VERIFICA COMPARATIVA SOTTO L'AZIONE DEL VENTO DI TORRI DI TRASMISSIONE CON ELEMENTI DI ACCIAIO E COMPOSTI

THE COMPARATIVE ASSESSMENTS OF THE LATTICE TRANSMISSION TOWER WITH STEEL AND COMPOSITE ELEMENTS UNDER THE WIND LOAD

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ABSTRACT

Lattice transmission towers, when submitted to different combinations of lateral and gravity loadings may suffer from potential buckling phenomena in some compressed members, producing the risk of the whole infrastructure instability. In order to prevent any buckling phenomena, a possible choice is to replace the steel sections of braces by concrete-filled steel tubes. For comparing purpose, two transmission towers with similar characteristics are selected as case studies. Detailed finite element models are built in Abaqus platform in order to investigated the performance of the two towers by evaluating displacement and base shear due to wind loadings. In the modelling of the non-linear behaviour of steel elements, the geometrical imperfections are considered. From the results of the non-linear dynamic analysis, the transmission tower with composite columns presents the best performance under wind load, in terms of both of strength and stiffness.

SOMMARIO

Le torri di trasmissione a traliccio, quando sottoposte a diverse combinazioni di carichi laterali e gravitazionali, possono subire potenziali fenomeni di instabilità in alcune membrature compresse, causando il rischio di instabilità dell'intera infrastruttura. Al fine di prevenire eventuali fenomeni di instabilità globale, una possibile scelta è quella di sostituire i profilati di acciaio dei montanti con elementi tubolari riempiti di calcestruzzo. A scopo di confronto vengono selezionate come casi studio due torri di trasmissione con caratteristiche simili. Modelli dettagliati agli elementi finiti sono costruiti nella piattaforma Abaqus per studiare le prestazioni delle due torri, valutando gli spostamenti laterali, l'accelerazione e il taglio alla base dovuti all'azione del vento. Nella fase di modellazione del comportamento non lineare degli elementi di acciaio, vengono tenute in conto le imperfezioni geometriche. Dai risultati dell'analisi dinamica non lineare, la torre di trasmissione con colonne composte presenta le migliori prestazioni sotto carico del vento, sia in termini di resistenza che di rigidità.

1 INTRODUCTION

Electricity transmission systems are considered as one of the important infrastructures, as they are transferring and distributing high-voltage power. These systems are divided into two main groups: the monopole and lattice towers. The first one can be made of steel, concrete and composite materials [1]; the last type is usually constructed with angled and tubular steel sections [2].

Despite the fact that the lateral loadings, such as wind and earthquake, are considered in the design process of the lattice transmission towers, a number of failures and collapses of these structures have been reported in the past major earthquakes [3-4], which aroused concern about the vulnerability of these systems.

In order to better understand the performance of the lattice transmission towers, several experimental and numerical studies have been done during the last decades [5-8]. Alam and Santhakumar [5] investigated the seismic behaviour of a 200 kV lattice transmission tower through a full-scale test. Albermani et al. [6] have done an experimental investigation in order to evaluate the performance of lattice towers under wind loads. Tian et al. [7] and Fu et al. [8] estimate the ultimate capacities of lattice transmission towers through a series of full-scall tests. All studies have indicated that the buckling of the structural elements is the main reason for the overall failure of the tower. To reduce the undesirable collapses, Tian et al. [9] developed the fragility curves for the transmission towers under the near-field ground motions in order to involve the seismic and structural uncertainties in the design process.

The elimination of the buckling phenomenon in the tower elements requires a precise estimation of the structural behaviour under the lateral loadings. However, the exact estimation is not so easy due to the complicated interactions such as the dynamic coupling effect between the transmission tower and lines. As an alternative, a possible choice for increasing the load carrying capacity and reducing the buckling probability is the use of concrete-filled tubular elements in the lattice transmission structures. The concrete-filled steel elements are commonly used in building structures and several researches have been done to evaluate their axial behaviour [10-11]. However, their application in the lattice transmission towers has not been investigated yet.

