Does the Shape of the Wind Rose Influence Tower Fatigue?

Nicola Grieve, Prof. W. Leithead

Wind & Marine Energy Systems CDT, Rm 3.36, Royal College Building
University of Strathclyde, 204 George Street, Glasgow, G1 1XW

nicola.grieve@strath.ac.uk

Introduction

Wind turbine towers experience cyclic loads which negative impacts on the tower due to fatigue damage. Many UK sites have a prevailing wind direction which concentrates the loads and hence fatigue damage on one section of the tower. If the wind and hence loads are distributed around the tower what is the impact on fatigue damage? The aim of this project was to investigate the impact of the wind rose shape and hence wind direction and create a simple methodology in which to do so.

Methodology

The wind turbine tower was modelled as a cantilever beam (Figure 1) and therefore a symmetrical tower model was created using small beams. The model consisted of different orientated beams located between 0 and 359 degrees as shown in Figure 2.

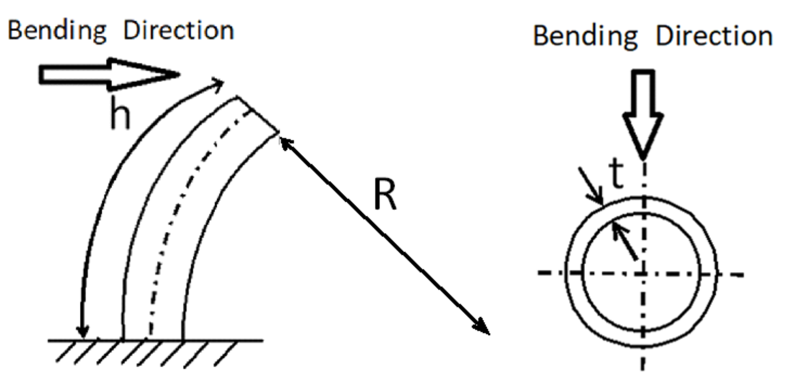

Figure 1- Tower modelled as cantilever beam

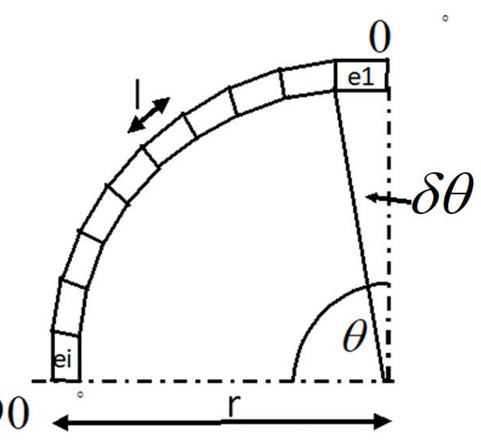

Figure 2- Tower model between 0 and 90 degrees

Since the tower was modelled using cantilever beams, the beam bending equation (1) [1] was utilised. The second moment of area I_b, for each beam was also defined using (2). By manipulation of (1) and (2) the bending stress S, was defined as (3). Using fatigue analysis relationships (4) the fatigue damage D was defined as (5).

$$\frac{M}{I}=\frac{S}{y}=\frac{E}{R} \quad (1)$$

$$I_b = I_h\cos^2(\theta)+I_v\sin^2(\theta) \quad (2)$$

$$S \sim \frac{1}{12}t^2\cos^3(\theta) \quad (3)$$

$$D=\left(\frac{t^2}{12}\right)^3\cos^6(\theta) \quad (5)$$

Power production simulations were carried out using Bladed. This allowed tower fore-aft bending moment data to be calculated for a range of mean wind speeds. Rainflow counting [2] was completed and the damage caused by each mean wind speed $D_f(\overline{U})$ was calculated using (4).

$$D_f(\overline{U})=AS^3 \quad (4)$$

The wind rose (Figure 3) provides probability values for wind speed $P(\overline{U})$ and direction and allows α, the prevailing wind direction to be identified.

A Weibull distribution was also incorporated in the wind speed probability.

