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Wind tunnel solar model design – Best practices

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SUMMARY:
Wind tunnel tests of ground mounted solar structures is the most accurate method of obtaining pressure coefficients for the design of its components (e. g., purlins, posts). However, the reliability of these results depends on accurately modelling the geometric features (e. g., chord to thickness ratio) and appropriately instrumenting the models for capturing the pressure patterns. Due to the typical smaller scales of these models, it is challenging to model some of the small features accurately. In addition, the thickness of the models needs to be of a certain size to allow for internal instrumentation, which, in full-scale, does not represent the true aerodynamics due to the exaggerated thickness. This issue could be resolved by treating the edges of the models. A series of wind tunnel tests were designed at a scale of 1:10 with different edge-treated models. The optimum edge-treatment design, representing the most accurate aerodynamics of the prototype, was determined by comparing the overall pressure coefficients and pressure distributions of several load cases. In addition to that, the optimum number of pressure taps required to accurately account for the pressure distributions, and hence, the overall load coefficients have also been investigated and presented in this paper.

Keywords: Wind tunnel testing, Ground mounted solar structures, Solar wind tunnel pressure models

1. INTRODUCTION

Major international wind loading standards recognize the limitations of codified wind load calculation procedures and acknowledge or prescribe wind tunnel study as the recommended method for determining wind loads on structures that either have an unusual shape (i.e., a shape unlike any of those defined in the standard) or for which more accurate loads are desired (with codified methods frequently including some conservatism). Modelling the aerodynamic loading on a structure in the wind tunnel requires special consideration of wind conditions to obtain data/results from the model that can be applied to the prototype. Not only the wind conditions, but also appropriate modelling of the structure itself is important to ensure the quality and reliability of the wind tunnel studies.

Wind loading on solar structures (e. g., fixed-tilt systems, horizontal axis trackers) is one of the most important considerations for the structural design of these kind of structures. The industry of solar racking is extremely competitive in the balance of system (BOS) costs. Therefore, racking manufacturers are continually challenged to come up with a reliable system that minimizes those costs. Even though some international standards like ASCE 7-22 provide recommendations on wind loads coefficients for some ground-mount solar structures, the potential for conservatism or inaccuracy is not ideal for a manufacturer. Another method of predicting wind loads on solar structures is using computational models. Although the computational wind engineering field is rapidly evolving and improving in efficiency, it is commonly thought to be more economical to use physical scale-model testing. Hence, data and results obtained from the wind tunnel tests of solar structures have often been used by the racking manufacturers for the structural design of these kinds of systems.

In wind tunnel pressure studies of ground mounted solar systems (trackers/fixed-tilt systems), representative arrays of the racking systems are typically tested. The modelled array needs to be deep enough to capture the loads in the interior region where the wind loads are usually lower compared to the perimeter regions. This often leads the wind tunnel ground mounted solar pressure models to be tested at smaller scales. Modelling the small features (e. g., thickness of the panels, underneath structures) of the racking systems can often be challenging due to the small scales at which these tests are conducted. In addition to this, the pressure models need to be of a certain dimension to allow instrumentation. Hence, there are physical limitations too while preparing scaled models that does not allow the solar pressure models to be built very thin. These limitations during model design and fabrication may have significant effects on the test data and may not produce accurate results. In addition to these, the pressure models need to be instrumented with enough pressure taps to obtain reliable data for analysing different load cases for the component design. It is obvious that heavily instrumenting the models (more pressure taps) provides higher resolution; however, this also comes with higher testing costs and time.

Wind tunnel pressure studies of ground mounted solar racking systems can produce misleading/unconservative results if the pressure test models are not built with proper attention to its different geometric features and appropriate instrumentation. Below is a list of few of the geometric parameters where attention should be given while preparing the wind tunnel pressure models of the ground mounted racking systems.

Modelling the underneath support structures: Depending on the design of the racking systems, the structures supporting the modules can vary (e. g., either a torque tube or dual-rail support structure for trackers). As investigated by Chowdhury *et al*. (2022), these support structures, if not modelled appropriately, could produce significantly different pressure distributions on the panels. Hence, it is important to model these support structures more accurately to account for the aerodynamic impact that these support structures could have on the overall loading.

Panel thickness/edge treatments: At the typical model scale, the thickness of the models would be too thin to allow enough space for pressure measurement instrumentation. Hence, the thickness of the models is often restricted to a certain minimum thickness, which at full-scale could be much thicker than the prototype. These thicker models could introduce stronger flow separation at the edges which, in turn, could make the pressure coefficients unnecessarily conservative. One way to tackle this issue is to treat the edges so the models do not represent an overly thick bluff edge in full-scale. There have been numerous studies which show that different edge treatments can alter the flow separation which also alter the pressure distributions on the surface underneath the separated flow. A comprehensive review of these studies can be found in Taylor *et al*. (2011). Most of these studies were conducted in low turbulence uniform approach flows which are not representative of the highly turbulent boundary layer approach flow over typical ground mounted solar structures. However, these studies give the indication that similar can be true for solar models in appropriate flow, and can produce misleading pressure coefficients compared to the prototypes if the edges are not modelled properly.

