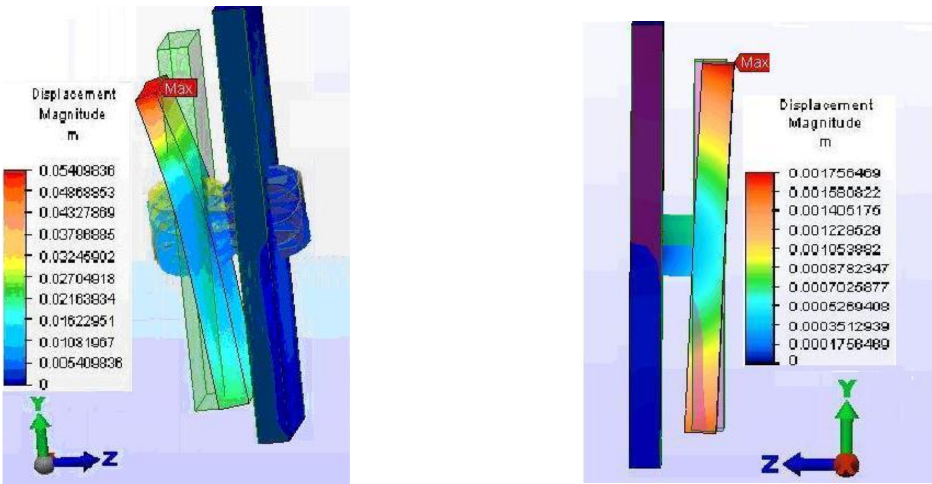
a) b)

Figure 3. Von Mises stresses on the plates for the concentrated load case. a) beam model of bolt; b) cylinder model.



a) b)

Figure 4. Von Mises stresses on the plates for the distributed load case. a) beam model of bolt; b) cylinder model.



a) b)

Figure 5. Displaced configurations for the distributed load case. a) beam model of bolt; b) cylinder model.

Finally, Table 1 shows maximum stress values around the hole at the plates, the percentage of the ratio between the maximum stresses at the small plate and the large one and the maximum displacements of both joint models. In general, it is seen that the large plate exhibits the higher maximum stresses, with exception of the previously mentioned case of the distributed load and the bolt modeled with a beam.

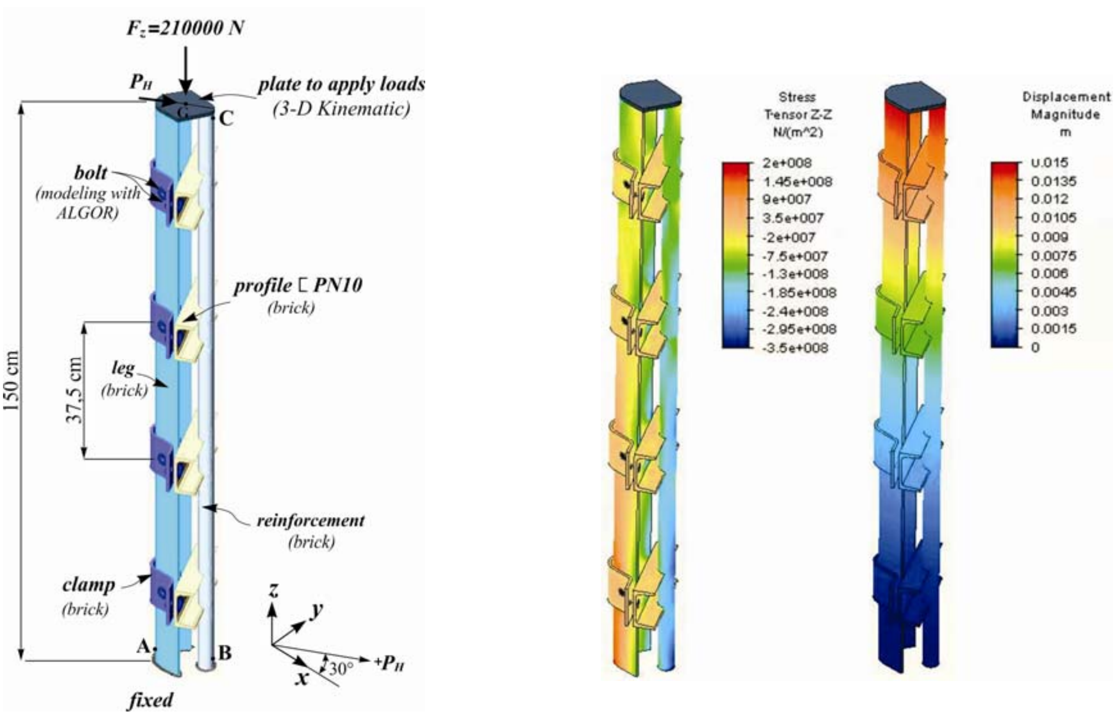
LOAD	**JOINT**	**Max. Stress large plate N/m^2**	**Max. Stress small plate N/m^2**	**Stress % (small plate/large plate)**	**Maximum Displacement m**
Concentrated 63kN	Bolt as beam	2.09 10^9	7.0 10^8	33	0.0018
	Cylinder	2.85 10^9	1.5 10^9	52	0.0020
Distributed 63kN per unit area	Bolt as beam	9.80 10^9	2.0 10^{10}	209	0.0540
	Cylinder	2.11 10^9	1.0 10^9	47	0.0175

