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**Structural Considerations for Low Profile Solar Photovoltaic System**

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**Introduction**

Alternative and renewable energy has led to rapid increase in permit application of solar photovoltaic arrays installation in both commercial and residential. Due to the lack of prescriptive guidelines in current code and standards, engineers approach to the design of support systems for wind forces and seismic forces has been based largely on interpretation of ASCE 7 requirements on component and claddings for roof surfaces. Manufacturers often resort to the use of wind tunnel test results which lead to substantially lower wind loads. The lack of requirements for peer review on wind tunnel test setup and procedures presents problem and non-uniformity in enforcement. Additionally, the imposed dead loads and calculated wind forces on roof system bring up concerns from building officials on how much reduction of code specified live load can be allowed. Acceptance of design approach by enforcement agencies has been reviewed under CBC section 104.11 as alternatives to building code requirements.

In view of concerns among design professionals, building officials and the industry, SEAOC Wind Committee undertook the task to assign a Solar Photovoltaic Systems Committee (PV Committee) to address the issues and develop design guidelines. The Subcommittee has well over 30 participants including structural engineers, building officials, solar industry representatives and academia specialized in wind. The purpose of this article is to present a brief summary of recommended guidelines for the design of solar PV systems.

**Planning**

During the initial planning, a design engineer, responsible to design support system for low profile photovoltaic system, should provide a due diligence survey of the roof framing system. Initial planning should cover study of as-built condition or a field survey of sizes, spacing and span of framing members and identification of sheathing and lumber grade immediately below the area impacted by the addition of the solar PV system. After an independent analysis of typical framing members intended to support PV system and noting the limitations, if any, an informed decision can then be made if attached or unattached photovoltaic panel system may be a suitable for the roof structure under consideration.

**Structural requirements**

Design for support of PV systems must conform to California Code of Regulars (CCR) Title 24 which include but not limited to California Building Code and California Residential Code. The applicable uniform roof live and concentrated load is prescribed in the Building Code. The design wind force and seismic force are prescribed in ASCE 7. Other design requirements such as snow load, snow drift, deflection and ponding should be considered where applicable. The design of various structural materials is covered in specific material chapters and the applicable adopted material standards.

**Gravity loads**

Weight of photovoltaic panel systems, including rack support systems together with the weight of ballast system, if applicable, should be considered as dead loads in addition to all other dead load supported by the roof system. Uniform and concentrated roof live loads should be included, in addition to all dead loads, except the live load need not apply to the area under the solar photovoltaic system where the clear space between the arrays and the roof surface is 42 inches or less. The space with 42 inches or less height can be considered as inaccessible space (similar to attics.) In addition, other roof loads such as snow, snow drift or rain should be taken into account when applicable.

**Wind forces**

Based on wind tunnel test findings [O’Brien and Banks, 2012], presence of accelerated airflow is the result of cornering winds. The leading rows of solar PV array layout are also subjected to higher wind forces. Additionally, the influence corner and edge zones are wider. The use of ASCE-7 *Minimum Design Loads for Buildings and Other Structures* wind provisions on roof elements or component and claddings can under-estimate wind forces on PV arrays.

The development of an interim guideline on wind design by SEAOC Solar PV systems committee has been in response to the design profession, building officials and the solar industry. Design engineers should study the guideline PV2-2012, *Wind Design for Low-Profile Solar Photovoltaic Arrays on Flat Roofs* [SEAOC 2012]. A new figure for design wind loads has been developed based on wind tunnel test data. The plots for net pressure coefficients was developed using similar technique as component and claddings in ASCE 7 standard. Design of solar PV arrays needs to consider the tilt angle of arrays, location on roof, effective wind area, net pressure coefficients and sheltering effects from adjacent row of arrays, HVAC equipment, parapets, penthouse and skylights.

The definition of effective wind area in ASCE 7 is generally applicable to solar arrays. For a framed, stanchion system, determination of effective wind area is based on the corresponding tributary panel area or a portion of the aggregate panel area if panels are interconnected. For a roof bearing system having different load paths for upward, downward, and lateral forces, and depending on the hold down system and/or the method of interconnection between the panels, the appropriate effective wind area in each direction should be used. In a long narrow array, the effective width of the solar panel effective wind area to evaluate the pressure coefficient need not be less than one-third the panel length in the span direction of the element. The induced wind force should be applied over the actual area tributary to the component being considered. Consideration for uplift and/ or sliding should be based on the effective wind area of array framing to the vertical support.

**Seismic forces**

The increase dead weight of the solar PV systems including rack framing should first be calculated together with the mass of the existing roof framing assembly. For existing building, CBC sections 3403.4 and 3404.4 need to be satisfied. Attached roof-bearing and fully framing solar PV systems should be design based on the applicable requirements of ASCE 7 sections 13.1.5 and 15.3. For low profile solar PV attached systems, it is commonly to take ap = 1.0 and Rp = 1.5.

There is no prescriptive procedure in ASCE 7 for the design of unattached (ballast-only) arrays. Seismic movement causes displacement of the array relative to the roof. Adequate clearance between rows of solar arrays is needed to avoid collision between arrays. An unattached arrays uses ballast system for wind uplift forces. However, the solar PV system relies on friction to resist seismic force and to prevent sliding off the roof without parapets. PV1-2012 document, *Structural Seismic Requirements and Commentary for Rooftop Solar Photovoltaic Arrays* [SEAOC 2012], gives an prescriptive guideline for the design of unattached solar PV systems. The guideline has been developed based on shake table tests. The coefficient of friction should be determined by experimental tests conforming to ASTM G115, *Standard Guide for Measuring and Reporting Friction Coefficients*.

**Summary**

This article gives a brief summary of common structural considerations for design of solar PV systems including gravity loads, wind forces and seismic forces. The guidelines described in this article reflect consensus opinion of members of SEAOC, building officials, solar industry representatives and academia. Recommendations have been derived based on wind tunnel tests for wind as well as shake table tests in the case of seismic. Submittal of proposals for changes to ASCE 7-16 is currently at the committee task groups for review. In the interim, these guidelines may be used as an alternate to otherwise non-codified design provisions.

It is intended that design engineer will provide adequate planning prior to laying out the solar PV system and design. The support system and detailing must follow a continuous load path from the photovoltaic modules to the final point of resistance. For quality assurance, structural observation and inspection during and subsequent to installation of the arrays should be performed by qualified personnel.

**References**

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