The current paper is aimed at investigating the performance of lattice transmission towers with concrete-filled tubular bracings under wind loads. For this purpose, the tubular lattice transmission given in [12] is selected as a base for a case study. In order to investigate the effects of concrete-filled braces on the tower behaviour, the same overall configuration [12] is assumed and some hollow tubular braces are replaced with concrete-filled tubular ones. The detailed finite element model is built on the Abaqus platform and nonlinear time history analyses are performed on the models under the wind loads. At the end, the top displacement and base shear of the towers are investigated.

2 NUMERICAL CALIBRATION OF A REFERENCE FULL-SCALE TEST

In order to validate the modeling procedure, a 1000 kV double circuit steel tubular transmission tower of [12] is modelled again in the Abaqus platform and the results are compared in this section. The reference tower is designed according to the Chinese code for seismic hazard with a peak ground acceleration of 0.2 g. The configuration of the tower as well as the leg and bracing members information are illustrated in Fig. 1. As it can be observed, the studied transmission tower consists of a tower body and three cross arms. The overall height of the tower is 87.3 m and is constructed on a square base with dimensions of 14.69 m × 14.69 m. The total weight of the tower is 61.44 tons. The leg components are made of Q420 and Q345 steel tubes and the bracing members are selected to be of Q345 steel tubes. These components are connected through the flange and tube-gusset joints, respectively. The six conductor lines are supported by the top, median, and bottom cross arms, while two ground wires are hanged from the top cross arm. More information about the prototype structure can be found in [12].

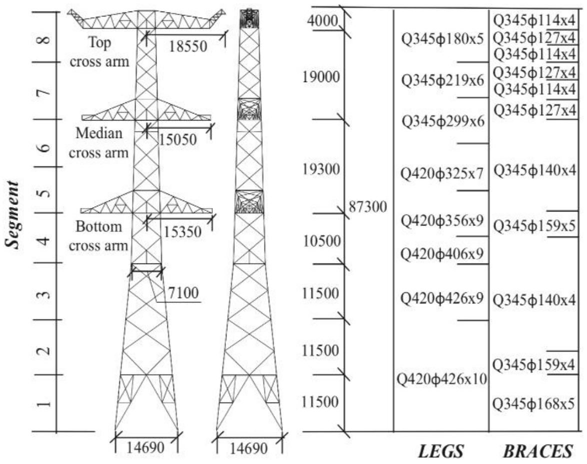
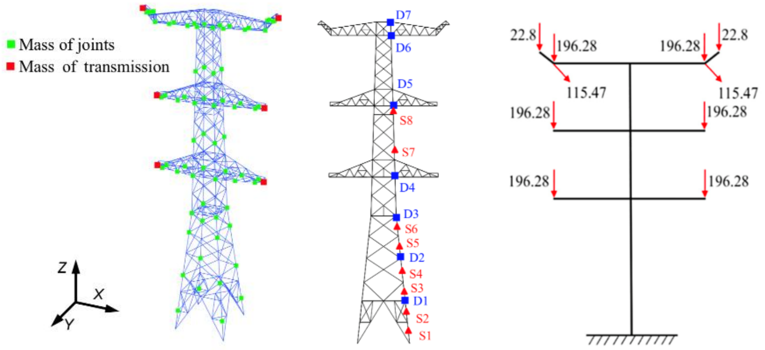


Fig. 1. The configuration of considered transmission tower [12]

