SOLAR PANELS & ANCHORING

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May 19, 2021

SEAAK Meeting

BBFM Engineers Inc.

Provided by Ben May, Alaska Solar

INTRODUCTION

- Solar Power: Why here? Why now?
- ASCE 7-16 New Rooftop Solar Panel Design Provisions
- Flat and Sloped Roof Design Examples
- Rooftop and Array Configurations Outside of Code Procedures
- Ground Mounted Solar Arrays: Calculation Comparison of Different Methods

SOLAR POWER INCENTIVES AND PROGRAMS

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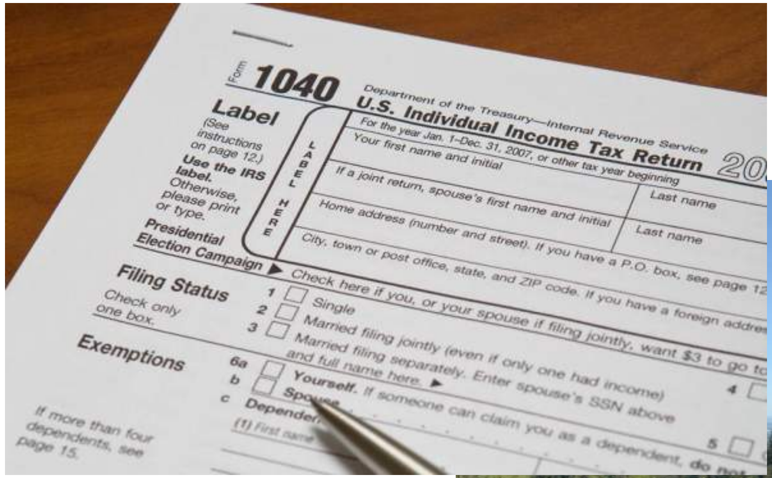
- Federal Income Tax Credits
- Solarize Anchorage Program
- Utility buy-back of unused power



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ASCE 7-16 SOLAR PANEL DESIGN PROVISIONS

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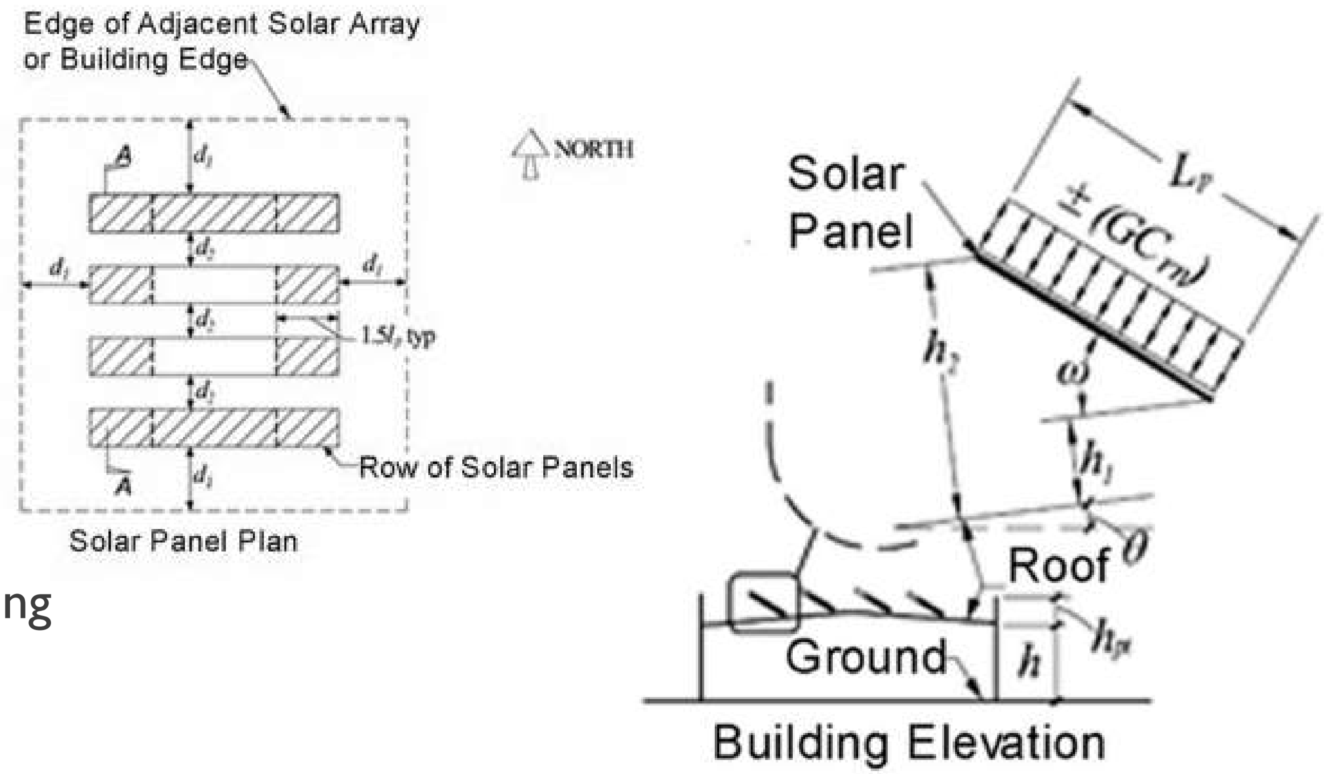
ROOFTOP ARRAYS – ASCE 7-16 CHAPTER 29.4.3

