POWER RAIL™ P6

DESIGN GUIDELINES

system design using industry codes & standards

Version 1, Rev A
PCN 052510-1

PRECAUTIONS

Be sure to read and completely understand these guidelines before attempting to install this Power-Fab product.

- These design guidelines are not intended to supersede any company, construction or safety standards. These guidelines are offered only for reference, and to illustrate safe installation by the installer.
- For proper performance and personal safety, be sure to select the proper Power-Fab product before installation.
- Design values are listed as manufacturer’s recommendations only. Please consult a local civil or structural engineer licensed in the location of the installation to perform necessary site-specific analysis to certify individual designs for permitting purposes.

Following the procedures listed in this manual, Power Rail products are guaranteed by Power-Fab to be structurally adequate, and meet the minimum requirements of current building codes, including International Building Code (2006 IBC), Uniform Building Code (UBC), California Building Codes (2007 CBC), and American Society of Civil Engineers (ASCE) 7-05. However, your local inspector or building authority takes precedence in determining the suitability of a design, as well as being an excellent resource for a number of detailed, site-specific analysis parameters, discussion following.

Please contact us with any questions or concerns about these design guidelines, call or email at:

Phone: 800-260-3792

Email: info@power-fab.com

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SYSTEM LOADS ANALYSIS

Several methods exist to determine the design loads on a fixed solar structure. Manufacturer's recommendations listed here are based upon analysis of many building and design codes in effect, including International Building Code (IBC), Uniform Building Code (UBC), and California Building Codes. We have determined that the Analytical Methods proposed by the American Society of Civil Engineers (ASCE) 7-05 are the most universally referenced and accepted design method for structures such as those used to support solar modules. Items from the code are referenced below. For the full entirety of the code used to make these calculations, please consult the American Society of Civil Engineers, referring to code *7-05 Minimum Design Loads for Buildings and Other Structures*.

1. WIND LOADING

1.1. Velocity Pressure

The force transmitted to a structure due to wind is proportional the pressure of wind applied to that structure. Following section 6.5.13 of the ASCE 7-05 code, the velocity induced pressure on an open structure is calculated by equation 6-15:

$$q_z = 0.00256 K_z K_{zt} K_d V^2 I \quad \text{(PSF)}$$

(Eq. 6-15)

Where

qz = velocity pressure at array level
Kz = velocity pressure exposure
Kzt = topographic effect
Kd = directionality coefficient
V = Basic Wind Speed (MPH)
I = importance factor

Basic Wind Speed, as per the most recent code, is defined as the nominal design regional 3-second gust speeds at 33 feet above surface, for an exposure category C. Additionally, shaded Special Wind Regions exist with unique characteristics that differ from the surrounding zone. Reference figure 6-1 of ASCE 7-05 for your region, or contact your local building authority for the wind speed (velocity) zone of your installation.

Velocity Pressure Exposure is a factor to account for the effect of local ground obstructions and their effect on the energy of the wind gust. This exposure coefficient is dependent on the type of structure where the product is installed, the height of the supporting structure, and the *Exposure Category* as defined in table 6-3 of ASCE 7-05. For purposes of robust design, the worst-case exposure category shall be used.

Topographic Factor may be needed to account for local elevation changes or micro-scale topography which can influence the wind pressure incident on the installation site. Contact your local authority or a qualified design professional for a site analysis to determine if these elements are present and if a *Topographic Factor* is needed.

Wind Directionality Factor, or the directionality coefficient, is a statistical load reduction factor which takes into account the reduced probability of a maximum wind and maximum pressure coefficient occurring at a given wind direction. Values are given by ASCE 7-05 table 6-4 and used in conjunction with other load factors from ASCE 7-05 section 2.4.

Importance Factor is similar to design factor of safety. Reference ASCE 7-05 table 1-1 to verify the *Occupancy Category* and table 6-1 to verify the correct *Importance Factor* is used for the installation.

