Does the Shape of the Wind Rose Influence Tower Fatigue?

Nicola Grieve, Prof. W. Leithead, Dr H. Yue

Wind & Marine Energy Systems CDT
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

Assumptions and simplifications

- Internal forces and shear stress were negligible.
- Yaw was not considered.
- Tension and compression were assumed to be equal.
- the tower experienced no distortion or buckling.
- Only tower fore aft forces and moments were considered.
- The tower was narrow walled with no taper.
- Tower features were not considered.
- The distribution of stress around the tower was symmetrical.
- The bending angle was very small with a large radius of curvature R.

Modelling

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

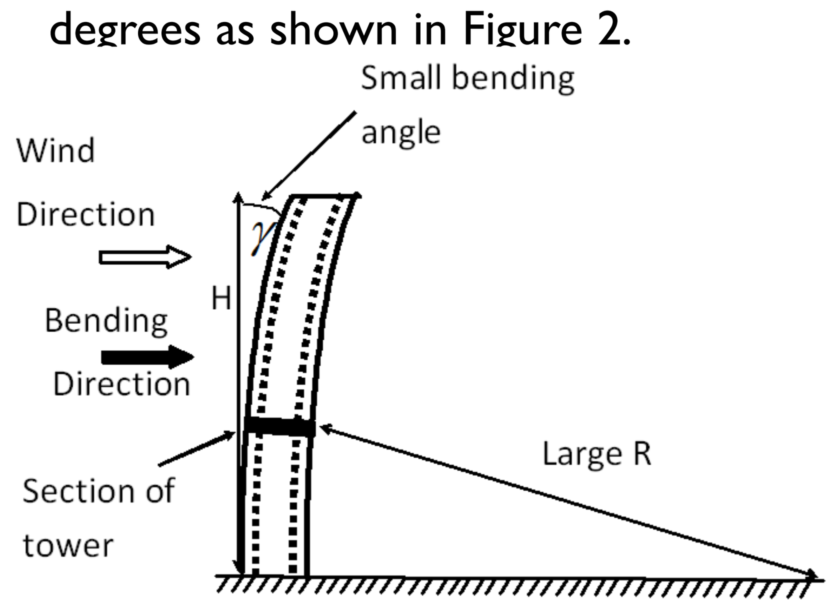

Figure 1- Tower modelled as cantilever beam

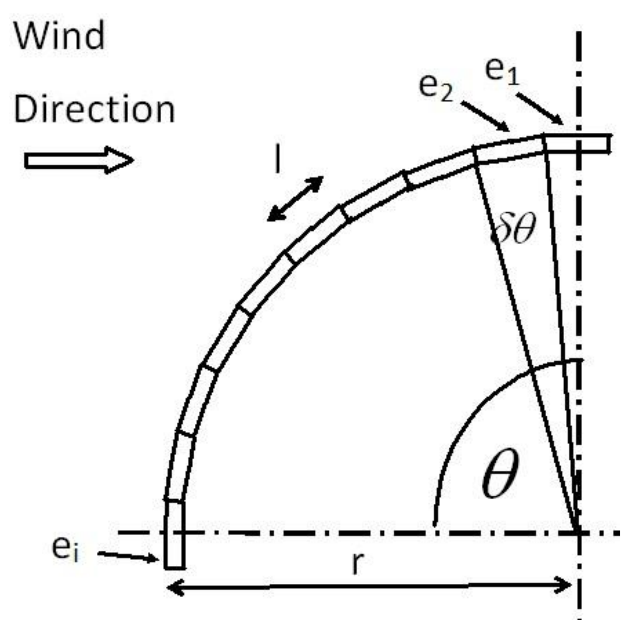

Figure 2- Tower model between 0 and 90 degrees

Final Function.

$$D = \int_{0}^{2\pi} \int_{\bar{U}_{\min}}^{\bar{U}_{\max}} P(\bar{U}(\theta)) \times \left(\left(D_f(\bar{U}) \right) \cos^{2m}(\theta - \alpha)^{\frac{1}{2}} \right) d\bar{U} d\theta$$

Probability of mean wind speed and mean direction (wind rose data)

Fatigue Damage for each mean wind speed (from Bladed simulations - bending moment data and rainflow counting).

Fatigue Analysis and bending moment based derivation for fatigue damage.

α included to account for asymmetries due to prevailing wind direction.