Taps across the chord: The wind tunnel model should be designed with an adequate number of pressure taps to accurately capture the pressure distributions along the module surface. If this information is not captured accurately, the analysed loads can either be conservative or unconservative. On the other hand, having too many pressure taps can make the model building process more expensive and time consuming without increasing accuracy. Hence, it is important to build the models with the optimum number of pressure taps.

In this paper, effects of two of the above-mentioned parameters: panel thickness/edge treatment effects and optimum number of pressure taps will be investigated. Comparatively large scale (1:10) ground mounted solar wind tunnel models were built and tested in CPP's boundary layer wind tunnel. Analyses will be conducted to investigate the edge treatments that produce the similar aerodynamics of the separated flow to the full-scale solar panels. In addition to that, the optimum number of pressure taps required to capture the pressure distributions along the panel surface will also be deduced.

2. EXPERIMENTAL SETUP

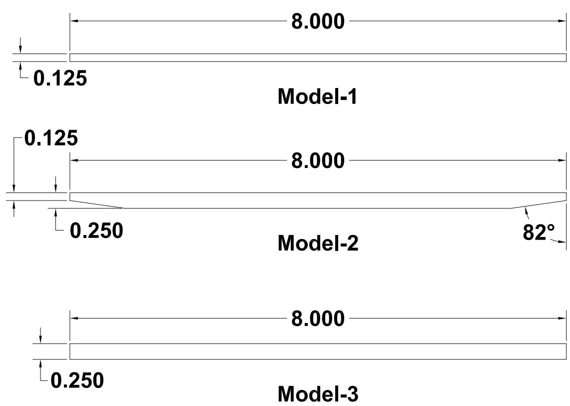
2.1. Test Models

Several test models at a scale of 1:10 were built with different thicknesses and edge treatments. The cross section of three of those models are shown in Figure 1(a). Model 1 is the "ideal" model; representing the thickness to chord ratio of a full-scale solar panel. The thickness of the other two models represents the thickness to chord ratio of typical solar wind tunnel pressure models; however, the edges are treated differently. Several other models (not shown in the figure) were also built with different edge treatments. However, the results will be presented for these three models shown in Figure 1(a) and for another edge treated model (not shown in the figure) that produced the most accurate results when compared to Model-1.

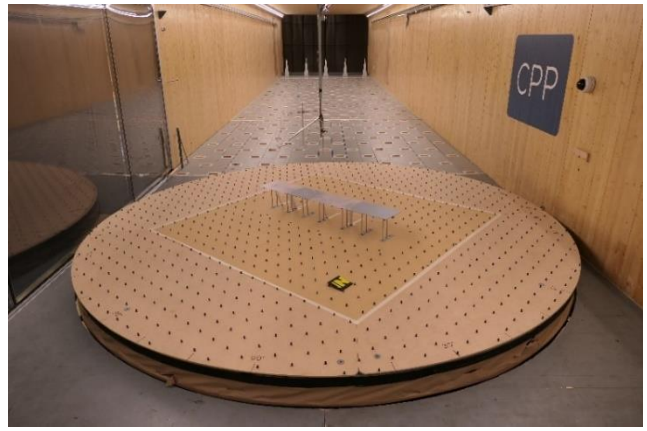
All the models were instrumented with 7 tap rows along the span. Each of the tap rows contains 4 tap pairs (one top tap and one bottom tap constitute one tap pair), except for Model-1. Model-1 was instrumented with 8 tap pairs per tap row. During the analysis of this model, selective tap pairs can be turned on and off to investigate the optimum number of taps required to produce similar pressure patterns to 8 tap pairs per tap row.

2.2. Wind Tunnel Facility and Test Conditions

Tests were conducted at CPP's wind tunnel facility for 19 wind directions (90° to 270° with 10° degree increments). The models were tested for 7 tilts (0° to 60°). Tilts were set such that wind directions 90° to 180° represent downforce wind directions (panels nose down to wind) and wind directions 180° to 270° represent uplift wind directions (panels nose up to wind). A photograph of the model as tested in the wind tunnel is shown in Figure 1(b). All the tests were conducted in open terrain exposure (exposure C in ASCE 7). Attention was put to match the high-frequency end of the turbulence spectrum. When the high-frequency end of the spectrum is matched, and normalization is made using the peak gust speed, peak pressure coefficients (ratio of peak surface pressures to peak dynamic pressures) are less sensitive to spectral differences between full-scale and model-scale in the low-frequency range Richards *et al*. (2007).



(a)



(b)

Figure 1: (a) Cross section of the test models (dimensions are shown in model scale inches) and **(b)** Photograph of the model as tested in CPP's wind tunnel facility.

3. RESULTS

Data from the wind tunnel tests will be analysed for two load cases: peak net normal forces and peak moments about the axis running along centreline of the row. Analyses will be conducted for several tributary areas representing either a solar panel purlin or a post located near the end of the row and at the middle of the row. The peak pressure coefficients for all the models will be compared against Model-1 (the “ideal” model) to identify the best edge-treated model. Particular focus on comparing the pressure distributions across the tributary area will be put to validate the aerodynamics of the edge-treated models. Model-1 data will be analysed for several sets of tap pairs per tap row and compared against the 8 tap pairs per row in order to identify the optimum number of tap pairs required to most closely simulate the pressure coefficients and pressure distributions across the selected tributary area.

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