Fig. 2a depicts the Abaqus model of the tower, where the B31 beam element is used for modeling the members. The model is fixed to the ground and the damping ratio is assumed to be 2%. The P-delta effect is included in the analyses as a source of geometric nonlinearity. In order to get the buckling of the elements, an initial camber of L/500 (L is the length of the specimen) is considered in the modeling phase. The stress – strain behaviour of the members is defined with an elastic modulus of 201 GPa, yield stresses of 345 MPa and 420 MPa for Q345 and Q420 materials, respectively, a mass density of 7850 kg/m^3 and a Poisson's ratio of 0.3. The full definition of the tube material can be set by fitting the resulted force - displacement curve of the simulation with reliable experimental data. In this paper, an experimental test of [13] for a tube with a length, diameter, and thickness of 2200 mm, 102 mm, and 6 mm, respectively, is considered for this purpose, as shown in Fig. 3. After the development of the FE model, displacement responses of the model in four different nodes (see Fig. 2b) are compared with the corresponding results of [12]. For this purpose, the loading tree of Fig. 2c is considered and applied to the model in the following steps: 0%, 50%, 75%, 90%, 95%, 100% and 0%. The results are illustrated in Fig. 4. As it can be observed, there is good agreement between the results.



(a) (b) (c)

Fig. 2. a) Finite element model of the transmission tower; b) Displacement measuring points; c) Loading tree of the tower (kN).

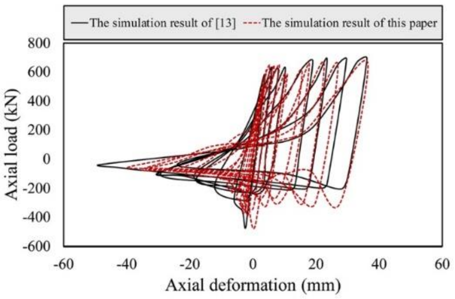


Fig. 3. The hysteretic behaviour of the steel tubular element in Abaqus in comparison with the simulation of [13].

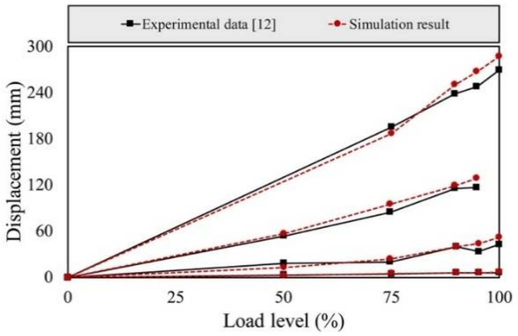


Fig. 4. Comparison of the displacement responses of the experimental and simulation results

3 NUMERICAL STUDY

In order to investigate the effects of concrete-filled tubular braces on the performance of lattice transmission towers, two different models are adopted here as case studies. The first model is the same as the one introduced in the previous section and the second one is selected to be similar to the first model where a number of bracing members are replaced with concrete-filled tubular sections. The dimension of the both bracing elements, i.e., steel tubular and concrete-filled tubular sections are the same and the concrete material of the last sections is selected to be ultra-high-performance concrete (UHPC) with the compression strength of 120 MPa. Fig, 5 shows the configuration of the models. The red-coloured elements in the figure represent the concrete-filled sections. The four measuring-points, D_i, are also illustrated in the figure and their displacement responses are controlled in this paper.

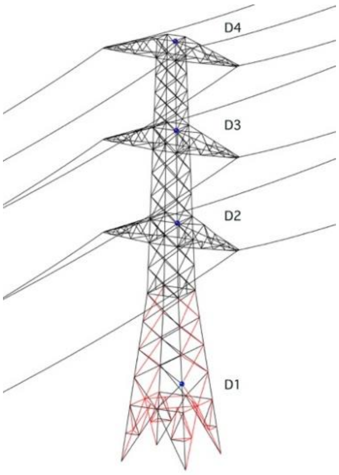


Fig. 5. The configuration of the considered models

4 WIND SPECTRUM

The simulated wind speed is the sum of average wind speed, V_a, and fluctuation wind, V_f, as follows:

$$(z,t) = V_a(z) + V_f(z,t) \tag{1}$$

The average wind speed is a function of altitude and is often expressed by a power-low or logarithmic wind speed profile (equation (2)). The fluctuating wind speed can be generated by a proper power spectrum, $S_u(z,n)$, according to equation (3), where n is frequency, f_z is normalized frequency according to equation (4), z is the altitude, and V_* is the friction velocity and is taken to be 32 m/s and k is Karman constant equal to 0.4. The well-known Kaimal spectrum is selected here for this purpose. The total time for each time series is considered to be 600 s with a time interval of 0.1 s. The considered wind spectrum as well as the fitted record are given in Fig. 6.

