Dynamic response of a tall transmission tower under downburst-like outflows

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SUMMARY:

Electrical transmission towers can be vulnerable to high-intensity non-synoptic wind events such as downbursts. This vulnerability can be higher with old or damaged towers. This paper presents the dynamic response of an aeroelastic-damaged delta tower subjected to downburst winds. The experimentally produced downburst wind compares well with recorded downburst events and other experimentally produced downbursts. The results indicate a higher acceleration response at the tower top in comparison to the cross arm. Also, winds perpendicular to the open section of the delta tower were the most onerous judging by the peak base shear, peak base moments and acceleration rms.

Keywords: Transmission tower, downburst, dynamic behaviour

1. INTRODUCTION

Electrical power distribution networks are the backbone of modern societies. These networks include substations, conductors, and high-voltage transmission towers. Tall transmission towers are mostly required for water crossings and areas requiring longer spans. Towers higher than 100m usually have a lower natural frequency (i.e., 0.5Hz – 1.5Hz) making them more susceptible to wind excitation. Inspection of some damaged towers has identified failures due to high-intensity wind events such as downbursts (Savory et al., 2001). Preventing damages to tall transmission towers due to downbursts is particularly important given the economic losses that could be incurred because of power outages.

To better understand the impact of downbursts on transmission lines (TLs) and improve design recommendations, researchers have used experimental (Elawady et al., 2017) and numerical, (Aboshosha and El Damatty, 2015;) methods. Previous experimental simulations of downbursts have used an impinging jet method (Elawady et al., 2017) which represents three-dimensional (3D) downburst outflows and a flow redirection method (Le and Caracoglia, 2019; Alawode et al., 2022) which constitutes two dimensional (2D) downburst outflows.

US energy infrastructure had a C grade according to the ASCE infrastructure report card 2021 (ASCE, 2021). This was mostly due to the reliability and ageing of current infrastructures including power distribution networks. Older transmission towers (especially those with missing bolts, and corroded parts) can be more susceptible to wind damage, especially from high-intensity winds such as downbursts. Studies analyzing the dynamic response of old, or partially damaged tower responses to wind are few (Reinoso et al., 2020). This study, therefore, aims at advancing the knowledge of the dynamic behaviour of old/defective tall electrical transmission towers and lines during downburst events.

2. METHODOLOGY

The experimental study was conducted at the Wall of Wind (WOW) open jet wind tunnel capable of wind speeds up to ~70m/s. The newly installed downburst simulator at the facility uses a flow redirection method to generate 2D downburst outflows. Figure 1 shows the schematics of the simulator. The device has two slats at the lower end which both open to a pre-determined angle and close with the fall of the gravity gate to create the downdraft of the downburst outflow.

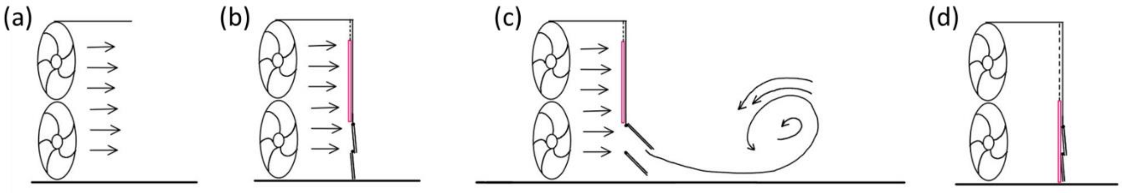


Figure 1. Schematics of the downburst simulator (a) Open-Jet facility (b) Downburst simulator added, Fan-On, Slats-Closed, Gravity gate-Up (c) Fan-On, Slats-Open, Gravity gate-Up (d) Fan-Off, Slats-closed, Gravity gate-Down

Wind speed and turbulence characteristic measurements at the center of the turntable were measured with Cobra probes sampled at 625 Hz. The decomposition of the wind velocity followed the classical approach shown in Equation 1.