1.2. Design Wind Pressure

Once the free stream velocity pressure is known for the given exposure (qh), a subsequent, more specific analysis of wind pressure must be performed. As Power Rail is a flush mounted system, it has been determined that the design pressure analysis for 'components and cladding' per ASCE 7-05 6.5.2.2 is the most applicable wind loading criteria. Accordingly, design pressure is given by:

$$p = q_h \left[\left(GC_p \right) - \left(GC_{pi} \right) \right] \quad \text{(PSF)}$$

(Eq. 6-22)

Where

p = design wind pressure
qh = velocity pressure at array level, qz
GCp = external pressure coefficient
GCpi = internal pressure coefficient

External Pressure Coefficient is given by ASCE 7-05 figures 6-11 through 6-16. The figures and coefficient sets used should best correspond to the roof zone and configuration of the installation site.

Effective Wind Area is used to calculate the induced load on the module, and select the *External Pressure Coefficient* is based on the size of the module. In the case of the module, as there are a minimum of two rails per module, the *Effective Wind Area* per module equals one half of the module area.

Internal Pressure Coefficient is given by the structure type where the array is to be mounted. Specifically, the Enclosure Classification as defined in ASCE 7-05 section 6.2 determines which coefficient is appropriate from ASCE 7-05 figure 6-5, and used in equation 6-22. Generally, Power Rail is installed in classifications of Open, and this coefficient is therefore taken to be zero. Please consult a licensed design professional or the local building authority to determine the case for questions regarding a specific installation.

1.3. Additional Considerations

Roof Zone Setback requirements are also based on ASCE 7-05, figure 6-11 through 6-16, as used to determine GCp.

The ASCE 7-05 section 6.5 Method II Analytical Procedure is understood to be a conservative approach to calculating design wind forces on open structures such as the Power Rail. For this reason DPW Solar has performed full-scale wind tunnel testing per ASCE 7-05 section 6.6, Method III. Please contact DPW for additional information in utilizing this method in situations where roof loading or anchorage is of added concern.

2. SNOW LOADING

Snow loading is of additional concern both for its additive effect on the loading of solar structures such as Power Rail, and the net combined effect of the overall snow load and concentrated point loading induced on the structure to which the rack is attached.

2.1. Ground Snow Load

Ground snow load is taken to be the worst case snow loading at a given site. From ASCE 7-05 section 7.2, ground snow loads are tabulated in figure 7-1 in psf. Several site-specific variables affect the design snow load accumulation. These include both thermal and exposure factors, as well as the importance or safety factor.

2.2. Flat Roof Snow Load

Flat Roofs are classified as any roof with a slope less than or equal to 5°. However, the flat roof value is used to determine subsequent snow loading on other structures. Using equation 7-1 from ASCE 7-05:

$$p_f = 0.7 C_e C_t I p_g \quad \text{(PSF)}$$

(Equation 7-1)

Where

pf = flat roof snow load
Ce = exposure factor
Ct = thermal factor
I = importance factor
pg = ground snow load

Exposure Factor is effectively borrowed from the wind analysis ASCE 7-05 section 6.5.6, with some additional criteria for mountainous and Alaskan sites. It is predictive of whether the site has a tendency towards blowing snow or large stable accumulations. Values are tabulated in ASCE 7-05 table 7-2. It is recommended to use the same exposure terrain category from the wind analysis (B, C, or D) unless the site is in a mountainous or Alaskan region. If in doubt, please confer with a licensed design professional or building authority.

Thermal Factor determines whether a roof is warm or cold. Reference ASCE 7-05, table 7-3 to correlate the structure to a Thermal Factor category. Because solar modules are not part of the building envelope, it is recommended to typically use the 'cold' value.

Importance Factor is similar to *Occupancy Category* as in section 1.1 above, utilizing ASCE 7-05 table 7-4. Again, reference ASCE 7-05 table 1-1 for the *Occupancy Category* of the install site.

Installations on roofs less than or equal to 5° should use with the flat roof snow load. However, roofs not meeting that criteria require additional analysis.

