The 2014 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM14)
Busan, Korea, August 24-28, 2014

Dynamical response of transmission line towers subjected to thunderstorm downbursts based on experimental study

*Yong Chen1) and Lei Pan2)

1), 2) Department of Civil Engineering, Zhejiang University, Hangzhou 310058, China
1) cecheny@zju.edu.cn

Feng Pan3) and Yong Guo4)

3), 4) Zhejiang Electric Power Design Institute, Hangzhou 310012, China

ABSTRACT

Thunderstorm downburst is responsible for the damage and collapse of numerous electric power transmission towers. A retrofitted deterministic-stochastic hybrid model (DSHM) method is utilized to achieve the stationary dynamic response of the transmission tower. A downburst simulator is experimentally set up with a high-frequency base balance installed under the flat plate. A tube transmission tower for 500kV electric power transmission system is manufactured with a scale of 1:500. The wind force of each segment is sequentially attained by measuring the base force of the cut towers. The location of the transmission tower is changed by varying the distance from the planar center of the tower and the center the downburst. Also, the rotation angle of the tower is changed in the experiment to study the varying of the wind force coefficients. The experimental study on the wind loading varying with the Reynolds number is conducted via an atmospheric boundary layer wind tunnel. The results show that it is more dangerous in case of that the tower is located at where is 0.6 Djet far from the center of the downburst.

1. INTRODUCTION

Thunderstorm downburst is a strong downdraft spreading form the center to periphery and occurs during the thunder weather (Letchford et al., 2002),. It is responsible for numerous failure incidents of transmission towers. Kanak et al. (2007) reported that at least 19 electric self-supported transmission line towers are damaged in South-Western Slovakia in 2003, where a downburst occurred. Xie et al. (2006) reported that 18 transmission line structures of 500 kV and 57 transmission line structures over 110 kV collapsed due to strong downburst events. This may due to that the design code is based on the atmospheric boundary layer wind by now.

---

1) Associate Professor

Chay (2006) employed an analytical/stochastic method of simulating downburst winds to explore the quasi-static loading conditions. The results are presented in comparison to several existing transmission tower design codes. Darwish (2011) conducted a parametric study to determine the critical downburst configurations causing maximum axial forces for various members of a tower. The sensitivity of the internal forces developing in the tower's members to changes in the downburst size and location was studied. Pan (2012) employed deterministic-stochastic hybrid model (DSHM) to characterize the effect of downburst on a 1000 kV transmission towers. EI Damatty (2013) introduced a procedure to account for the critical effects of downburst on transmission line structures. All these studies are mainly numerical.

This study presents an experimental study on the wind loadings on the transmission line tower, by using a physical scaled model of transmission tower. A large diameter jet was built to conduct the experimental study. The wind loading coefficients are presented herein. Relationship between the loading and position were experimentally investigated. Further, a frame work is proposed to take into account the turbulent flow, and to achieve the dynamic response of the transmission tower.

2. EXPERIMENTAL SETUP

The downburst simulator, which is constructed based on the impinging jet model, is shown in Fig. 1(a). In this case, the jet diameter D_{jet}=0.6 m, the jet height H=2D_{jet}. According to the design theory of the wind tunnel, the simulator incorporates four parts: Fan, diffuser, settling chamber and contraction. A transmission line tower is placed on the flat floor, on which a lot of roughness bricks are layered to simulate the ground roughness. A high-frequency base balance (HFBB) is installed under the bottom of the tower to measure the overall loadings of the tower, as shown in Fig. 1(b). The scale factor of the model is 1:500. The jet velocity is fixed at 11.7m/s。

(a) Simulator (b) Transmission line tower

Fig. 1 Experimental setup.