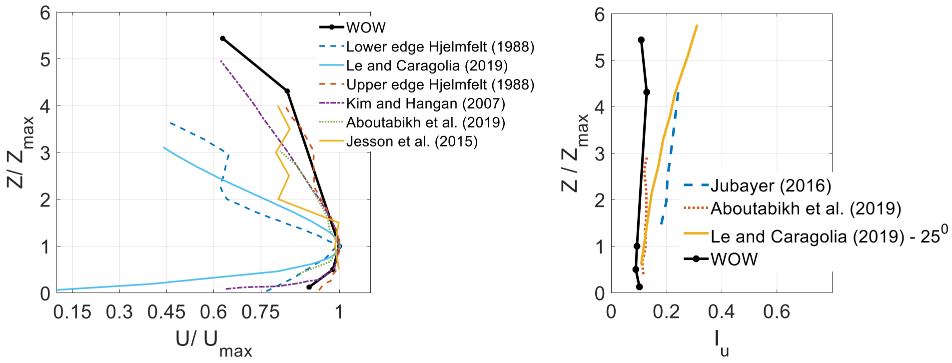
$$U(t) = \bar{U}(t) + U'(t) = \bar{U}(t) + \sigma_U(t)\tilde{U}'(t) \qquad (1)$$

Where $U(t)$ is the wind velocity in the horizontal direction, $\bar{U}(t)$ is the slowly varying mean wind velocity, $U'(t)$ is the residual fluctuating wind velocity, $\sigma_U(t)$ is the slowly varying standard deviation of $U'(t)$, and $\tilde{U}'(t)$ is the reduced turbulent fluctuation. The analysis of turbulence intensity I_u for the downburst is defined in Equation 2.

$$I_u = E\left[\sigma_{u'(t,z)}/\bar{U}_{\max(t)}\right]_T \qquad (2)$$

Where $I_{u,T}$ is the time-varying expected value of instantaneous turbulence intensity, $\sigma_{u',(t,z)}$ is the non-stationary slowly varying standard deviation of $U'(t)$ at a height z, and $\bar{U}_{\max(t)}$ is the maximum $\bar{U}(t)$ across the height. T is set to the experimental sampling rate making it a nearly instantaneous turbulence intensity. Figure 2 shows the wind velocity and turbulence intensity profiles in the simulation, in comparison with other downburst simulations in literature.

The prototype transmission tower in this study was a vertical self-supported delta lattice tower with a 13 m by 13 m base (Length x Width) and 60m height. The model was made of aluminum tubes and sections. A length scale of 1:50, and a time and velocity scale of 1:7.07 was used in the modeling to ensure dynamic similarity. The prototype tower had a natural frequency of 1.71Hz, and 1.75Hz (i.e., 12.09Hz and 12.37Hz in the target model scale) in the weak and strong axis respectively. Since a reduction in natural frequencies can be an indicator of damage detection in structures, especially with a 5% change (Salawu, 1997), the damaged tower model was constructed to have a lesser natural frequency than the target (i.e., 9.07Hz and 11.75Hz). A 0.5mm thick styrene cladding was added to the aluminum frame to replicate the tower's drag. Figure 3 shows the model tower and instrumentation. The accelerometers, strain gauges and load cells were all sampled at 625Hz. The tests were carried out from 0° to 90° at 15° increments at $\overline{U}_{\max(t)}$ = 7.7, 8.0, 9.4, 10.2, 10.7, 10.8m/s.