2.3. Sloped Roof Snow Loads

Sloped roofs have racking surfaces inclined at greater than 5°. The sloped roof snow load is driven by the flat roof snow load as determined in section 2.2, and adjusting with the following formula:

$$p_s = C_s p_f$$

(Equation 7-2)

Where

ps = sloped roof snow load
pf = flat roof snow load
Cs = roof slope factor

Roof Slope Factor is determined from ASCE 7-05 sections 7.4.1 through 7.4.4. The selection of which section to use is determined by the Thermal Factor, Ct, from section 2.2. Again, because Power Rail mounted modules are not part of the building envelope a 'cold roof' analysis is recommended. Per ASCE 7-05 section 7.4.2 for Cold Roof Slope, figure 7-2c is utilized to determine the roof slope factor.

Slippery Surface allowances are used where "sufficient space is available below … to accept all of the sliding snow". Please consult a licensed design professional or local building authority prior to exercising this allowance.

3. SEISMIC LOAD

The Power Rail and its connectors are part of the seismic force resisting systems when it is attached to a structure. As a component of the system design loads, an outline of the seismic design parameters is listed in this section for applications where seismic events are a concern.

3.1. Ground Motion

Seismic design criteria are ultimately driven by the *Design Spectral Response Coefficient*, which is a function of the *Adjusted Maximum Considered Earthquake (MCE) Spectral Response Coefficient*. Given by ASCE 7-05, equation 11.4-1:

$$S_{MS} = F_a S_S$$

(Equation 11.4-1)

Where

Sms = MCE spectral response coefficient
Fa = Site Coefficient
Ss = mapped MCESR coefficient (short)

Site Coefficient is determined by ASCE 7-05 section 12.14.8.1, or using table 11.4-1 where the *Site Class* is known.

Mapped Maximum Considered Earthquake Spectral Response Coefficient for Short Periods is determined by ASCE 7-05 section 11.4.1, using figures 22-1 through 22-14.

With the above values it is possible to determine the seismic design spectral response value for analysis by:

$$S_{DS} = \frac{2}{3} S_{MS}$$

(Equation 11.4-3)

Where

Sds = design spectral acceleration parameter
Sms = MCE spectral response coefficient

Design Spectral Acceleration Parameter is used to determine the design forces due to a seismic event and is determined from the result in equation 11.4-1.

3.2. Seismic Design Force

Seismic force analysis looks at the forces on the Power Rail array as a unit, given to be acting through the center of gravity of that array. ***Seismic Design Force*** is given by ASCE 7-05, equation 13.3-1:

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)} \left(1 + 2\frac{z}{h}\right)$$

(Equation 13.3-1)

Where

Sds = design spectral acceleration parameter
ap = component amplification factor
Ip = component importance factor
Wp = component operating weight
Rp = component response factor
z = height in structure at attachment
h = average roof height of structure

Design Spectral Acceleration Parameter is the result of equation 11.4-3.

Component Amplification Factor is determined by ASCE 7-05 table 13.5-1 or 13.6-1. Solar mounting structures are generally recommended as 1.0.

Component Importance Factor is given by section 13.1.3 of ASCE 7-05. Solar mounting structures are generally recommended as 1.0.

Component Operating Weight is a product of the Power Rail, hardware, and the modules attached to the structure. Please contact DPW Solar for your specific PRM system's weight.

Component Response Factor is determined by ASCE 7-05 table 13.5-1 or 13.6-1.

The height of the structure at attachment, z, is taken relative to ground level. The average roof height is typically the same, depending on how the system is installed. Per ASCE 7-05, "The value of *z/h* need not exceed 1.0".

3.3. Seismic Load Effect

For use in load combination analysis, seismic load effect is broken down into effects on both the horizontal and vertical plane. Horizontal effect is given by equation 12.4-3:

$$E_h = \rho Q_E$$

(Equation 12.4-3)

Where

Qe = Fp = seismic design force

ρ = redundancy factor

Redundancy Factor is defined in ASCE 7-05 section 12.3.4. According to this section, as solar structures are type (3.) nonstructural components, the *Redundancy Factor* can be taken as 1.0.

