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Wind tunnel tests of transmission tower subjected to combined yawed and tilted wind

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SUMMARY:
The objective of the present study is to investigate the aerodynamic coefficients of transmission towers subjected to combined yawed and tilted wind. This study has been conducted on a series of experiments involving a steel lattice transmission tower model. A rigid tower model with a scale ratio of 1:25 was tested in the wind tunnel. The wind tunnel test results suggest that the effect of the tilt angle on longitudinal and transverse aerodynamic coefficients is not significant. However, lift aerodynamic coefficients in gravitational direction has a linear relationship with the tilt angle, and increase dramatically at tilt angle of ±30° corresponding to 39% of the maximum longitudinal aerodynamic force. In particular, it is found that the crossarm is a major factor that significantly increases the lift coefficient. In this study, a new formula was proposed to calculate the aerodynamic coefficient by considering these tilt and yaw angles at the same time. The proposed equation was verified by comparing with the wind tunnel test results.

Keywords: transmission tower, wind tunnel test, yaw angle, tilt angle, skew wind.

1. INTRODUCTION

Transmission towers, an important social infrastructure, have been designed and built based on the design codes. However, the failure of transmission towers in extreme wind has been still frequently reported. As shown in Fig.1, the wind on transmission towers sitting on the slopes of mountains may not be horizontal but instead may have an angle of attack on the tower's face.

Figure 1. Towers on a mountain slope.

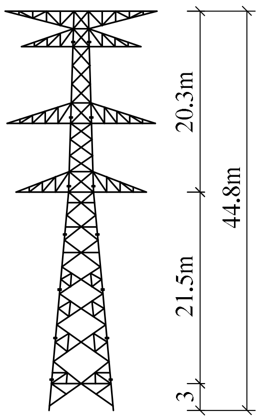


Figure 2. Prototype tower.

Figure 3. Tilted model in the wind tunnel.

There are extensive experimental and analytical studies for evaluating the wind load acting on transmission towers. However, most studies are on horizontal wind loads, and those on vertically tilted wind are limited. Although a few studies have looked at the effect of tilted wind on drag coefficients (Bayar, 1986; Zhou et al., 2019; Zhang et al., 2021), research on lift coefficients is scarce. Design codes such as ASCE-74 and IEC 60826 provide the longitudinal and transverse components of horizontal wind load based on solidity ratio, but no vertical wind loads.

This study aims to investigate the aerodynamic forces acting on a transmission tower subjected to combined yawed and tilted wind. The aerodynamic forces acting on the tower model are measured in the wind tunnel by varying the horizontal and vertical angles. The test results and discussions are summarized in the paper.

2. WIND TUNNEL TEST

The tests were conducted at the Jeonbuk (Chonbuk) National University's KOCED Wind Tunnel Center in Korea. Test section of the closed-circuit wind tunnel is 5.0 m wide, 2.5 m high, and 20 m long, and the maximum speed of wind is 31 m/s. The turbulent intensity and flow uniformity are less than 0.6% and 1%, respectively. All tests were conducted in uniform flow.

A scaled model was constructed duplicating the details of a full-scale tower of 44.8m high shown in Fig. 2. Geometric scale of the model was 1:25 considering the test section size. The blockage ratio is less than 1% at all yaw and tilt angles. As shown in Figure 3, the test model and the 6-axis loadcell were seated on a supporting system capable of changing the tilt angle.

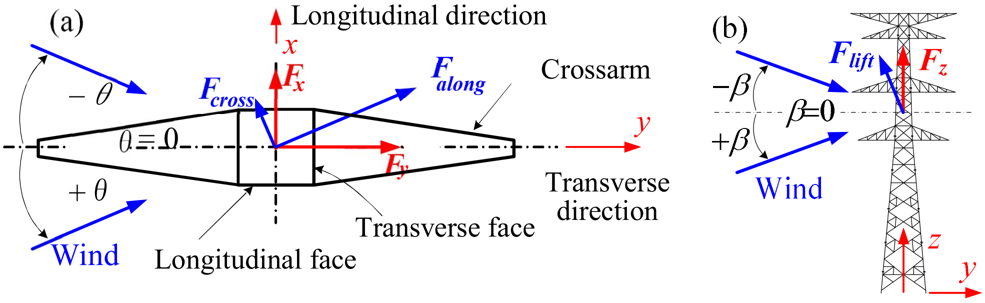


Figure 4. Coordinate system and wind angles: (a) plan view, (b) front view.