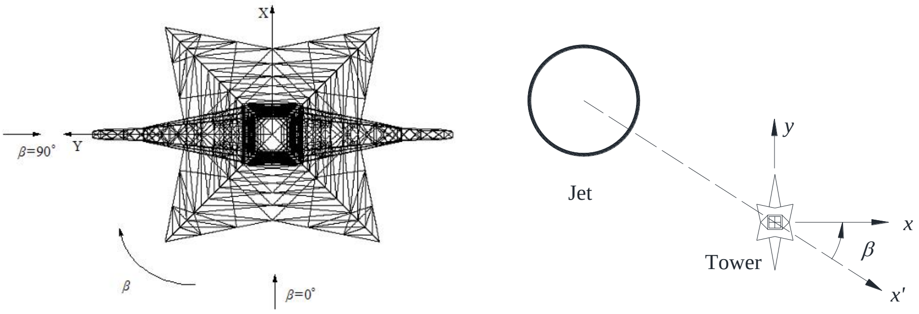
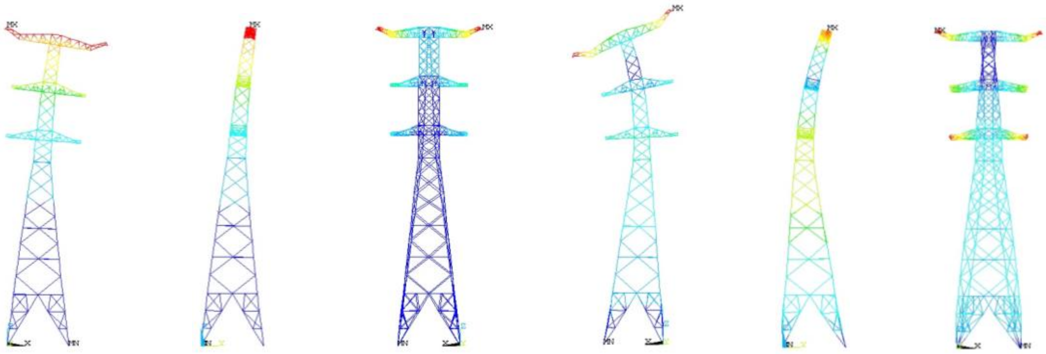


Fig. 2 The relative coordinate system of the tower.

In order to measure the downburst effects on the transmission tower, the tower was cut into five parts sequentially. Thus, the loading of each part could be attained by subtracting the loading after the cutting from the loading before the cutting. Fig. 3 shows the photo of the transmission tower in each measuring procedure. Fig. 4 shows the first six modes of the tower, and the corresponding natural frequencies of prototype model are 1.1176 Hz, 1.1325 Hz, 1.7885 Hz, 2.6617 Hz, 2.8428 Hz and 3.8728 Hz sequentially。

(a) Geometry (b) Model 1 (c) Model 2 (d) Model 3 (e) Model 4 (f) Model 5

Fig. 3 Transmission towers for test.



(a) 1st mode (b) 2nd mode (c) 3rd mode (d) 4th mode (e) 5th mode (f) 6th mode

Fig. 4 The first six modes

3. DOWNBURST LOADING COEFFICIENTS

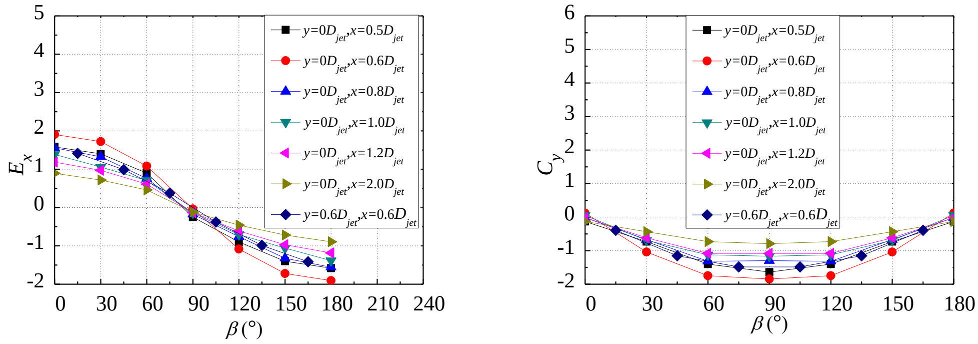
The wind forces in direction of x and y measured by HFBB could be normalized by

$$E_x = F_x \big/ (0.5 \rho V_{\text{jet}}^2 S) \qquad E_y = F_y \big/ (0.5 \rho V_{\text{jet}}^2 S) \tag{1}$$

in which F_x, F_x and M is the base forces in direction of *x* and *y* respectively, ρ is air density, S is the tower's project area in *y*-*z* plane, V_{jet} is the jet velocity. E_x and E_y are therefore designated as wind loading coefficients.

