Strength Comparison of Flat Roof Solar Mounting Systems

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Abstract

The trend of installing solar panels in residential buildings has been primarily driven by efforts to lower energy costs, signifying a notable shift towards embracing solar energy solutions. The market offers a wide range of structural mounting systems for solar panels. This paper concentrated on analyzed the most utilized mounting system for flat roofs and determining the strength capacity usage in a 160-mph wind speed hurricane event and compare the different installation patterns found in the existing installed mount systems in residential building around the island of Puerto Rico. The study underscores the overall reliability of the structural integrity while acknowledging deficiencies in one of the mounting systems employing the N=L installation pattern.

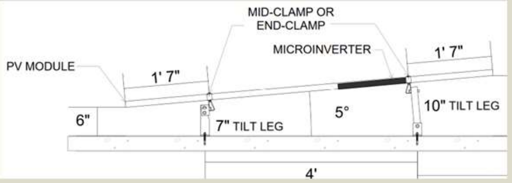
Introduction

The rising installation of photovoltaic solar systems in buildings is due to high energy costs and the need for more reliable energy sources. The market offers various electrical and structural components for solar integration, especially focusing on flat roof mounting systems. This study examines three specific flat roof mounting system designated B, U, and H through structural analysis using the Allowable Strength Design (ASD) method to evaluate their strength against wind loads and comparing the most used legs installation patterns, based on a comparative study within an existing photovoltaic project (PV). The legs in the mounting system role a considerable determination of the strength capacity to resist wind loads. In this study the quantity of legs installed in the mounting system were designated with equations N+1=L and N=L, where N is the numbers of solar panels and L are the numbers of legs in a solar panels mount array.

Project Background

- This evaluation examines an existing residential photovoltaic system located in Guaynabo.
- Mounting systems consist of support columns (legs), longitudinal support (rail), and clamps.
- The existing mounting system in the residential is the mounting system B with the installation pattern N+1=L.

3D Scanning of the residential Building showing the PV system (Source: Verdifica PSC)



Side View of Mounting System B from selected PV Project with Dimensions

Image Illustration of Mounting System B

Image Illustration of Mounting System U

Image Illustration of Mounting System H

Illustration Example of N+1=L Installation Pattern

Illustration Example of N=L Installation Pattern

Illustration Example of N-1=L Installation Pattern (5 Solar Panels With 4 Legs)

Methodology

Wind Load Parameters

Minimum Design Loads and Associated Criteria for Buildings and Other Structures Desing Loads ASCE 7-16 were used for calculated the wind loads. Wind loads parameters and calculated velocity pressure are listed as follows:

- Wind Speed: V = 160 mph
- Wind directionality Factor: K_d = 0.95 (Rooftop)
- Exposure: B
- Topographic Factor: K_{zt} = 1
- Ground Elevation Factor: K_e = 1
- Gust Effect Factor: G = 0.85
- Average elevation: z = 12 ft
- Velocity Pressure Exposure Coefficient for Exposure: K_z = 0.57

$$q_z = 0.00256 K_z K_{zt} K_s K_d K_e V^2$$

The velocity pressure calculated was q_z = 35.5 psf.

Wind Loads Forces

The load analysis for rooftop structures and equipment in this study follows Section 29.4.1 Rooftop Structures and Equipment for Buildings, focusing on calculating lateral and vertical forces. These forces are determined using:

$$F = q_z G C A_f$$

where:
q_z = velocity pressure evaluated at height *z*
G = gust effect factor
C_f = force coefficient
A_f = projected area normal to the wind

Wind Load Combination

These mounting systems are particularly susceptible to high uplift wind loads and less to seismic loads. For analyzing uplift wind load conditions, the most critical scenario for this structure is determined by ASD load combination 7, as follows:

$$0.6D+0.6W$$

where:
D = Dead Load
W = Wind Load

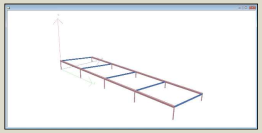
Material Specification

According to the manufacturers cutsheet details for the three mounting systems, the aluminum alloy utilized is designated as 6005A-T61, with its material properties specified as follows:

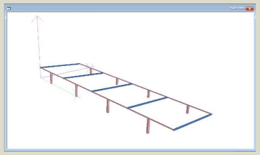
- F_{ty} = tensile yield strength = 35 ksi
- F_{tu} = tensile ultimate strength = 38 ksi
- E = modulus of elasticity = 10,100 ksi

Modeling

STAAD.pro, software for structural analysis and design, was utilized to model the mounting system, facilitating the determination of reactions and results from the applied loads. Two model scenarios were modeled for each three mount systems using installation pattern N+1=L and N=L as shown.