Roofs with slopes ≤ 7°

- Panel tilt $\omega \leq 35\,°$
- $L_p \leq 6.7\,ft$
- $h_1 \leq 2\,ft, h_2 \leq 4\,ft$
- All panels 0.25 in min. and 6.7 ft max. spacing
- $d_{1\min} = \max(4, 2(h_2 - h_{pt}))$

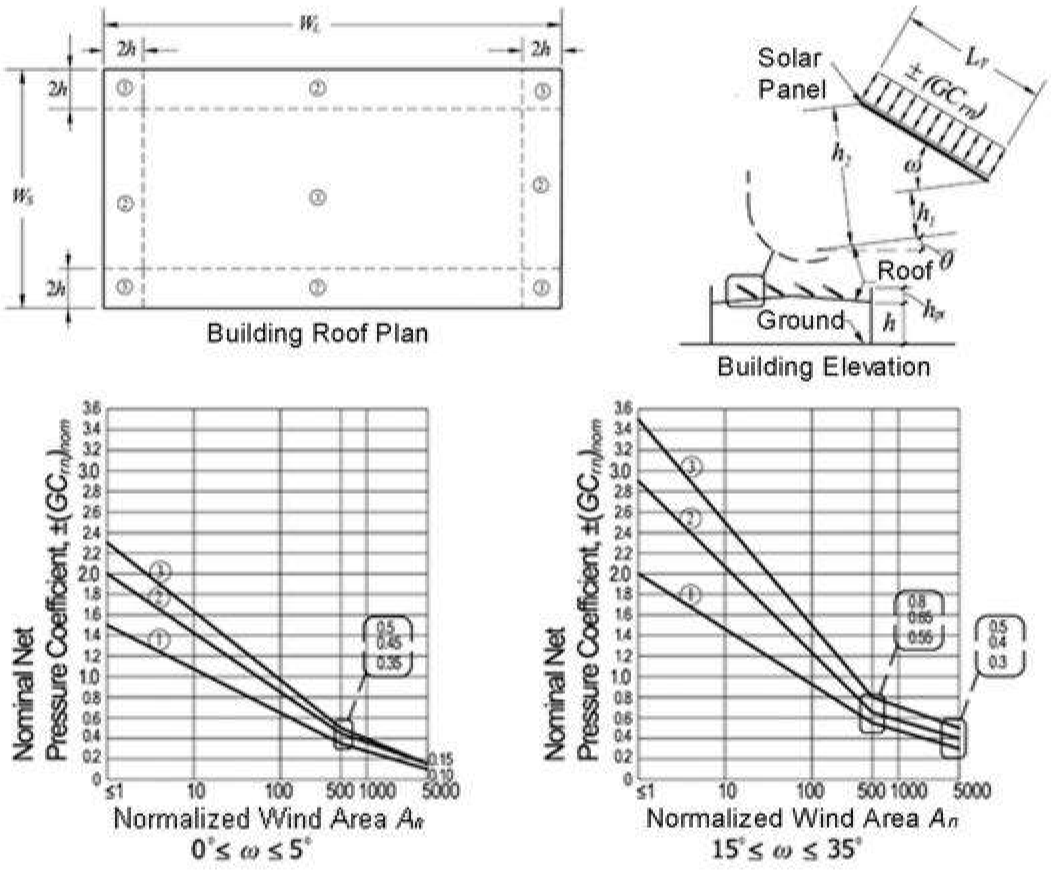


Copywrite ASCE 7-16 Figure 29.4-7

FLAT ROOFS CONTINUED

- $p = q_h(GC_{rn})(\frac{lb}{ft^2})$ (eqn 29.4-5)
- $(GC_{rn}) = (\gamma_p)(\gamma_c)(\gamma_E)(GC_{rn})_{nom}$ (eqn 29.4-6)
- $A_n = \left(\frac{1000}{[\max(L_b, 15)^2]}\right) A, where\ A = effective\ wind\ area$