Table 1: Stress and displacement maximum values at the plates holes.

3 REINFORCED LEG WITH 4 CLAMPS

Now, one typical leg with reinforcement is analyzed. The adopted configuration corresponds to an existing guyed tower (see Figure 6a, cf. Figure 1, right). The original leg is made of an angular section (60^o, 0.0064 m thick) and the reinforcement of a 1 ½ in. round bar.

A portion of the reinforced leg is simulated in a finite element environment, fixed at the base and free at the top. A fixed vertical load is applied (corresponding to the normal force in the design sheet) and a horizontal load is parametrically varied. In all cases, the loads are static although a temporal analysis is made with MES-ALGOR. The joints were modeled with the beam model, i.e. a tool available in this modulus of the finite element code. Figure 6b shows the stress and displacements results for one of the studied horizontal loads, i.e. P_H= 6300 N.



a) b)

Figure 6. Reinforced leg with four clamps joined with bolts (beam model). P_H= 6300 N. a) geometric configuration and loads. b) Stress component normal to the cross-section and displacement magnitudes.

Figure 7 depicts the results of the stress component normal to the cross-section, for a horizontal load varying from -5% to 5% of the vertical load (fixed, 210 kN). Both the values attained at the leg and the reinforcement, are shown. As expected, since a linear material was employed, the results are located on straight lines. The dashed lines indicate the yield stress value for this material.

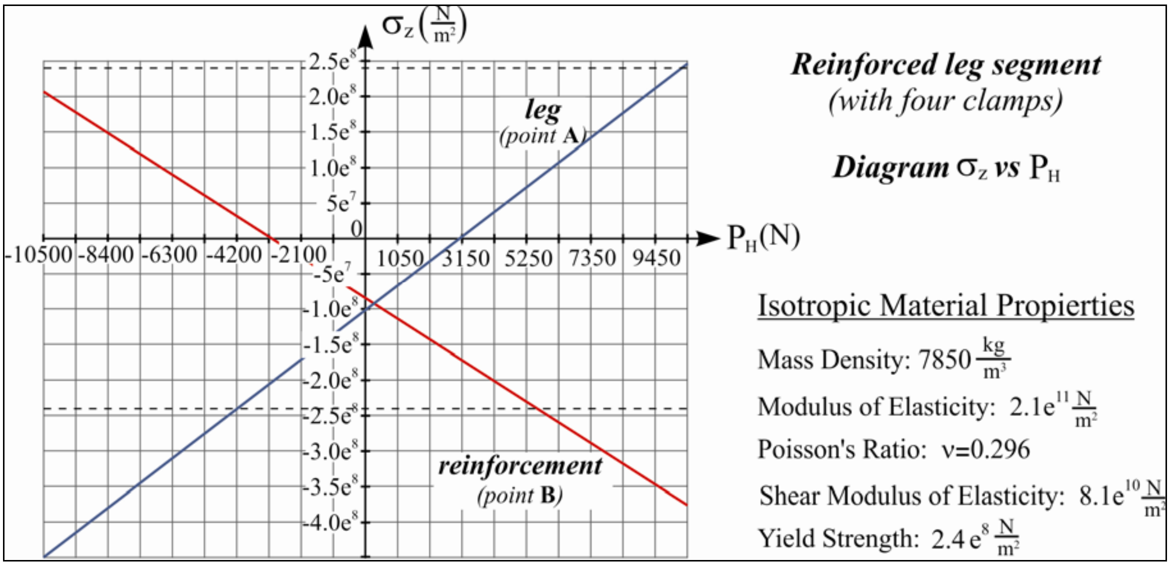


Figure 7. Four clamps case. Stress component normal to the cross-section at the leg and at the reinforcement at points A and B, respectively (see Figure 6a).