Seismic Design Force is the result of equation 13.3-1 as per section 3.2 above.

The vertical component of the seismic load combination is given by equation 12.4-4:

$$E_v = 0.2 S_{DS} D$$

(Equation 12.4-4)

Where

Sds = design spectral acceleration parameter

D = effect of dead load

Here the result of equation 11.4-3 can be used for the *Design Spectral Acceleration Parameter*. As the structure, for purposes of analysis, is comprised of no composite loads, the *Dead Load* is equal to the *Component Operating Weight* as used in equation 13.3-1 in section 3.2.

$$E = E_h + E_v$$

(Equation 12.4-1)

Where

E = seismic load effect

Eh = effect of horizontal seismic forces

Ev = effect of vertical seismic forces

Here, the net seismic effect is the sum of the horizontal and vertical components.

4. LOAD COMBINATIONS

In accounting for the probability of various system loads occurring in conjunction, ASCE 7-05 prescribes a series of load combinations for which the worst case (highest) loading combination governs the system design. For this procedure, Allowable Stress Design combinations will be used, according to ASCE 7-05 section 2.4.1. A number of the combinations will not apply to solar racking systems. As such, with unused terms removed, the relevant combinations are:

3. D+S
6. D+0.75(W or 0.7E)+.75S
7. 0.6D+W
8. 0.6D+0.7E

Where

D = dead load	Dead Load equates to the net system weight, including panels.
S = snow load	Snow Load is the result from section 2 above.
W = wind load	Wind Load is the result from section 1 above.
E = earthquake (seismic) load	Earthquake Load is the result from section 3 above.

The design of a Power Rail system is concerned both with rail/mounting structure loading, and attachment point loading. It should be noted that in order for the loading cases above to be used, the various condition case loads must be in the same units. It is apparent that the wind and snow loads are in units of pressure, and the seismic loads are in units of lbs. The pressure loads will be resolved in the following section.

5. PRODUCT SELECTION & SPECIFICATION

With site loading conditions determined, a power rail system can be matched to the desired solar module layout. As mentioned previously, both attachment point loading and structural loading determine how the product is specified. We will first examine a governing case of structural loading, and further refine the design by including the attachment loads.

5.1. Rail Support Specification

Stress on the Power Rail itself is proportional to the loading determined above, and the length of the rail between supports. As referenced in the assembly instructions, there are two key characteristic dimensions for the power rail install. The first term, Span, is the center-to-center distance between rail supports. Cantilever (sometimes abbreviated C'ver) is the distance from the outermost support to the end of the rail (see figure 5-1 below).

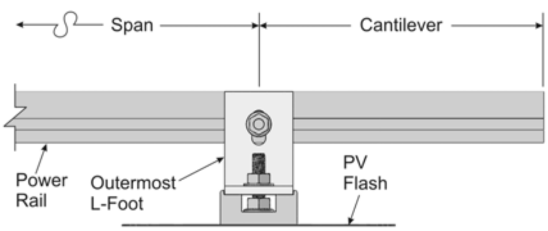

Figure 5-1: Cantilever Measurement

Additionally, these dimensions may be co-constrained by the span between rafters or purlins, if a direct-to-structural mounting method is used. For the purposes of design, we present two methods for specifying the upper limit of this dimension, based upon the stress and deflection characteristics of the selected Power Rail product.

5.2. Simplified Method

In the interest of simplifying the selection and specification of structurally attached Power Rail products, this method assumes several variables as worst-case, and directly correlates the Span and Cantilever values to the governing design criteria given for a specific Power Rail profile.