$$V_* = \frac{kV_a}{ln\,(z/z_0)} \tag{2}$$

$$\frac{nS_u(z,n)}{{V_*}^2} = \frac{200f_z}{(1+50f_z)^{\frac{5}{3}}} \tag{3}$$

$$f_z = \frac{nz}{V_a} \tag{4}$$

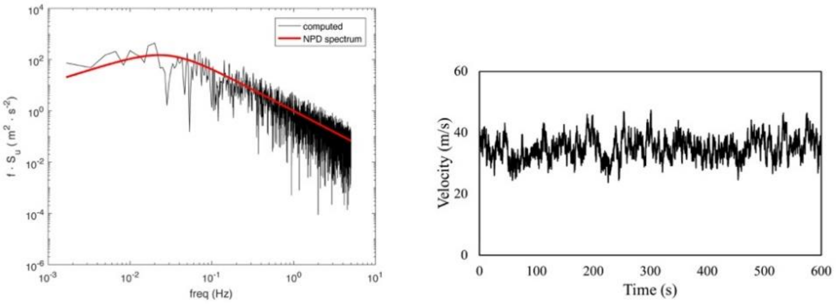


Fig. 6. The considered wind spectrum and record

5 RESULTS AND DISCUSSION

In order to capture the effects of wind velocity on the towers, they are imposed to the incrementally increasing velocities. For this purpose, models are devised into 10 segments, where the corresponding forces of each velocity are applied on these segments. Fig 7 illustrates the displacement of four measuring points of the models with respect to the velocities.

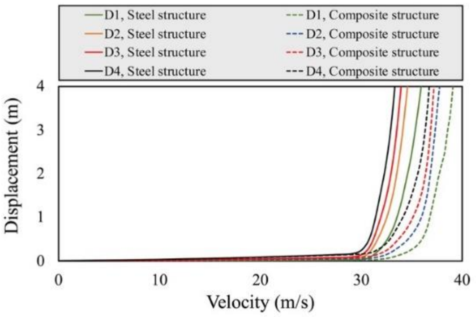


Fig. 7. The comparison of the displacement responses of the models

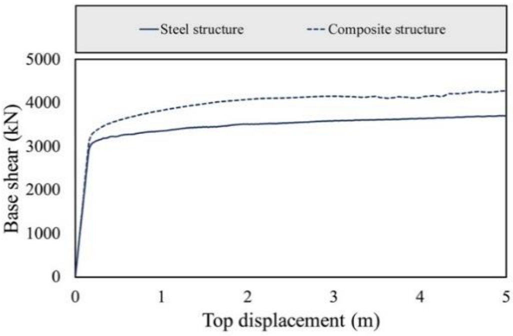


Fig. 8. The comparison of the base shear of the models

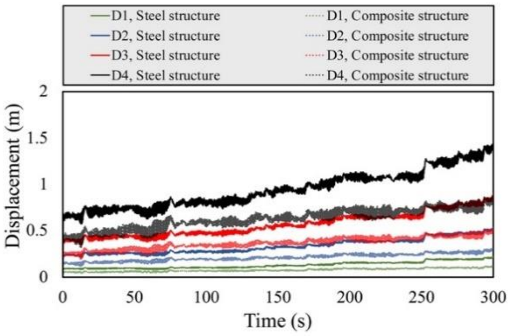


Fig. 9. The comparison of the displacement time histories of the models

As it can be seen, the displacement responses of the composite structure are less than the corresponding responses of the steel structure. Each curve is continued until the global instability takes place in the models. This is observed in Fig.7 by the steepest increase of the displacement responses, which indicates the tower displacement is rapidly increasing toward infinite values for small changes in velocities. It should be noted that the critical velocities of the composite model are higher than the steel one. The base shear – top displacement responses of the models are depicted in Fig. 8. As it can be seen, the application of concrete-filled bracing elements increases the energy dissipating capacity of the structure.