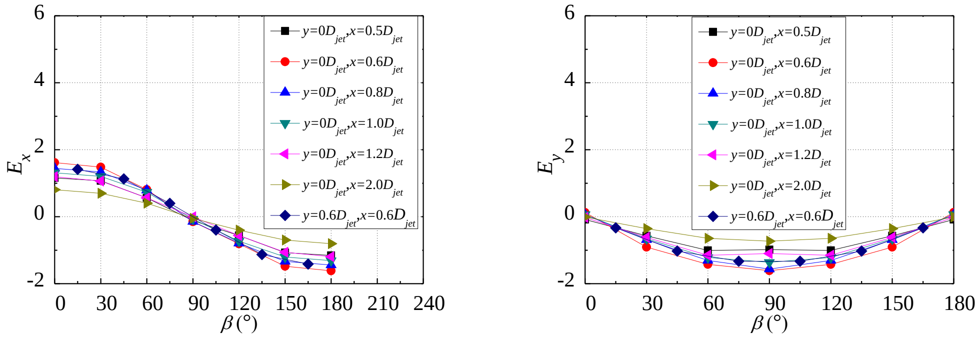
Figs. 4-8 illustrate the normalized base forces attained via HFBB. With consideration of the whole tower, it is found that the base forces would reach their maximum values while the tower is placed at where is about 0.6 D_{jet} far from the center of the downburst. However, the site on which the base forces reaches its maximum changes with the models. This phenomenon indicates that where the horizontal wind velocity reaches its maximum (conventionally 1.0 D_{jet} to 1.2 D_{jet}, depends on the roughness of the ground) maybe not the most dangerous place for this tower, because the whole wind profile is more critical if one considers the whole loadings of a tower structure.

In order to reduce the effect of Reynolds number, a new supplemented larger model with a scaling factor value of 1:145 was manufactured. The critical length in Reynolds number is the diameter of the maximum tube found in the tower. Two models were immersed into the ABL wind tunnel to process a HFBB approach. By varying wind speed, the wind force coefficients of the whole tower vary with Reynolds number, and the corresponding curve is shown in Fig. 10. Accordingly, with consideration of prototype model and $\beta = 0^{\text{o}}$, the wind loading measured in direction of *x* and *y* should be multiplied by 0.75 and 0.65 respectively, because of a small scaling factor (1:500) and a low wind velocity in downburst testing.



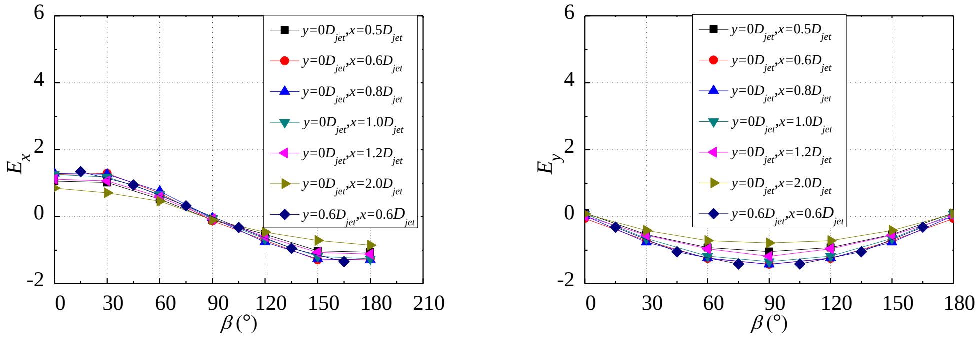
(a) E_x (b) E_y

Fig. 4 Downburst loading coefficients of Model 1.