Assuming:

70"	=	Max Module Length
40"	=	Max Module Width
30'	=	Max Roof Height
1	=	Roof Installation Zone

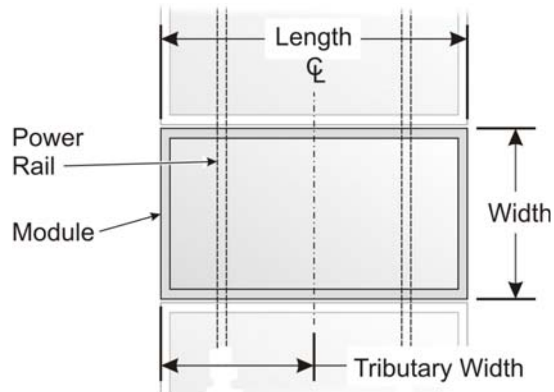

Figure 5-2: Typical Module Dimensions

To specify the Span and Cantilever values for an application, simply cross reference the Wind Load and Snow Load values to the corresponding cell in table 5-1 which lists these dimensions. For wind loading cases of exposure 'B', reference the row above, and for exposure 'D', the row below the design wind speed for that exposure.

It is important to again note that these are the maximum allowable design values based on the rail characteristics. If the multiple of the structural spans to which the rail anchors are to be attached is greater than the maximum span value, the next multiple of the attached structural span shall be used in order to keep the rail design capacity below its maximum.

WIND SPEED (MPH)	SPAN / C'VER	SNOW LOAD (PSF) 0	10	20	30	40	50	60	70	80	90	100
	90C	72 / 36	60 / 32	54 / 26	48 / 24	43 / 21	40 / 20	36 / 18	33 / 16	31 / 15	29 / 14	28 / 14
	100C	60 / 32	58 / 28	48 / 24	46 / 23	42 / 21	38 / 19	36 / 18	33 / 16	31 / 15	29 / 14	28 / 14
	110C	58 / 28	54 / 26	48 / 24	44 / 22	40 / 20	37 / 18	35 / 17	33 / 16	31 / 15	29 / 14	28 / 14
	120C	54 / 26	54 / 26	46 / 23	42 / 21	39 / 19	36 / 18	34 / 17	32 / 16	31 / 15	29 / 14	28 / 14
	130C	48 / 24	48 / 24	44 / 22	40 / 20	37 / 18	35 / 17	33 / 16	32 / 16	30 / 15	29 / 14	28 / 14

Table 5-1: Wind Speed & Snow Load Application Table

5.3. Analytical Method

In the event that the design conditions fall outside of the range of the simplified method, or otherwise if a detailed engineering review is required, we suggest this method. The preceding section 1 references the ASCE 7-05 Analytical Method II for determining the wind load values. Whereas it is outside of the scope of this document to detail the process of beam structural analysis; key beam structural parameters are listed here along with discussion to aid the engineer.

In regards to the ASCE 7-05 Analytical Method II analysis, the components and cladding section is suggested in that the constraints and assumptions of that section seem to best align with conditions to which a solar module is potentially exposed. A full analytical study will look at the specific force coefficients in a given installation roof wind zone where the rack is installed. As mentioned above, with respect to beam loading, the wind and snow loads are typically the primary governing load combinations.

Once the governing load combination is resolved, it may be applied to the rail via the module size in question. For the purposes of a conservative analysis, our span and cantilever suggestions are typically made with the assumption that the load is fully distributed. In practice, however, the loads may be applied to the rail as point loads at the positions of module attachment, provided they are known. Please also note that typical installations utilize two power rails per module when considering the tributary area. With the beam appropriately loaded, beam analysis may be performed. Details pertinent to the beam analysis for the Power Rail products are as follows:

Power Rail P6 Properties		
Property	Value	Units
A	0.579	in^2
Ix	0.149	in^4
Iy	0.068	in^4
S_{top}	0.202	in^3
S_{bot}	0.200	in^3
Alloy	6005A-T51	

*Additional properties available upon request.

6. SUPPORT SELECTION & SPECIFICATION

With the rail characteristic dimensions determined, the final design element is to determine the rail attachment and support product. Generally, the roof composition and type of penetration is of primary concern when selecting an appropriate support. Within the Power Rail support family, we can classify two subcategories: Direct to Structural and Decking Attached supports. For instructions regarding specific attachment systems, please see the installation instruction for that specific support.