- $L_b = \min(0.4(hW_L)^{0.5}, h, W_s)$
- $(\gamma_p) = \min\left(1.2, 0.9 + \frac{h_{pt}}{h}\right)$
- $(\gamma_c) = \max(0.6 + 0.06L_p, 0.8)$
- $(\gamma_E) = array\ edge\ factor$

Nominal Net Pressure Coefficients, $(GC_{rn})_{nom}$



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ROOFTOP ARRAYS – ASCE 7-16 CHAPTER 29.4.4

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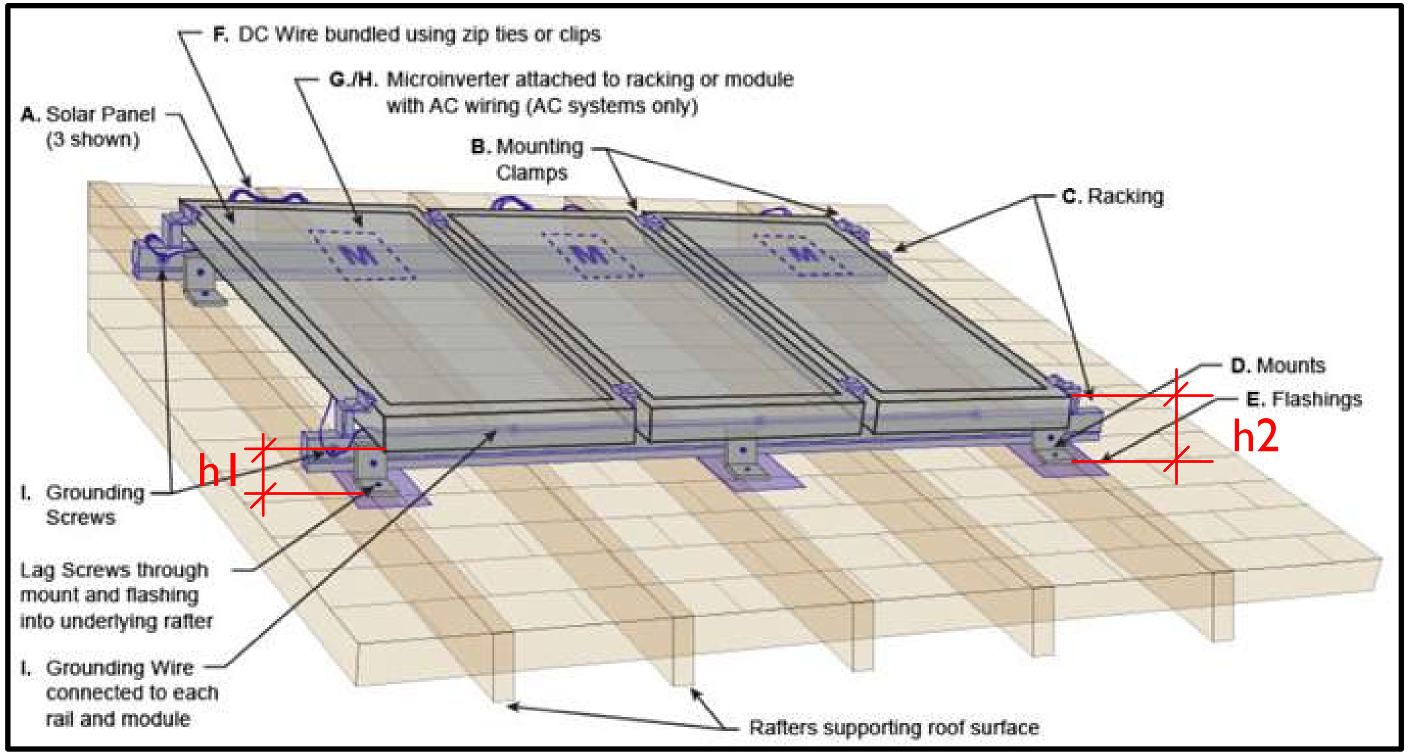
Panels parallel to roof surface