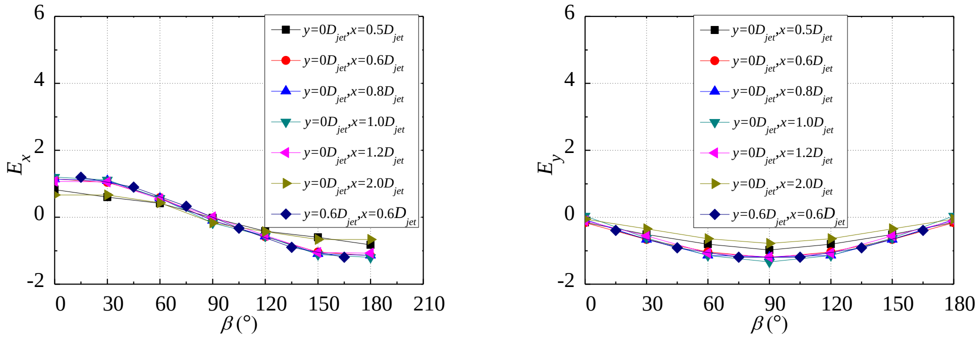
(a) E_x (b) E_y

Fig. 5 Downburst loading coefficients of Model 2.



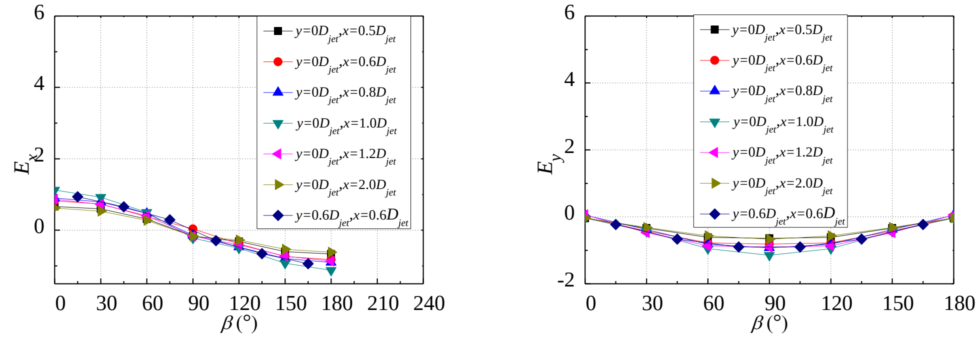
(a) E_x (b) E_y

Fig. 6 Downburst loading coefficients of Model 3.



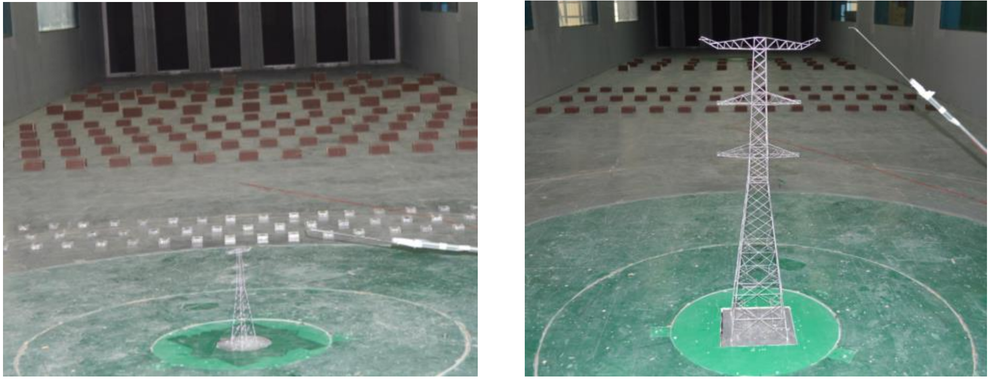
(a) E_x (b) E_y

Fig. 7 Downburst loading coefficients of Model 4.



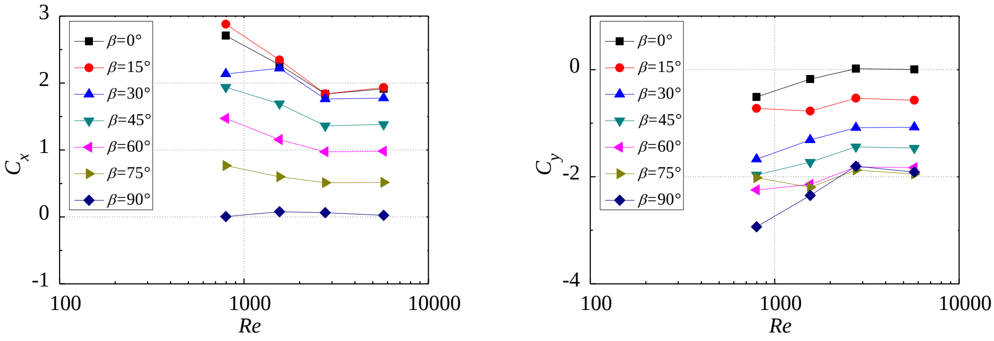
(a) E_x (b) E_y

Fig. 8 Downburst loading coefficients of Model 5.



