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Wind directionality factor for solar ground mount

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SUMMARY:
Many building codes and wind loading standards include a factor for wind directionality in their wind load calculation procedures which reduces the effective design wind speed. The justification generally cited is that the geometry of the structure means that it is more vulnerable to some wind directions than others, so it is conservative to assume that the design wind event will come from the same direction as the greatest vulnerability (i.e. the direction with the highest wind load coefficient). This reduction factor can be calculated by combining wind load coefficients with directional extreme winds. In this paper we perform such a calculation to determine the appropriate wind directionality factor for utility scale ground-mounted solar installations. These structures are unusual in that they are not randomly aligned and so often have the worst wind direction for an extreme wind climate align with the worst wind direction for structural loads. In some cases they are also susceptible to a wide range of wind directions. We recommend codes and standards use a directionally factor of 0.95 on pressure and 0.97 on speed for these structures, though this situation is not unique to solar racking.

Keywords: solar ground mount, wind directionality, wind loads, codes and standards

1. INTRODUCTION

It is common practice for wind tunnel laboratories to provide solar racking companies with generic wind load coefficients that can be combined with code-based reference pressures to allow application of the results around the world. For example, a wind tunnel study of a fixed-tilt racking system will provide uplift coefficients relevant for when winds come from the high side (e.g. the north in the northern hemisphere) and downforce coefficients to apply when winds originate from the low or equator side.

Many code-based reference pressure calculation procedures include a wind directionality factor. ASCE 7 has included a wind directionality factor since the early 1980s. This factor started as part of the load combination equation and was separated into an independent factor by the 1998 wind loads committee (Ellingwood and Tekie, 1999). In ASCE 7 the directionality factor K_d is used in the velocity pressure calculation:

$$q_z = 0.00256 K_z K_{zt} K_e K_d V^2 \quad (1)$$

where q_z is the velocity pressure in psf, and K_z, K_{zt} , and K_e account for exposure (terrain), topography, and air density. V is the design gust wind speed.
In AS1170.2:2021, the wind directionality factor M_d is applied to calculate the site wind speed

$V_{sit,\beta}$ from the regional gust speed:

$$V_{sit,\beta} = V_R M_c M_d \left(M_{z,cat} M_s M_t \right) \quad (2)$$

where the other factors again account for exposure (Mz,cat) and topography (Mt), but also climate change (M_c) and shielding (M_s).

In both ASCE 7 and tropical cyclone regions of Australia, a directionality factor less than 1.0 is provided unless the structure is circular (or nearly circular), for example for chimneys and tanks. This is based on detailed wind load calculations combining the directional extreme wind climate with load coefficients measured for all wind directions, which have shown that it is generally conservative to combine the all-direction design wind speed with the most severe wind load coefficient, which typically occurs only for a limited range of wind directions. The reasoning is that it is unlikely for the wind direction for the design event storm to match the worst wind direction for the structure's loading. Of course, for a circular structure, all directions have the same load coefficient, so no reduction is found in this analysis.

K_d values between 0.85 and 1.0 are tabulated in ASCE 7 for different structures, but not all structures are listed, and the minimum value of 0.85 recommended for several structures (including buildings) is generally treated as the default by racking companies, developers and others designing and reviewing ground mounted solar racking. AS1170.2 provides a universal M_d value of 0.90 in the tropical cyclone regions of Australia. This is equivalent to a K_d of 0.81.

The 0.85 values used in ASCE 7 is a judgement-based factor originally used in the reliability study described in Ellingwood et al. (1980). K_d values less than 1 are sometimes justified using low-rise building coefficients with the assumption that the building could have any orientation. This presumed random structural orientation does not apply to solar racking system, which are generally carefully aligned to maximize solar energy production. If the design winds are known to come from the direction of the equator, then they will certainly produce the peak downforce loads on the fixed tilt racking system, in which case the directionality factor for those loads would, in theory, be 1.0.

Single axis solar trackers (which have rows aligned north-south) present some unique challenges for this analysis, as their stow policy (they stop tracking and move to a predetermined tilt in high winds) will affect the wind directions at which they are most vulnerable. For example, a tracker that stows flat (parallel to the ground) is equally vulnerable to east and west winds, as would a tracker which stows nose-down facing the wind.

This study presents an analysis of site-specific wind loads for some sample solar sites to investigate the suitability of code-based directionality factors for both solar trackers and fixed tilt systems.