- Any roof slope
- Panel tilt $\omega \leq 2\,°$
- $h_2 \leq 10\ in$
- All panels 0.25 in min. and 6.7 ft max. spacing
- $d_1 \geq 2h_2\ from\ roof\ edge\ or\ ridge$



https://www.solarpowerworldonline.com/2014/03/anatomy-rooftop-solar-mounting-system/

SLOPED ROOF CONTINUED

- $p = q_h(GC_p)(\gamma_E)(\gamma_a)(\frac{lb}{ft^2})$ (eqn 29.4-7)
- (GC_p) is from C&C figures 30.3-2A-I through 30.3-7 or 30.5-I
- $(\gamma_E) = array\ edge\ factor$
- $(\gamma_a) = solar\ array\ pressure\ equalization\ factor$

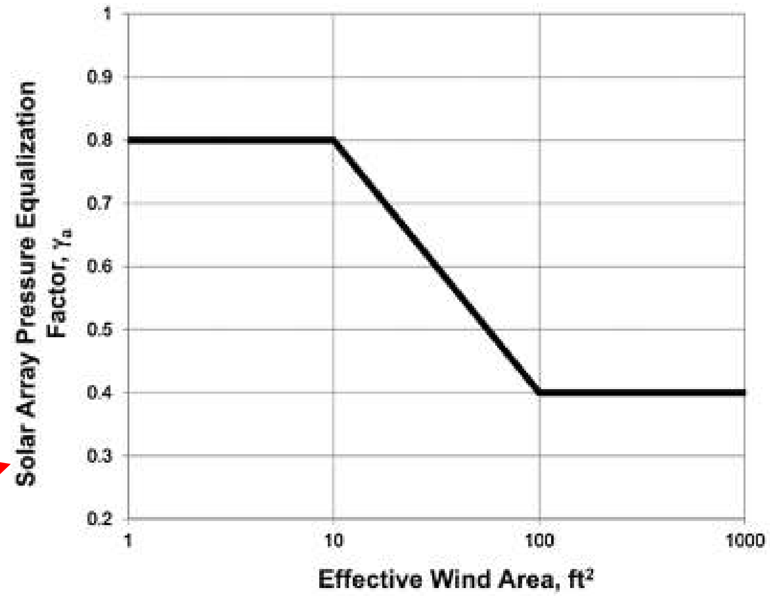


Figure 29.4-8 Solar panel pressure equalization Factor γ_a, for enclosed and partially enclosed buildings of all heights

ARRAY EDGE FACTOR (γ_E)

- $\gamma_E = 1.5$ for uplift loads if **exposed** and within $1.5L_p$ from the end of row at exposed edge
- $\gamma_E = 1.0$ elsewhere for uplift and all downward
- If $d_1 > 0.5h$