(a) (b)

Figure 2. Wind profiles (a) Wind Velocity profile (b) Turbulence intensity profile

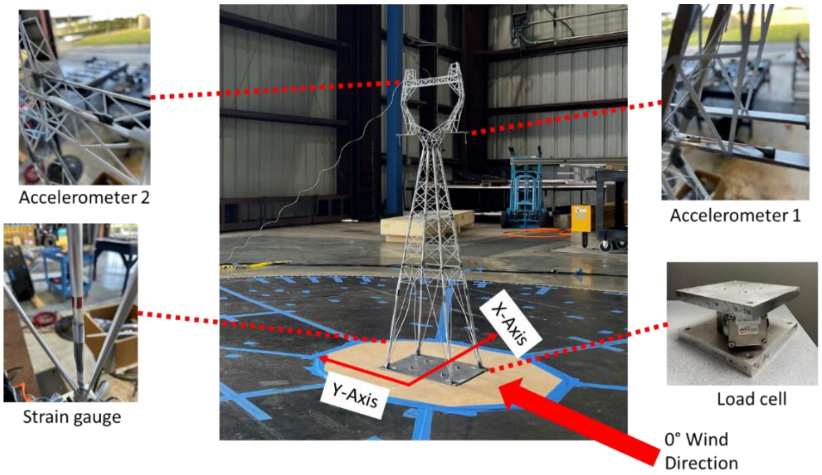
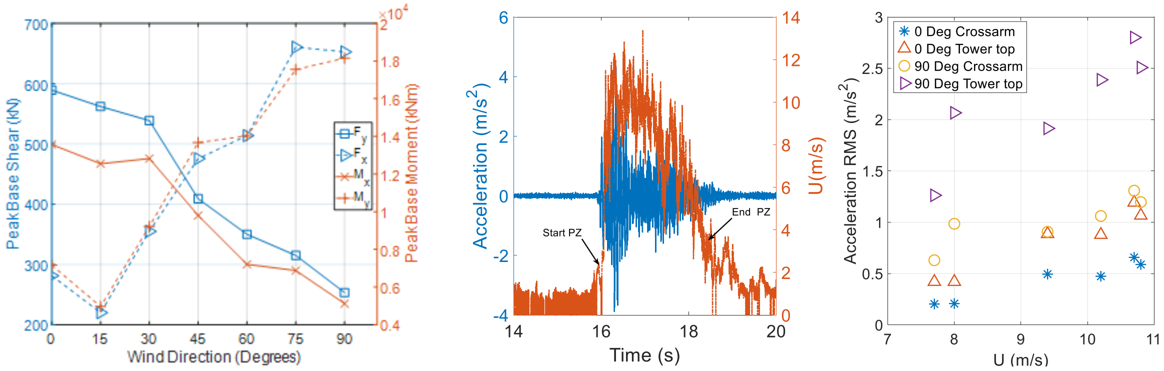


Figure 3. Tower Instrumentation

3. PRELIMINARY RESULTS

Peak base shear and base moments of the damaged tower under downburst winds from 0° to 90° wind direction are shown in Figure 4a. The results indicate that the 90° wind direction is the most onerous wind direction for single delta towers with no conductors under downburst winds. The acceleration time history and wind speed are shown in Figure 4b, indicating the movement of the tower as the downburst winds reach the tower. Figure 4c shows the acceleration rms of the Tower top and cross arm at 0° and 90° for the different $\overline{U}_{\max(t)}$ within the peak zone (PZ) (i.e start and end of PZ is shown in Figure 4b). There is a general increase in acceleration rms with increasing $\overline{U}_{\max(t)}$ with the tower top having a higher acceleration rms in comparison to the cross arm at similar $\overline{U}_{\max(t)}$. The higher acceleration rms at 90° wind direction in comparison to the 0° wind direction is mostly due to the larger frontal area in that direction coupled with the lower natural frequency of the tower in that direction.



(a) (b) (c)

Figure 4. Dynamic response (a) Peak Base shear and moment at 76m/s (b) Time series of acceleration and wind speed (c) Acceleration rms

4. CONCLUSION

The study has shown the capability of the downburst simulator at the WOW. Also, downburst wind perpendicular to the open portion of the delta tower (i.e weak axis) is the most onerous wind direction. More tests are planned at the WOW for the undamaged tower, to compare the responses which would be presented at the conference.

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