(a) 1:500 (b) 1:145

Fig. 9. Test models with different scaling factors



(a) In direction of *x* (b) In direction of *y*

Fig. 10 Wind force coefficients.

4. DYNAMIC RESPONSE

According to DSHM (Chen 2004; Chen 2013), the wind speed, $U(z,t)$, in a microburst could be cast into

$$U(z,t)=\bar{U}(z,t)\left[1+\eta\lambda(z,t)\right] \tag{2}$$

where η is the desired turbulent intensity, and $\bar{U}(z,t)$ is the mean/non-turbulent wind speed at a height of z at the instant t, $\lambda(z,t)$ is a stationary Gaussian stochastic process with standard deviation of 1.0 and related to wind engineering spectrum. Note that this relationship holds for whole wind field. The relationship between the mean wind speed of the whole wind field and the jet velocity has a form of

$$\bar{U}(z,t)=\beta(z,t)V_{\mathrm{jet}} \tag{3}$$

where $\beta(z,t)$ is designated as wind field function. By substitution of Eq. (3) into Eq. (2), it yields

$$U(z,t)=\beta(z,t)V_{\mathrm{J}} \tag{4}$$

where

$$V_{\mathrm{J}}=V_{\mathrm{jet}}(1+\eta\lambda) \tag{5}$$

Then, one may imagine that the fluctuation of the wind velocity observed in the whole wind field at height of z is caused by the fluctuating jet velocity, V_{J}, which is correspondingly designated as the imaginary jet velocity

Note that the fluctuation of wind velocity leads to a relative small change of Reynolds number. The independency of Reynolds number could be then assumed, which means it could be assumed that the quasi-steady assumption still holds. Subsequently, the downburst loading that embodies the fluctuation could be computed by

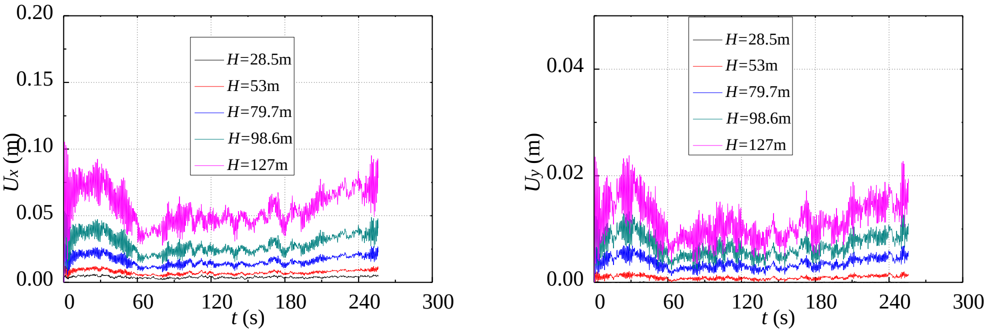
$$\tilde{F}_x=0.5\rho V_{\mathrm{J}}^2 SE_x \qquad \tilde{F}_y=0.5\rho V_{\mathrm{J}}^2 SE_y \tag{6}$$

Thus, the average wind loading of each part of the tower has a form of

$$\tilde{F}_{xi}=0.5\rho V_{\mathrm{J}i}^2 SE_{xi} \qquad \tilde{F}_{yi}=0.5\rho V_{\mathrm{J}i}^2 SE_{yi} \tag{7}$$