The dynamic analyses under the wind record are performed and the displacement responses in the four measuring points are presented in Fig. 9. As it can be seen, the results are in agreement with the results of Fig. 7, as the displacement of the composite model is lower than the steel one.

8 CONCLUSIONS

The performance assessments of the lattice tubular towers are investigated in this paper and an idea of application of concrete-filled tubular sections is presented in order to postpone the local and global instability of the towers under strong wind loads. For this purpose, a reference model with steel tubular elements is analyzed and in the second model some of the bracing elements of the reference model are replaced with concrete-filled sections. Then, the performance of the models is monitored under static and dynamic analyses. The results indicated that the application of the concrete-filled section in some bracing members reduces the displacement responses of the tower and increases its stability under the wind loads. It is also obtained that the structural base shear is increased when the concrete-filled sections are replaced with the hollow tubular sections; which corresponds to the increase of its energy absorbing capacity.

REFERENCES

[1] Atashfaraz B., Taiyari F., Raad H.H., Formisano, A., Post-tensioned tendons for enhancing the seismic behaviour of base-isolated monopole transmission towers, Engineering Structures, 247, 113222, 2021

[2] Tian L., Pan H., Ma R., Zhang L., Liu, Z, Full-scale test and numerical failure analysis of a latticed steel tubular transmission tower, Engineering Structures, 208, 109919, 2020

[3] Chan Y.F., Alagappan K., Gandhi A., Donovan C., Tewari M., Zaets S.B., Disaster management following the Chi-Chi earthquake in Taiwan, Prehospital and disaster medicine, 21(3), 196-202, 2006

[4] Xie Q., Zhu R., Earth, wind, and ice, IEEE Power and Energy Magazine, 9(2), 28-36, 2011
[5] Alam M.J., Santhakumar A.R., Reliability analysis and full-scale testing of transmission tower, Journal of Structural Engineering, 122(3), 338-344, 1996
[6] Albermani F., Kitipornchai S., Chan R.W., Failure analysis of transmission towers, Engineering failure analysis, 16(6), 1922-1928, 2009
[7] Tian L., Guo L., Ma R., Gai X., Wang W., Full-scale tests and numerical simulations of failure mechanism of power transmission towers, International Journal of Structural Stability and Dynamics, 18(09), 1850109, 2018
[8] Fu X., Wang J., Li H.N., Li J.X., Yang L.D., Full-scale test and its numerical simulation of a transmission tower under extreme wind loads, Journal of Wind Engineering and Industrial Aerodynamics, 190, 119-133, 2019
[9] Tian L., Pan H., Ma R. Probabilistic seismic demand model and fragility analysis of transmission tower subjected to near-field ground motions, Journal of Constructional Steel Research, 156, 266-275, 2019
[10] Zhao X.L., Grzebieta R. Strength and ductility of concrete filled double skin (SHS inner and SHS outer) tubes, Thin-walled structures, 40(2), 199-213, 2002
[11] Romero M.L., Ibañez C., Espinós A., Portolés J.M., Hospitaler A., Influence of ultra-high strength concrete on circular concrete-filled dual steel columns, Structures, 9,13-20, 2017
[12] Pan H., Tian L., Fu X., Li H., Sensitivities of the seismic response and fragility estimate of a transmission tower to structural and ground motion uncertainties, Journal of Constructional Steel Research, 167, 105941, 2020
[13] Tian L., Pan H., Ma R., Probabilistic seismic demand model and fragility analysis of transmission tower subjected to near-field ground motions, Journal of Constructional Steel Research, 156, 266-275, 2019.

KEYWORDS

Lattice transmission tower, steel member, composite element, wind load, buckling, non-linear dynamic analysis.