AND

Flat Roof Sloped Roof

$d_{1AdjArray} > \max(4h_2, 4\ ft), > 4\ ft$ OR

Flat Roof Sloped Roof

$d_{2AdjPanel} > \max(4h_2, 4\ ft), > 4ft$

then the panel is <u>**EXPOSED**</u>

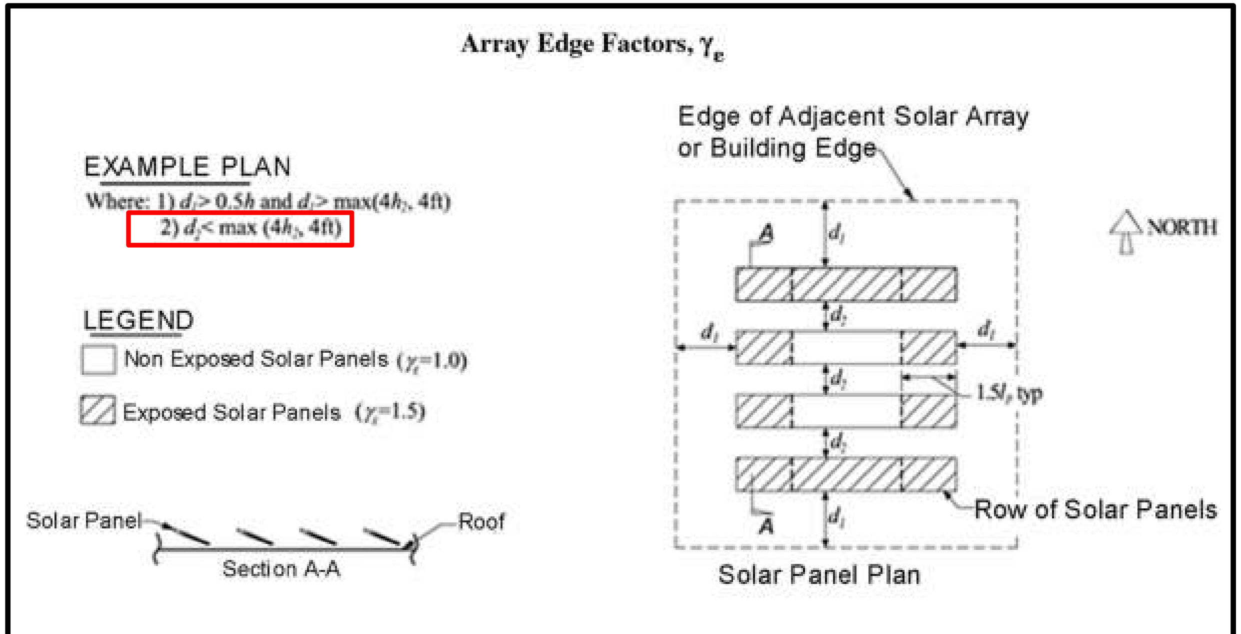


Figure 29.4-7 Design wind loads (All Heights): Rooftop solar panels for enclosed and partially enclosed buildings, roof θ≤7°

EXAMPLE 1. FLAT ROOF

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ASCE 7-10

7.7.1 Lower Roof of a Structure. Snow that forms drifts comes from a higher roof or, with the wind from the opposite direction, from the roof on which the drift is located. These two kinds of drifts ("leeward" and "windward" respectively) are shown in Fig. 7-7. The geometry of the surcharge load due to snow drifting shall be approximated by a triangle as shown in Fig. 7-8. Drift loads shall be superimposed on the balanced snow load. If h_c/h_b is less than 0.2, drift loads are not required to be applied.

For leeward drifts, the drift height h_d shall be determined directly from Fig. 7-9 using the length of the upper roof. For windward drifts, the drift height shall be determined by substituting the length of the lower roof for l_u in Fig. 7-9 and using three-quarters of h_d as determined from Fig. 7-9 as the drift height. The larger of these two heights shall be used in design. If this height is equal to or less than h_c, the drift width, w, shall equal $4h_d$ and the drift height shall equal h_d. If this height exceeds h_c, the drift width, w, shall equal $4h_d^2/h_c$ and the drift height shall equal h_c. However, the drift width, w, shall not be greater than $8h_c$. If the drift width, w, exceeds the width of the lower roof, the drift shall be truncated at the far edge of the roof, not reduced to zero there. The maximum intensity of the drift surcharge load, p_d, equals $h_d\gamma$ where snow density, γ, is defined in Eq. 7.7-1:

$$\gamma = 0.13p_g + 14 \text{ but not more than 30 pcf} \qquad (7.7\text{-}1)$$

(in SI: $\gamma = 0.426p_g + 2.2$, but not more than 4.7 kN/m^3)

This density shall also be used to determine h_b by dividing p_s by γ (in SI: also multiply by 102 to get the depth in m).