The displacements components of the point C (see Figure 6a) are plotted in Figure 8. Again the results lie on lines.

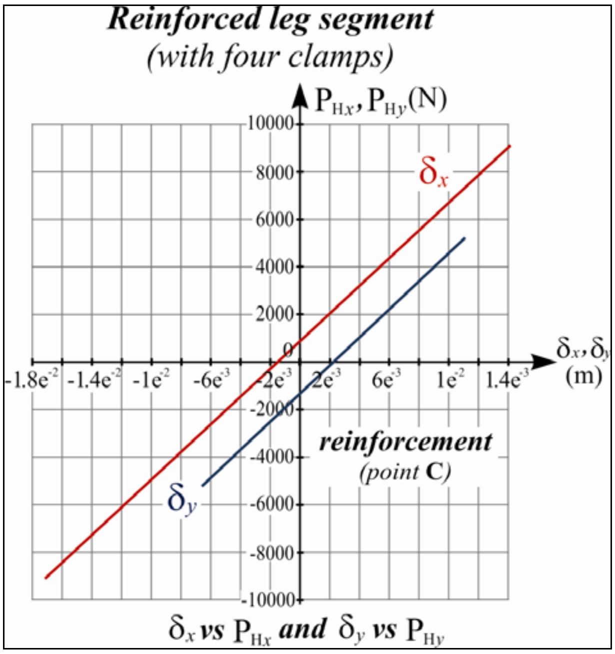


Figure 8. Displacements components of point C along the global axis x and y vs. the respective components of the horizontal load and a fixed vertical load of 210 kN.

4 NON-LINEAR MATERIAL

Now, a elasto-plastic material model was adopted. An isotropic hardening modeling was adopted with ρ=7855 kg/m^{3}m, modulus of elasticity 2 10^{11} N/m^2, ν=0.29, G=7.75 10^{10} N/m^2, σ_Y=2.48 10^8 N/m^2 and a strain hardening modulus of 6.63 10^8 N/m^2 and the corresponding curve is shown in Figure 9a.