Render Model N+1=L



Render Model N=L

Strength Criteria

The available strength for each structural component calculated using the Aluminum Design Manual 2020, Rn/Ω, must meet the requirements of the chosen ASD load combination 0.6D+0.6W expressed as the required strength, Ra, for uplift scenarios and the structural analysis shall satisfy:

$$R_a < R_n/\Omega$$

Strength Capacity Usages

The subsequent tables provides a detailed comparison of the reaction forces versus the available strength capacity of structural components in the three different mounting systems selected in this study.

Mounting System B Strength Capacity Usage

N+1=L

Element	Component	Ra/(Rn/Ω)
Clamp	Universal Fastener Clamp	35%
Long Leg	Bolts	26%
	Axial Tension	3%
	Slot Bearing Strength	14%
	U-Foot Tension	3%
	U-Foot Bearing Strength	11%
Short Leg	Axial Tension	5%
Anchor Bolt	Expansion Bolt	24%

N=L

Element	Component	Ra/(Rn/Ω)
Clamp	Universal Fastener Clamp	35%
Beam	Rail	63%
Long Leg	Bolts	27%
	Axial Tension	3%
	Slot Bearing Strength	20%
	U-Foot Tension	4%
	U-Foot Bearing Strength	13%
Short Leg	Axial Tension	5%
Anchor Bolt	Expansion Bolt	25%

Mounting System U Strength Capacity Usage

N+1=L

Element	Component	Ra/(Rn/Ω)
Clamp	Rail Mid Clamp	40%
	Rail End Clamp	33%
Long Leg	Assembled Tilt Back Leg	42%
Short Leg	Assembled Tilt Front Leg	41%
Anchor Bolt	Expansion Bolt	23%

N=L

Element	Component	Ra/(Rn/Ω)
Clamp	Rail Mid Clamp	40%
	Rail End Clamp	33%
Beam	Rail	309%
Long Leg	Assembled Tilt Back Leg	47%
Short Leg	Assembled Tilt Front Leg	44%
Anchor Bolt	Expansion Bolt	25%

Mounting System H Strength Capacity Usage

N+1=L

Element	Component	Ra/(Rn/Ω)
Clamp	Rail Clamp	35%
Legs	Bolt Leg	25%
	Slot Bearing Strength	11%
	Axial Tension	6%
Anchor Bolt	Expansion Bolt	23%

N=L

Element	Component	Ra/(Rn/Ω)
Clamp	Rail Clamp	35%
Beam	Rail	46%
Legs	Bolt Leg	26%
	Slot Bearing Strength	12%
	Axial Tension	7%
Anchor Bolt	Expansion Bolt	24%

Conclusions

In installations using the N+1=L leg pattern, all three mounting systems successfully met the strength criteria set forth in the aluminum manual, following the ASCE 7-16 load analysis from Section 29.4.1 for Rooftop Structure and Equipment for Buildings, specifically for wind speeds of 160 mph. In contrast, with the N=L pattern installation, Mounting System U failed to meet these strength criteria, whereas Mounting System B and H showed to meet strength criteria. Particularly, for installations using either N=L or N-1=L patterns, reinforcing the mounting systems by adding necessary legs near the clamps is a reliable solution. For systems with a small number of solar panels arrays, the N+1=L installation pattern is reliable for residential solar mounts. However, the participation and consulting of a structural engineer is crucial for any photovoltaic system installation to ensure compliance with contemporary engineering standards and codes.

Future Work

With the increasing variety and demand for mounting systems, it is beneficial for future research to explore various options for commercial and industrial buildings under different scenario cases. While this current research does not focus on the maximum wind speed resistance of solar mounts, it is a highly recommended topic for future studies. Additionally, in the unfortunate event of another hurricane, it would be suggested to analyze an existing project that failed due to hurricane winds as a case study for further evaluation and improvement. This approach would provide valuable insights into enhancing the resilience of mounting systems against extreme weather conditions.

Acknowledgements

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