6.1. Direct To Structural

As the name implies, Direct To Structural supports attach directly to building structural elements located below the roof decking. Because of the direct nature of these supports, high individual support capacities can be obtained. An important consideration with Direct To Structural supports, however, is that the span between supports not exceed the maximum span of the Power Rail product, as determined in the preceding section.

6.2. Decking Attached

Decking Attached supports utilize the combined capacity of multiple smaller structural screws to meet or in some cases exceed the capacity of a single direct to structural fastener. These supports also have the added benefit of flexibility of placement on the roof. In some cases, this ensures the maximum spans of the rail can be utilized.

6.3. Support Live Load Reactions

The maximum live loading on the supports is a function of the loads on the rail and, by extension, the span and cantilever values selected in the preceding sections. With those values known, it is possible to determine what the maximum load conditions are on a given support. We present two methods for determining this loading.

6.3.1. Simplified Method

Utilizing the criteria specified in the simplified method for product selection and specification (see section 5.2), the following table 6-1 specifies the maximum axial point loads for supports on a given installation.

WIND SPEED (MPH)		Axial Load (lb)
	90C	363
	100C	373
	110C	436
	120C	483
	130C	504

Table 6-1: P6 Support Upload, Load Reactions

To determine the maximum point load, simply cross reference the Wind Load values to the corresponding cell in the table which lists these dimensions. For wind loading cases of exposure 'B', reference the row above, and for exposure 'D', the row below the design wind speed for that exposure.

6.3.2. Analytical Method

If using the Analytical Method in section 5.1.2., a similar analytical approach must also be used to determine the point loading for supports. Granted, each analytical study will presumably involve specific dimensions both at the module level, as well as the span, and cantilever components. Lateral seismic loads should also be considered in this analysis.

6.4. Support Fasteners

With the support loading resolved, attachment fasteners may be selected. Again, the type of fastener varies with the type of support selected.

6.4.1 Direct to Structural Fasteners

Direct to Structural Fasteners typically fasten the supports to wood or metal structural elements. In the case of wood fasteners, the most universal reference for fastener capacity is the American Wood Council (AWC) selection criteria. The AWC provides an excellent set of online calculators as well as tables for determining the capacities of various standard fasteners. You may find their online connections calculator at:

http://www.awc.org/calculators/connections/default.htm

6.4.2 Decking Attached Fasteners

Decking Attachment Fasteners are typically supplied by DPW/Power Fab with the specific support as a kit. The specific fasteners supplied are from the GRK Fasteners Company. The specific product is an RSS™ screw. GRK provides excellent documentation of their fasteners' capacities, including references to ICC-ES™ testing and selection criteria for various decking substrates. DPW provides the RSS™ screws in the PHEinox™ configuration with 1/4" diameter. For additional information, please reference:

http://www.grkfasteners.com/en/selection_guide_RSS.htm

7. EXPEDITED PERMIT PROCESS (EPP) & DEAD LOADS

To aid the system designer in use of the Solar America Board of Codes and Standards (Solar ABC's) *Expedited Permit Process for PV Systems* (EPP), the following information is provided for use in the *Mounting System Information* for Manufactured Mounting Systems, section (2.2).

a. Mounting System Manufacturer: **DPW/Power-Fab**

i) Model#: **P(r)-PRM(n)-(mmmwww)**

Where:

r	=	Power Rail Type (i.e. 6 for P6 Rail)
n	=	Number of Modules (d, for drawing-specific complex systems)
m	=	Module Manufacturer Abbreviation
w	=	Module Model STC. Wattage

b. Total Weight: **# Modules x Module Weight (see mfg spec.) + Racking Weight (via Quote or Configurator)**

c. Total Number of Attachment Points: **Provide per analysis/design or via Quote/Configurator**

d. Weight per Attachment: $\frac{b.}{c.}(above)$

e. Maximum Spacing Between Attachment Points: result of **Span**, section 5.1 above

f. Total Surface Area of PV Modules (sqft): **#Modules x Module Area (see mfg. spec.)**

g. Distributed Weight of PV System (psf): $\frac{b.}{f.}(above)$

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