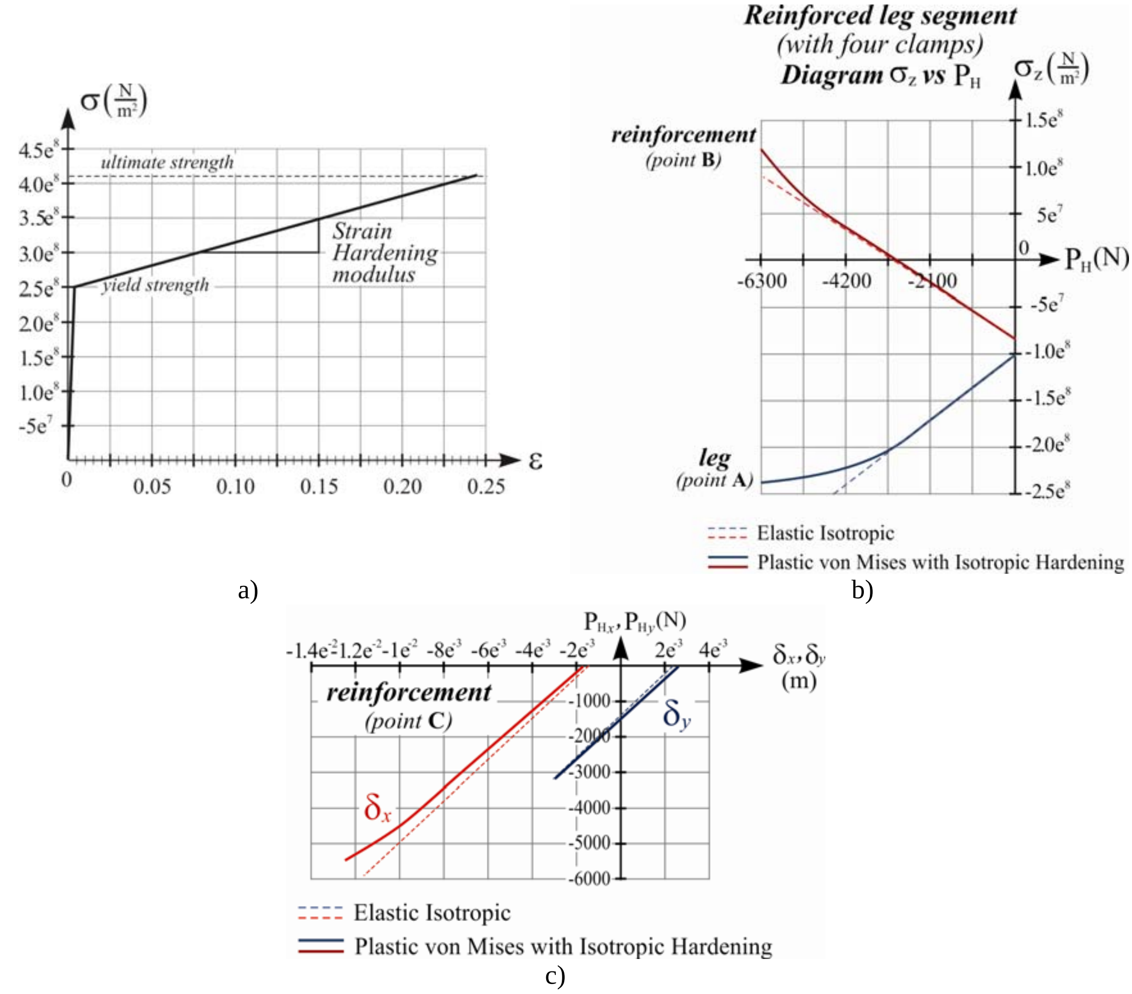
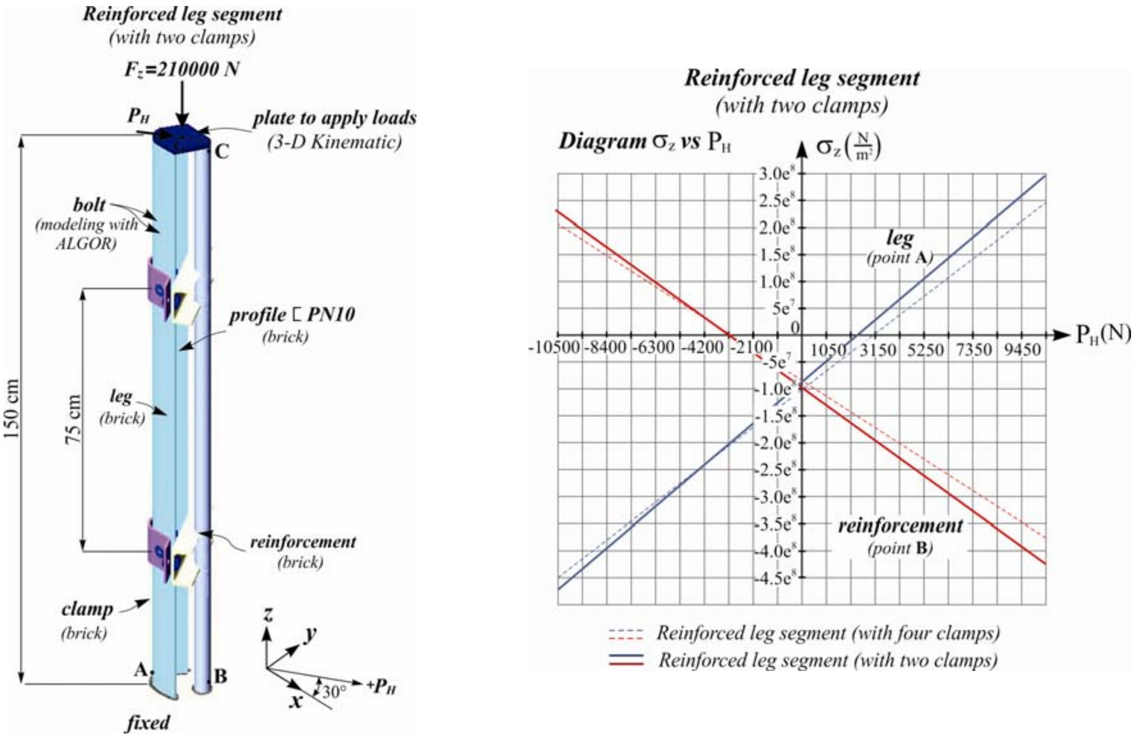


Figure 9. Reinforced leg with elasto-plastic material (isotropic hardening model). a) material model curve; b) Stress component normal to the cross-section vs. horizontal load; c) displacements along the global directions *x* and *y* vs. respective component of the horizontal load. Results with the bilinear material model in full lines; results with linear model in dashed lines.