The same wind is integrated around each element of the tower. Using wind roses based on real wind data (Figure 3 – Figure 5), the function is discretised and the fatigue damage, due to different prevailing wind directions identified using α, can be estimated.

$$D = \sum_{j=1}^{m} \sum_{i=1}^{n} \left(P(\bar{U}_i(\theta_j)) \times \left(\left(D_f(\bar{U}_i) \right) \cos^{2m}(\theta_j - \alpha)^{\frac{1}{2}} \right) \right)$$

Wind Roses

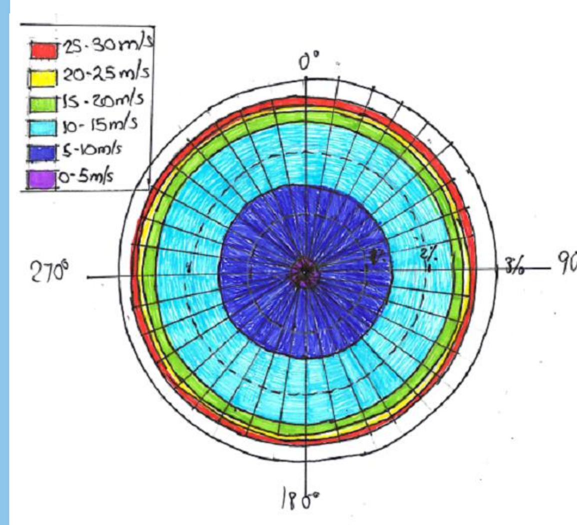

Figure 3 – WR1 – Equally Distributed case

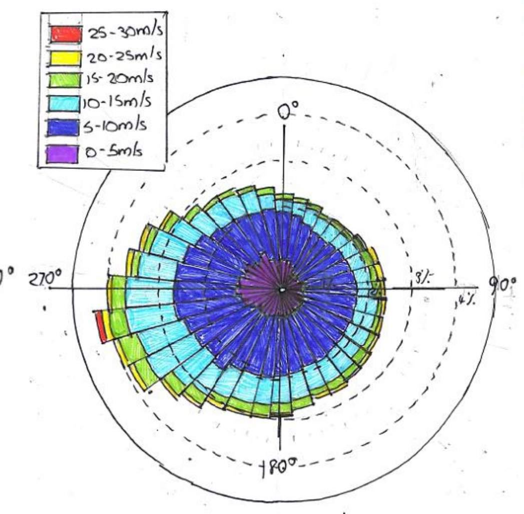

Figure 4 – WR2 Prevailing direction- 260°

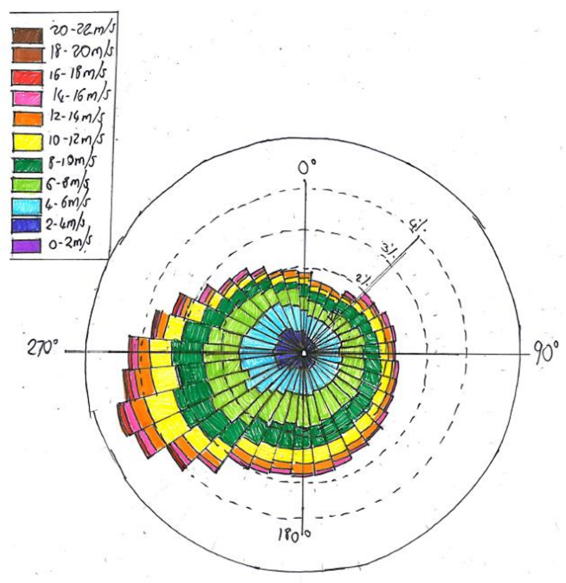

Figure 5 – WR3 Prevailing direction- 250°

Results

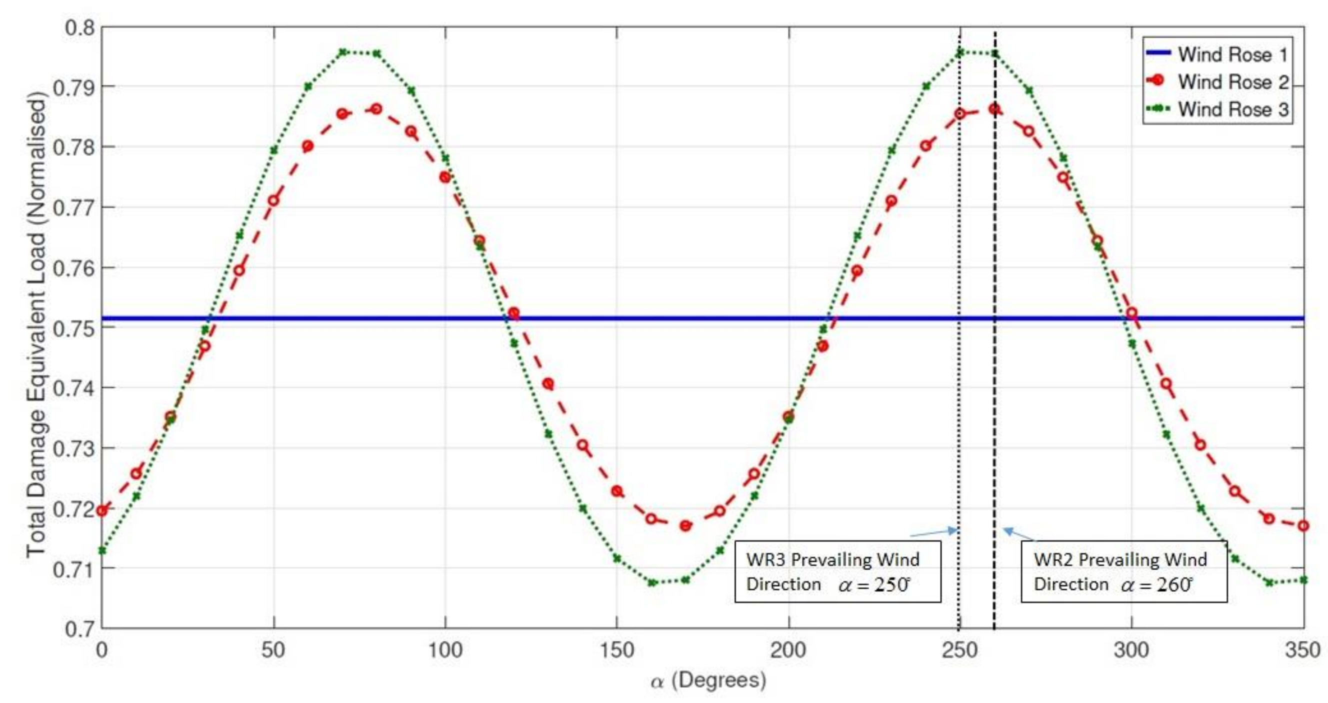

Figure 6-Fatigue damage equivalent loads for Each Wind Rose for a Range of Prevailing Wind Directions

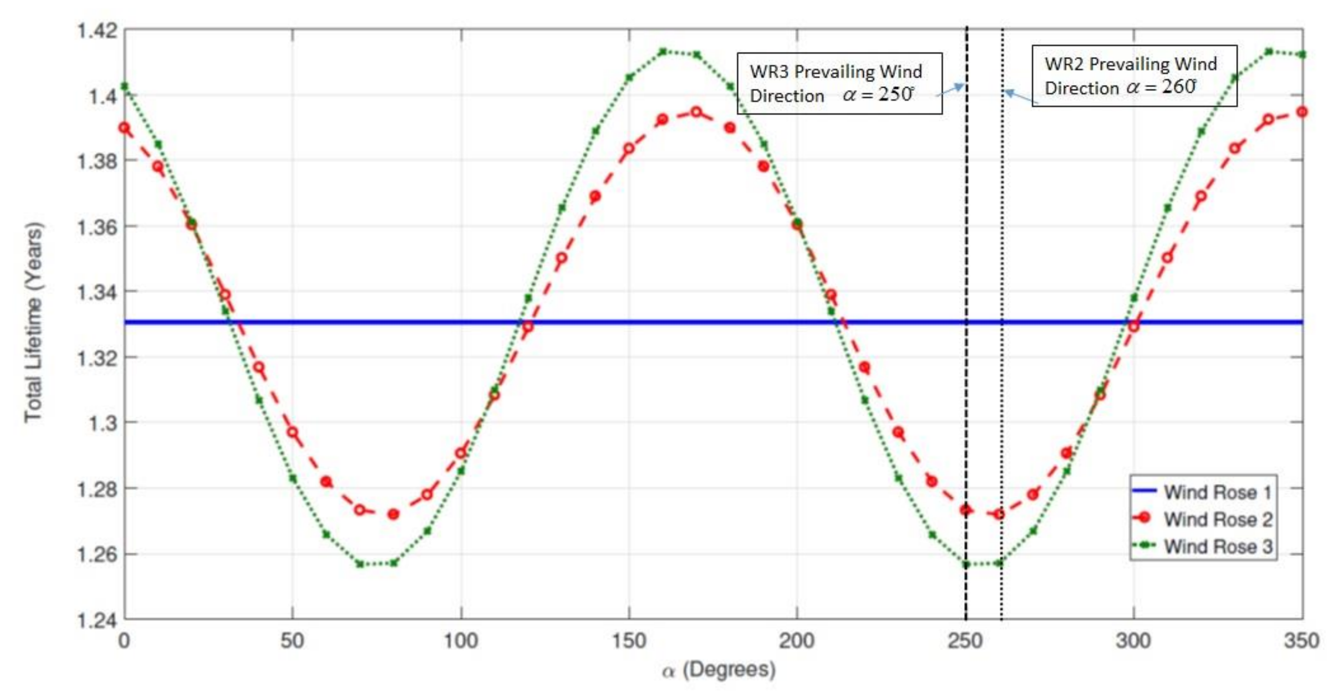

Figure 7-Estimated Tower Fatigue Life for Each Wind Rose for a Range of Prevailing Wind Directions

Conclusions and Future Work

Results indicate that when there is a prevailing wind direction, this will impact on the fatigue, the damage equivalent loads (DELs) will be higher with a shorter tower life. In some cases the prevailing wind direction leads to lower (DELs) and longer tower life.

Most wind turbine towers are designed based on the worst case scenario - direct loads. The wind roses here indicate that the wind is more equally distributed. By taking into account the wind rose shape when considering design loads and tower design, material and design costs could be reduced.

Future work would be to validate the model using finite element modelling and analysis. Stress concentrators, tower features such as doors, and tension and compression could all be considered.

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