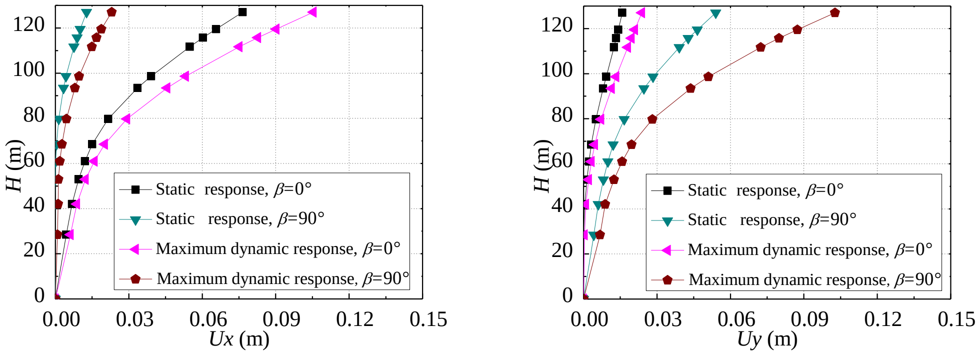
where V_{Ji} varies with z_i, the average height of the *i*th part of the tower, because $\lambda_i(z_i, t)$ varies with z_i.

Consider the transmission tower is located at where is about 0.6 D_{jet} far from the center of downburst, and it is subjected to a downburst integrated with turbulent component. Fig. 11 shows the corresponding displacement time histories of the top point of the prototype tower. Fig. 12 illustrates the maximum displacement response along the tower. For comparison, the static responses are also depicted in Fig. 12. It is found that the response would become larger if one takes into account the turbulence component of the flow. It is found the increment of the displacement response caused by the turbulence is larger while the radial axis x' is parallel to the transmission line, in comparison to the case that the radial axis x' is perpendicular to the transmission line



(a) In direction of *x* (b) In direction of *y*

Fig. 11. Displacement time histories of the top point of the prototype tower ($=0^{0}$)



(a) In direction of *x* (b) In direction of *y*

Fig. 12. Maximum displacement response along the tower

5. CONCLUSIONS

A frame work of computing the dynamic response of transmission tower that is subjected to downburst is proposed. The experimental study reveals that there exists a critical site on which the base force would reach its maximum. It relies on the height of the tower, and where the horizontal wind velocity reaches its maximum may not be the critical position. By using the retrofitted DSHM, the dynamic responses are obtained. In comparison to the static response, the dynamic responses are much greater, especially in case of that the radial axis is parallel to the transmission line.

ACKNOWLEDGMENTS

The work in this paper is supported by Science and Technology Project of State Grid Zhejiang Electric Power Company (Grant No. ZDK013-2012, kxk2012-017).

REFERENCES

Chay M.T., Albermani F., Hawes H., (2006). "Wind loads on transmission line structures in simulated downbursts", *1st World Congress on Eng. Asset Management*, 11-14 julio, Gold Coast, Queensland,Australia, 2006.

Chen L, Letchford C. W. (2004). "A deterministic-stochastic hybrid model of downbursts and its impact on a cantilevered structure", *Engineering Structure*, 26(5): 619-629.

Chen, Y. Liu, G.G., Sun, B.N. (2013), "Dynamic response of flat roofs subjected to non-stationary moving microbursts", *Engineering Applications of Computational Fluid Mechanics*, 7(4), 519-532.

Darwish, Mohamed M.; El Damatty, A. A. (2011). "Behavior of self supported transmission line towers under stationary downburst loading", *Wind and Structures*, 14(5): 481-498

El Damatty A. A., Hamada, A., Elawady, A. (2013), "Development of critical load cases simulating the effect of downbursts and torndos on transmission line structures", *The Eighth Asia-Pacific Conference on Wind Engineering*, Chennai, India.

Letchford C. W., Mans C, Chay M. T. (2002). "Thunderstorms—their importance in wind engineering (a case for the next generation wind tunnel)", *Journal of Industrial and Aerodynamics*, 90(12-15): 1415-1433.

Pan, F., Xie, F., Xing, Y. L., Chen, Y., Sun, B. N. (2012). "Wind-induced dynamic response of large steel tube frame for 1000kV UHV transmission lines to thunderstorm downbursts", *Kongqi Donglixue Xuebao/Acta Aerodynamica Sinica*, 30(4): 502-507

Xie Q. , Zhang Y. , Li J. (2006). "Investigation on Tower Collapses of 500 kV Renshang 5237 Transmission Line Caused by Downburst". *Power System Technology*, 30(10): 59-63