Figure 9b depicts the normal stress variation vs. the horizontal load. The full lines show the stress values for the leg (at point A) and the reinforcement (at point B). In dashed lines, the values corresponding to the linear material model are also plotted. The non-linear behavior is observed. For example, for the leg stress, the line becomes curve at σ_Z=3150 N/m^2 since some points of the model are stressed beyond the yield point. The displacements are found in Figure 9c where, again, a nonlinear behavior is apparent for certain levels of horizontal loads.

5 REINFORCED LEG WITH 2 CLAMPS

In order to evaluate the possibility of reducing the number of clamps, the same reinforced leg was analyzed using two clamps instead of four, in this case with the linear material model. The resulting stresses are shown in Figure 10 along with the previous case values. It is seen that there are very small changes in the values and it could be concluded that two clamps could be sufficient. But the most critical situation of this problem is the buckling which is not included in the present study. Therefore, further analysis should be carried out to draw a conclusion on this regard.



a) b)

Figure 10. Two clamps case. a) geometric configuration; b) stress component normal to the cross-section at the leg and at the reinforcement at points A and B, respectively. Results with two clamps in full lines and results with four clamps in dashed lines.

6 REINFORCED LEG WITH FOUR CLAMPS AND A DYNAMIC LOAD

Finally, a dynamic component was added to the horizontal load. The reinforced leg segment has four clamps and the material is linear. The vertical load is static and its value is 210 kN. The horizontal load is $P_H(t)=5250\sin(8\pi t)$ (N) and a generalized Rayleigh damping with the two parameters set at 0.05, was included. Figure 11 contains the data and results from this study. The top curve shows the dynamic multiplier of the harmonic load. The stress component normal to the top cross-section for both the leg and the reinforcement are shown in the second plot. Analogously, the results for a point at middle height are depicted. Finally, the bottom plot shows the temporal variation of the displacement of two points located at the top and at middle height, respectively. The dynamic responses are, as expected in agreement with a linear model behavior. More complex loads and other material models are under study at present.