2. METHODS

Multiple methods have been developed to combine the wind directionality at a site with the directional pressure coefficients from a wind tunnel (Holmes 2020). In this study, the storm passage method is used in combination with pressure coefficients from the CPP wind loads

databases for solar to determine directionality factors for generic arrays of solar racking.
The K_d directionality factor is simply the ratio of the peak load from this method, which is rigorous (has no approximations) and the peak load calculated by combining the peak load coefficient with the all-direction design pressure. M_d (for use with wind speed) is the square root of K_d.

2.1 Pressure Coefficients

CPP has conducted numerous wind tunnel studies on ground-mounted solar arrays. The CPP proprietary wind loads databases are wind tunnel test data for a generic array of single axis trackers or fixed tilt racking systems. Single axis trackers rows are oriented north-south while fixed tilt rows are oriented east-west, facing south in the northern hemisphere. Photos the CPP fixed tilt and single axis trackers databases are shown in Figure 1. For many load effects, the highest loads occur for winds from the quadrants normal to the row orientation.

Figure 1. (left) CPP fixed tilt database model, (right) CPP single axis tracker database model

The case studies presented in this paper will focus on the loads on the support piles for a common racking design, a 1-panel in portrait single axis tracker.

3. RESULTS

A single axis tracker that stows leading-edge down to the west during high wind events at a site near Panama City, Florida shows directionality factors of $K_d = 0.92$. An example uplift pressure coefficient vs. wind direction for piles in the array interior is shown in Figure 2.

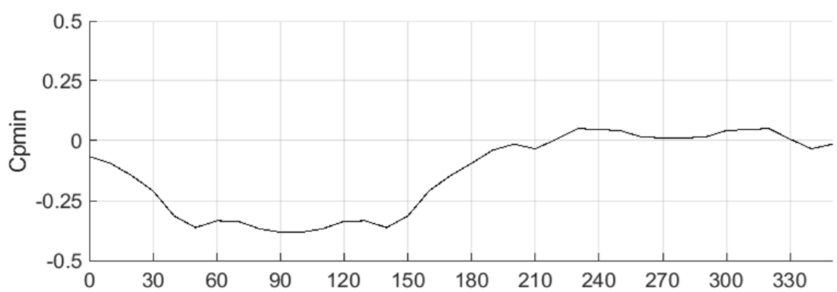

Figure 2. Pressure Coefficient directionality for example pile in the array interior

A histogram showing the likelihood of the extreme winds as a function of wind direction for hurricanes in the Panama City region is plotted in Figure 3. The hurricane simulations were provided by ARA (Vickery et al. 2009).

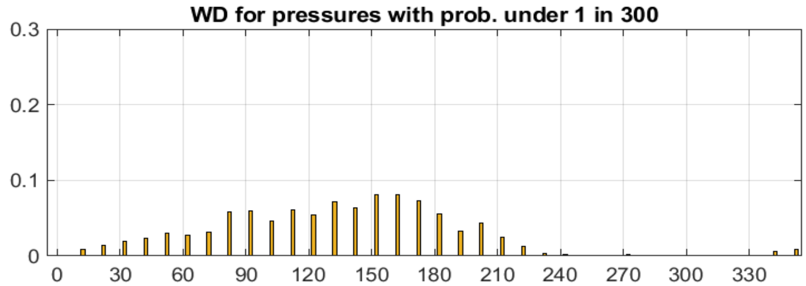

Figure 3. Pressure Coefficient directionality for example pile in the array interior

In this case we see that the worst pressure coefficient is relatively consistent across multiple wind directions and aligns closely (though not perfectly) with the worst wind direction implying the need for a K_d greater than the code prescribed 0.85.

Additional sites will be presented in the final paper along with the analysis of a fixed tilt system.

4. CONCLUSIONS AND RECOMMENDATIONS

Our studies suggest that a K_d of 0.95 would be more suitable for the piles of ground mounted solar arrays. It should be noted that these directionality factors will vary depending on the component studied, the associated tributary area and the stow policy in the case of a tracker.

This may not be unique to solar. Laboy-Rodíguez et al (2014) concluded that low-rise buildings designed in hurricane prone regions had a higher than intended risk when designed with a K_d of 0.85 and suggested a K_d of 0.90 for such structures in these regions.

In the absence of detailed studies like those presented in this paper, the use of wind direction reduction factors when it is clear that the worst winds align with structural vulnerability should be avoided.

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