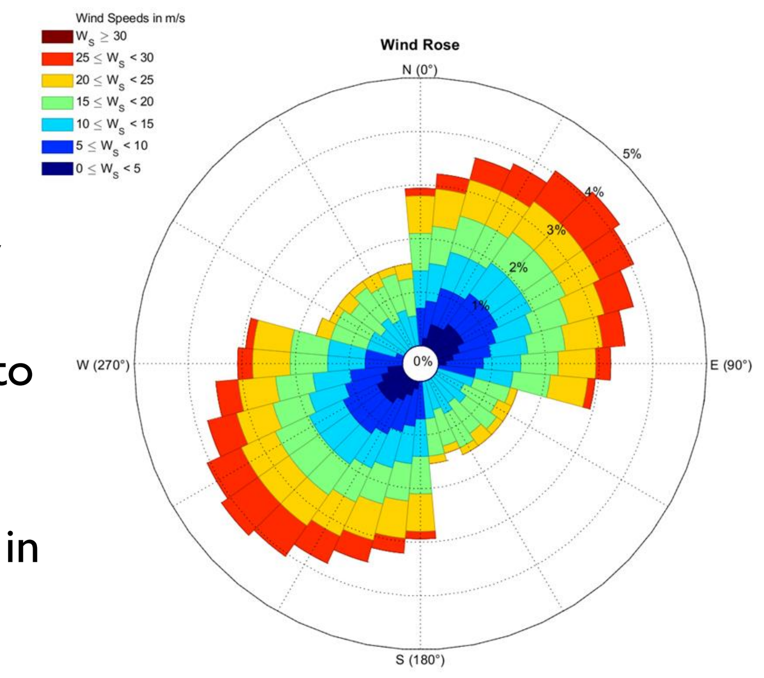

Figure 3-Generic wind rose created using [3]

Combining the wind speed probability, damage per mean wind speed, and fatigue damage for a range of mean wind speeds and integrating around the tower allowed the total fatigue damage to be estimated using (6).

$$D=\int_0^{2\pi}\int_{\overline{U}_{\min}}^{\overline{U}_{\max}} P(\overline{U})\times\left(\left(D_f(\overline{U})\right)\cos^6(\theta-\alpha)\right)d\overline{U}\,d\theta \quad (6)$$

Assumptions and simplifications

The tower features were not considered therefore the tower was symmetrical and damage around the tower was also symmetrical.

θ within the tower model was very small as were the beam dimensions.

$\frac{t^2}{12}$ and A were constant and not affected by fatigue damage.

Tower fore –aft bending moment had the largest influence on tower fatigue.

α was included to take into account large probability for prevailing wind direction and to make sure this was reflected in the results.