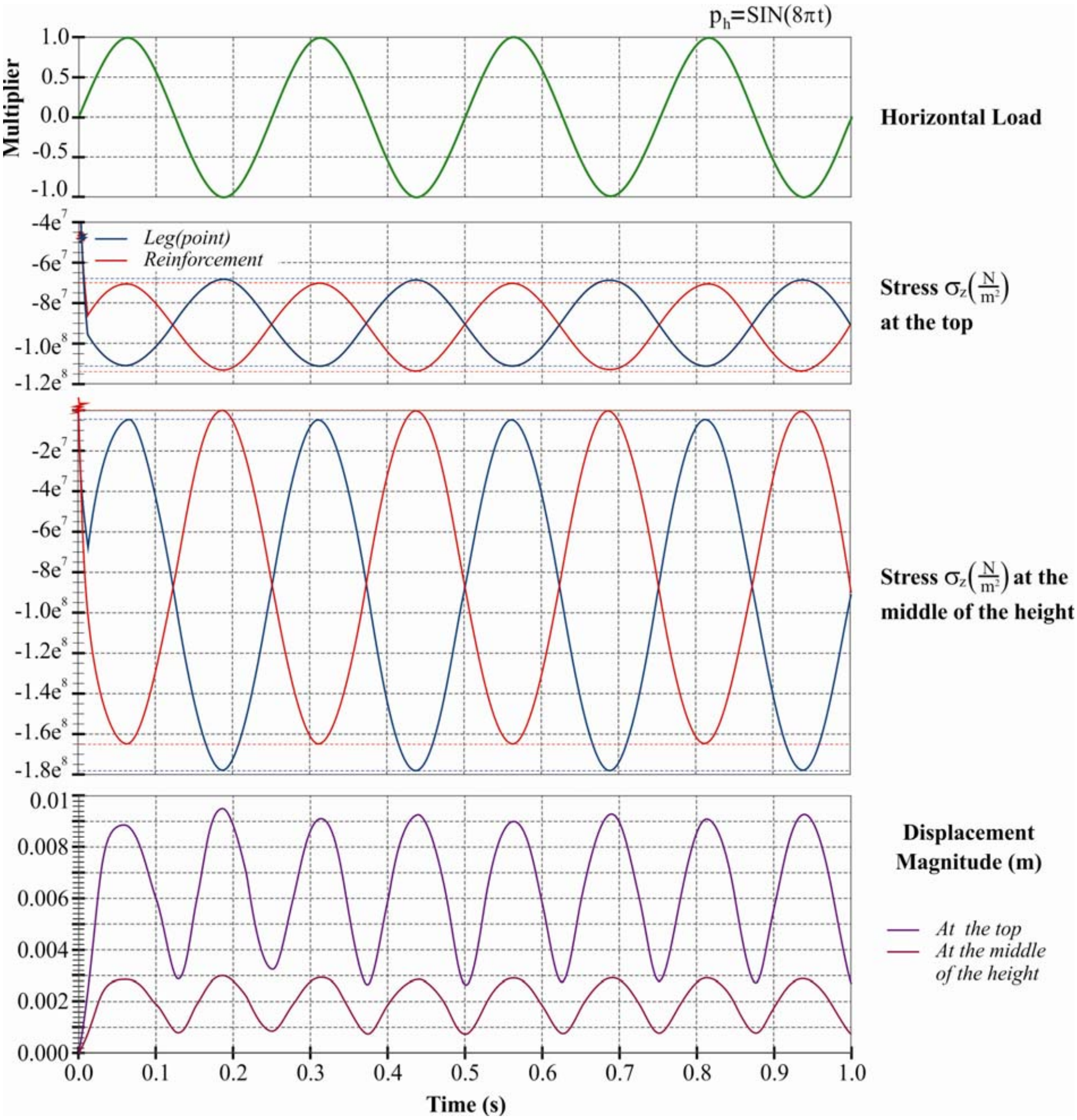


Figure 11. Reinforced leg with four clamps under horizontal harmonic load. Temporal variation of stress and displacements.

7 FINAL COMMENTS AND FURTHER STUDIES

The results of an ongoing study on reinforced legs of lattice towers were herein reported. The reinforcement of lattice communications towers is nowadays an extended practice. However, detailed studies are not very common and there is a need to understand the behavior. Some computational models have been analyzed with linear material models, two types of joint configurations, bilinear material model and a simple dynamical load. Regarding the joint model, a perfectly assembled cylinder and a bolt modeled as a beam were studied. Various load and boundary configurations were analyzed, some of which were reported. In this regard, it can be said that the second model is easier to construct, i.e. the mesh is straightforwardly found while the cylinder case poses further complexity in this issue. Also, the bolt model is more economical from the computational time viewpoint and thus the following models (leg with reinforcement) were solved with this joint. Additional complexities can be added to the problem. At present the authors are including a contact model at the joint to account for backlash and friction. However, and since the aim is to model a portion of the tower, the complexity of the model can be a drawback to the efficiency of the studies. The buckling analysis is a relevant issue and will be tackle in the next stage. Also a physical experimental model is under design for a single leg segment and for a three leg tower portion. The numerical computations will serve as a basis for the specimen design.

REFERENCES

Citipitioglu, A.M., Haj-Ali, R.M. and White, D.W., Refined 3D finite element modeling of partially-restrained connections including slip. *Journal of Constructional Steel Research*, 58:995-1013, 2002.

Egidi, C., Rey Saravia D. and Rosales, M.B. Structural Behavior of Reinforced Legs with Application to Lattice Communication Towers. *Mecánica Computacional* XXIX. Number 19. Structural Mechanics. MECOM 2010 y CILANCE 2010, 15-18 November 2010

Foces, A., and Garrido, J. A., Finite element Análisis de unions atornilladas viga-pilar realizadas con chapa frontal a tope. *Revista Internacional de Métodos Numéricos para Cálculo y Diseño en Ingeniería*, 21:35-53, 2007.

Jiménez Pérez, P. Modelación numérica de una union atornillada mediante elementos finitos. Minor thesis, Department of Engineering of Construction, Universidad Politécnica de Catalunia, España, 2008.

Tongkasame, C., *Retrofitting of angle legs of transmission towers to increase load capacity*, Ph.D. thesis. School of Natural and Built Environments, University of South Australia, Australia, 2008.

Zhuge, Y. and Mills, J. *Modelling of multi-panel transmission tower retrofitted with leg reinforcement*. 21th. Australasian Conference on Mechanics of Structures and Materials (ACMSM21), 7-10 December 2010, Melbourne, Australia.