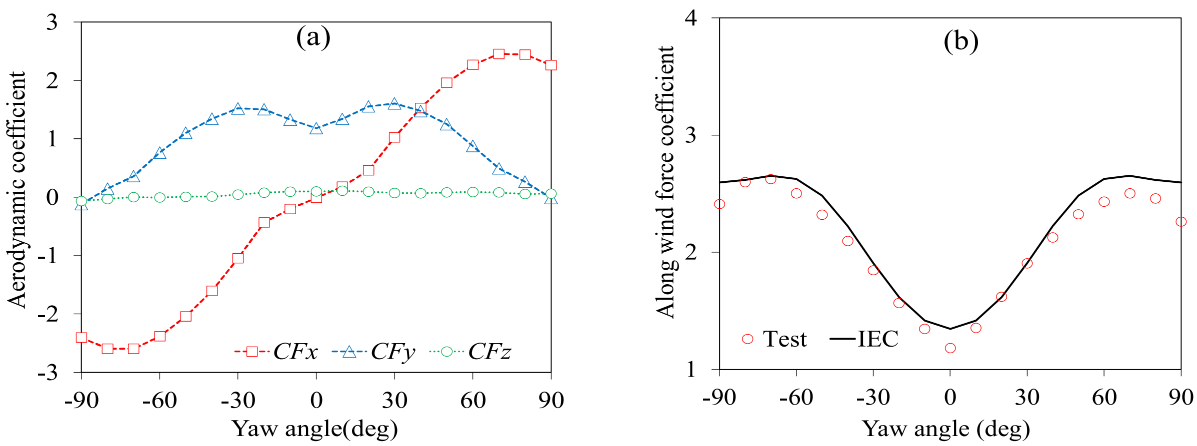


Figure 5. Aerodynamic coefficients at tilt angle of 0°, (a) measured coefficients in body axis, (b) along wind force coefficients in wind axis obtained from wind tunnel test and IEC 60826.

Fig. 4 shows the coordinate system and definition of wind angles. The yaw angle α, was rotated from -90° to +90° at 10° intervals. The tilt angle, β, is positive for upward wind and negative for downward wind. The tilt angle range was set at 0°~30° at 10° intervals. The normalized aerodynamic coefficients are calculated by dividing the measured forces by the wind pressure and the area of the projected net area on the longitudinal face. C_{Fx}, C_{Fy}, and C_{Fz} are in the body axis.

3. TEST RESULTS AND DISCUSSION

Figure 5(a) shows the body axis aerodynamic coefficients at 0° tilt angle. Figure 5(b) compares the along-wind coefficient in the wind axis with IEC 60826. The IEC-based coefficients match the measured ones well, so using the design code at 0° tilt angle is acceptable.

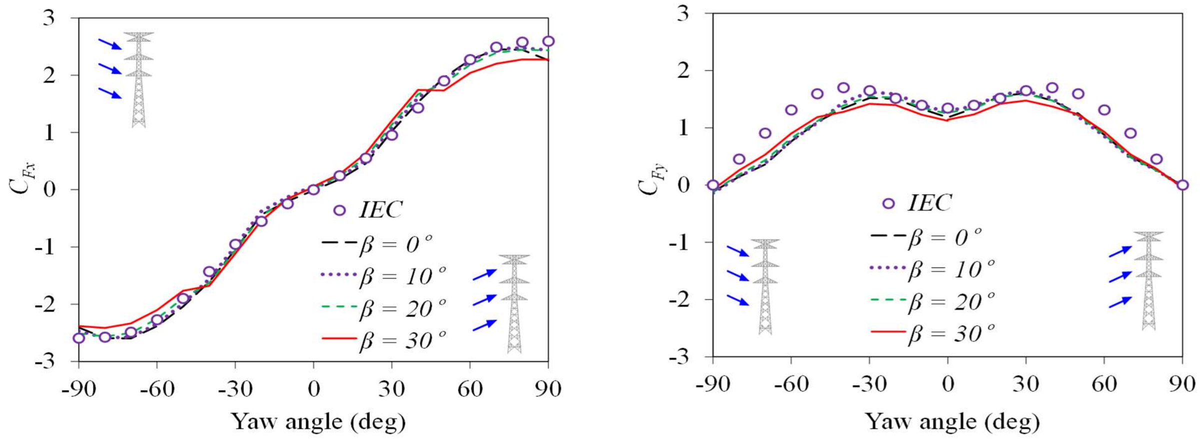
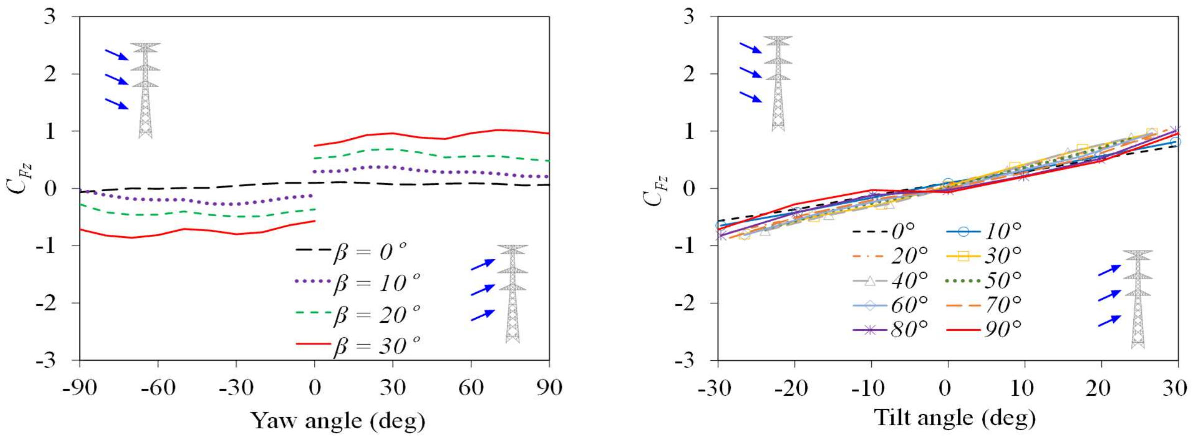


Figure 6. Aerodynamic coefficients in body axis under different tilt angles and yaw angles.