Results

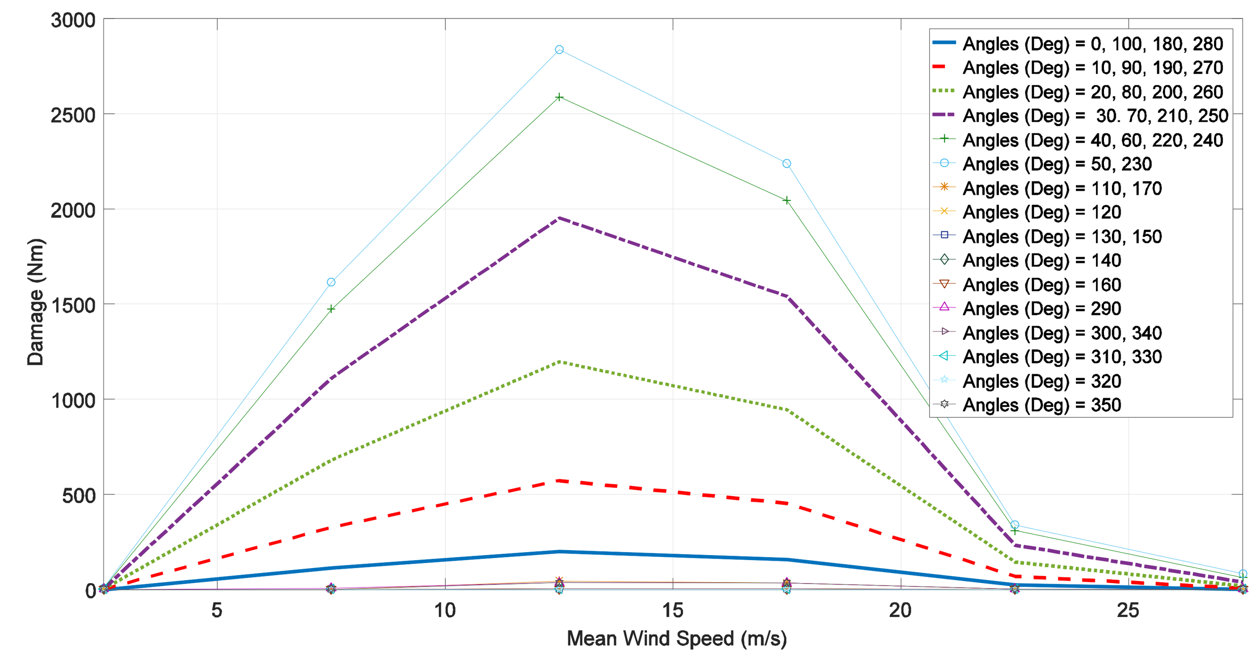

Figure 4-Fatigue damage across range of wind speeds for all wind directions

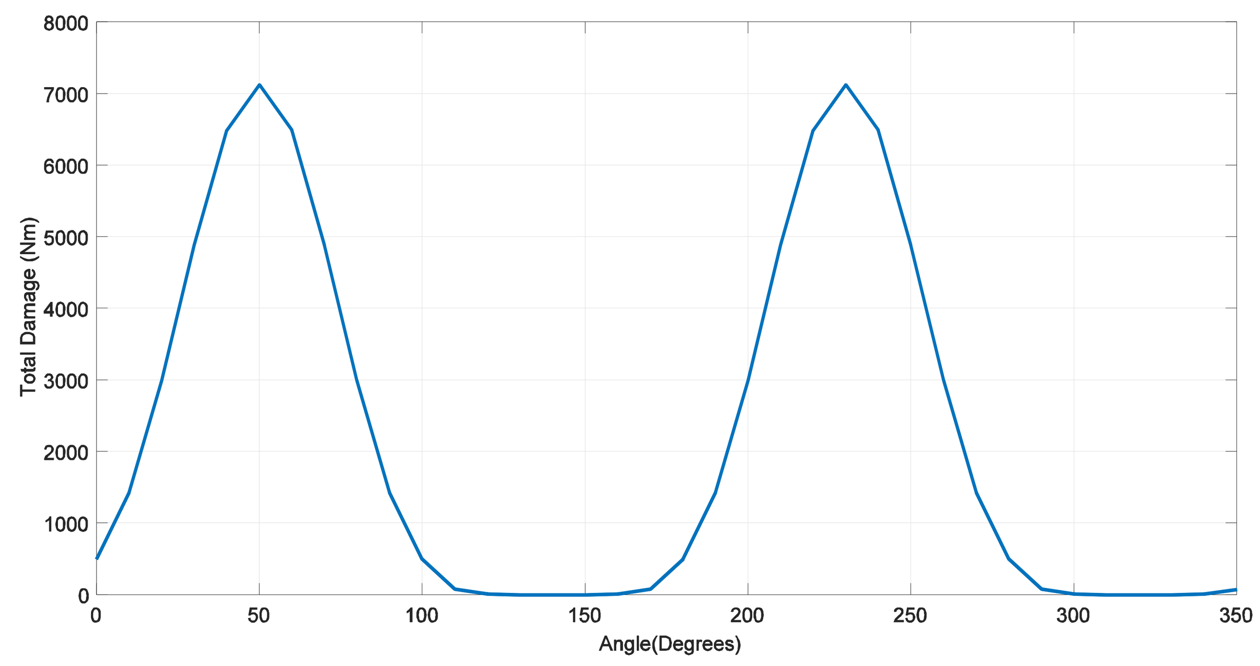

Figure 5- Total fatigue damage around tower

Total Damage = $7.97\times10^4\,Nm$

Conclusions and Next Steps

Most fatigue damage occurs at prevailing wind direction (50 and 230 degrees). Damage occurs around the tower symmetrically.

The next steps would be to look at real wind roses. Additionally turbulence, tension and compression loads and tower features could all be investigated.

References

[1] Benham, PP; Crawford,RJ; Armstrong,CG; Chapter 6 Bending Stress pp133-136, Mechanics of Engineering Materials. Second Edition, Pearson Prentice Hall 1996

[2] Nieslony, A; Rainflow Counting Algorithm available from https://uk.mathworks.com/matlabcentral/fileexchange/3026-rainflowcounting-algorithm (last accessed 11/10/2017)

[3] Pereira, D; Wind Rose, Available from https://uk.mathworks.com/matlabcentral/fileexchange/47248-wind-rose (last accessed 10/8/17)

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