Figure 6 shows the aerodynamic coefficients for different tilt and yaw angles. The longitudinal force coefficients (C_{Fx}) are reduced by up to 6% at a yaw angle of 90° compared to a tilt angle of 0°. The decrease in transverse force coefficients (C_{Fy}) due to changes in tilt angle is small, at most about 4%. Thus, tilt angle has an insignificant effect on longitudinal and transverse aerodynamic coefficients.



(a) Tilt angle from 0° to 30°. (b) Yaw angle from 0° to 90°.

Figure 7. C_{Fz} under different tilt angles and yaw angles.

The aerodynamic coefficients in vertical direction, C_{Fz}, are shown in Fig 7. In the figure, the tilt angle is negative for yaw angle from -90° to 0°, and is positive for yaw angle from 0° to 90°. It is clear from Fig. 7(b) that C_{Fz} highly dependent with the tilt angle. The C_{Fz} increase linearly follow the change of tilt angle of from -30° to 30° for all yaw angle. The maximum lift aerodynamic coefficients C_{Fz} at tilt angles of 10°, 20°, and 30°, are correspond to 14%, 26.4%, and 39% of the maximum longitudinal aerodynamic force, respectively.

The following equation, Eq. (1a), for the along-wind drag coefficient is newly proposed considering both yaw angle (θ) and tilt angle (β) in accordance with the current drag coefficient in IEC. The new equation uses the project area (S_{t3}) and solidity ratio (C_{xt3}) of the top/bottom face of segments. The Eq. (1b) is the decomposed three components of the drag coefficient in body axis.

$$C_d A_p(\theta,\beta) = (1 + 0.2\,sin^2 2\,\theta)(S_{t1}C_{xt}\ \ cos^2\theta + S_{t2}C_{xt2}\,sin^2\theta)\,cos^2\beta + S_{t3}C_{xt3}\,sin^2\beta \quad (1a)$$

$$C_{Fx} = C_d \times sin\,\theta \times cos\,\beta$$
$$C_{Fy} = C_d \times cos\,\theta \times cos\,\beta \quad (1b)$$
$$C_{Fz} = C_d \times sin\,\beta$$

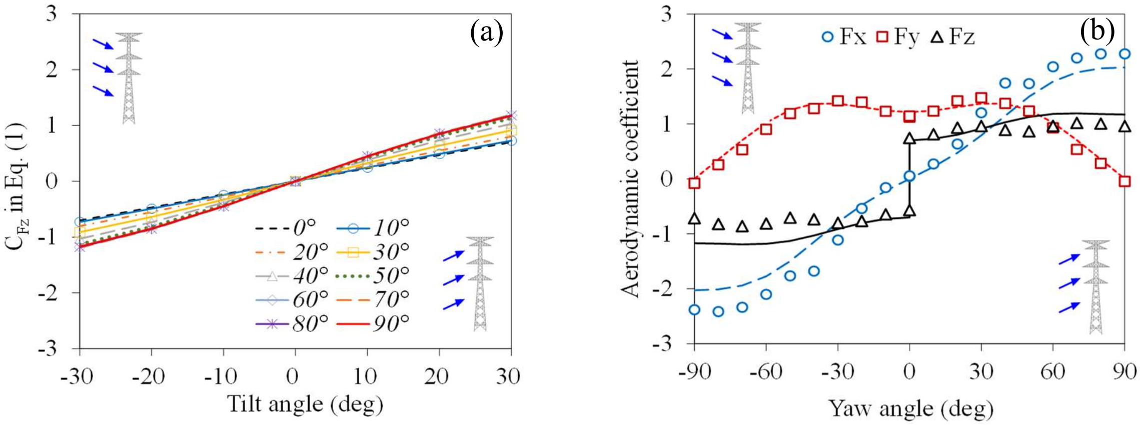


Figure 8. The propose equation and measurements: (a) C_{Fz} as a function of tile and yaw angle, (b) aerodynamic coefficients at tilt angle of ±30°[line: Eq. (1); symbol: measurement].

4. CONCLUSION

Wind tunnel tests found that the tilt angle has little effect on longitudinal and transverse aerodynamic coefficients. However, lift aerodynamic coefficients increase linearly with tilt angle. These findings impact lattice tower design, as current design standards underestimate wind effects. An improved equation has been proposed for calculating aerodynamic coefficients.

ACKNOWLEDGEMENTS

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