7.8 ROOF PROJECTIONS AND PARAPETS

The method in Section 7.7.1 shall be used to calculate drift loads on all sides of roof projections and at parapet walls. The height of such drifts shall be taken as three-quarters the drift height from Fig. 7-9 (i.e., $0.75h_d$). For parapet walls, l_u shall be taken equal to the length of the roof upwind of the wall. For roof projections, l_u shall be taken equal to the greater of the length of the roof upwind or downwind of the projection. If the side of a roof projection is less than 15 ft (4.6 m) long, a drift load is not required to be applied to that side.

ASCE 7-16

7.7.1 Lower Roof of a Structure. Snow that forms drifts comes from a higher roof or, with the wind from the opposite direction, from the roof on which the drift is located. These two kinds of drifts ("leeward" and "windward," respectively) are shown in Fig. 7.7-1. The geometry of the surcharge load due to snow drifting shall be approximated by a triangle, as shown in Fig. 7.7-2. Drift loads shall be superimposed on the balanced snow load. If h_c/h_b is less than 0.2, drift loads are not required to be applied.

For leeward drifts, the drift height h_d shall be determined directly from Fig. 7.6-1 using the length of the upper roof and the Snow Importance Factor from Table 1.5-2. However, the drift height need not be taken as larger than 60% of the length of the lower level roof. For windward drifts, the drift height shall be determined by substituting the length of the lower roof for l_u in Fig. 7.6-1 and using three-quarters of h_d as determined from Fig. 7.6-1 as the drift height. The larger of these two heights shall be used in design. If this height is equal to or less than h_c, the drift width, w, shall equal $4h_d$ and the drift height shall equal h_d. If this height exceeds h_c, the drift width, w, shall equal $4h_d^2/h_c$ and the drift height shall equal h_c. However, the drift width, w, shall not be greater than $8h_c$. If the drift width, w, exceeds the width of the lower roof, the drift shall taper linearly to zero at the far end of the lower level roof. The maximum intensity of the drift surcharge load, p_d, equals $h_d\gamma$ where snow density, γ, is defined in Eq. (7.7-1):

$$\gamma = 0.13p_g + 14 \text{ but not more than 30 lb/ft}^3 \qquad (7.7\text{-}1)$$

$$\gamma = 0.426p_g + 2.2, \text{ but not more than 4.7 kN/m}^3 \qquad (7.7\text{-}1.\text{si})$$

This density shall also be used to determine h_b by dividing p_s by γ (in SI: also multiply by 102 to get the depth in m).

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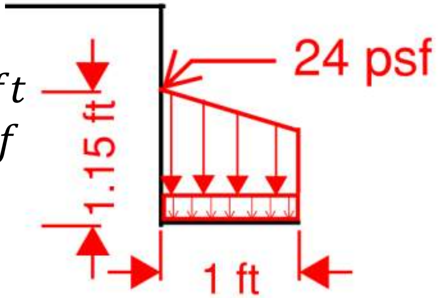
EXCEPTION: Drift loads shall not be required where the side of the roof projection is less than 15 ft (4.6 m) or the clear distance between the height of the balanced snow load, h_b, and the bottom of the projection (including horizontal supports) is at least 2 ft (0.61 m).

ASCE 7-10

$h_d = 1.15\ ft$

$P_d = 24\ psf$

$w = 9.2\ ft$

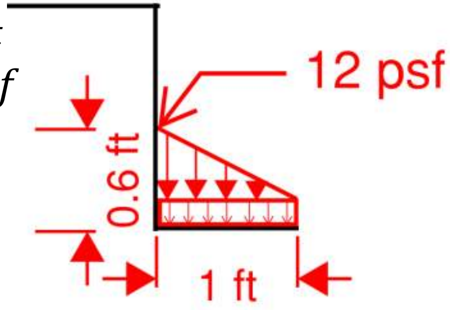


ASCE 7-16

$h_d = 0.6\ ft$

$P_d = 12\ psf$

$w = 2.4\ ft$



EXAMPLE 1.

- 12 panels are to be installed on a 32'x42' flat roof of an enclosed building. The roof elevation is 13'. V = 130 mph and Pg = 50 psf. Roof framing is assumed to be at 24" O.C. and the panels are to be placed 1' from the north edge of the roof facing south.

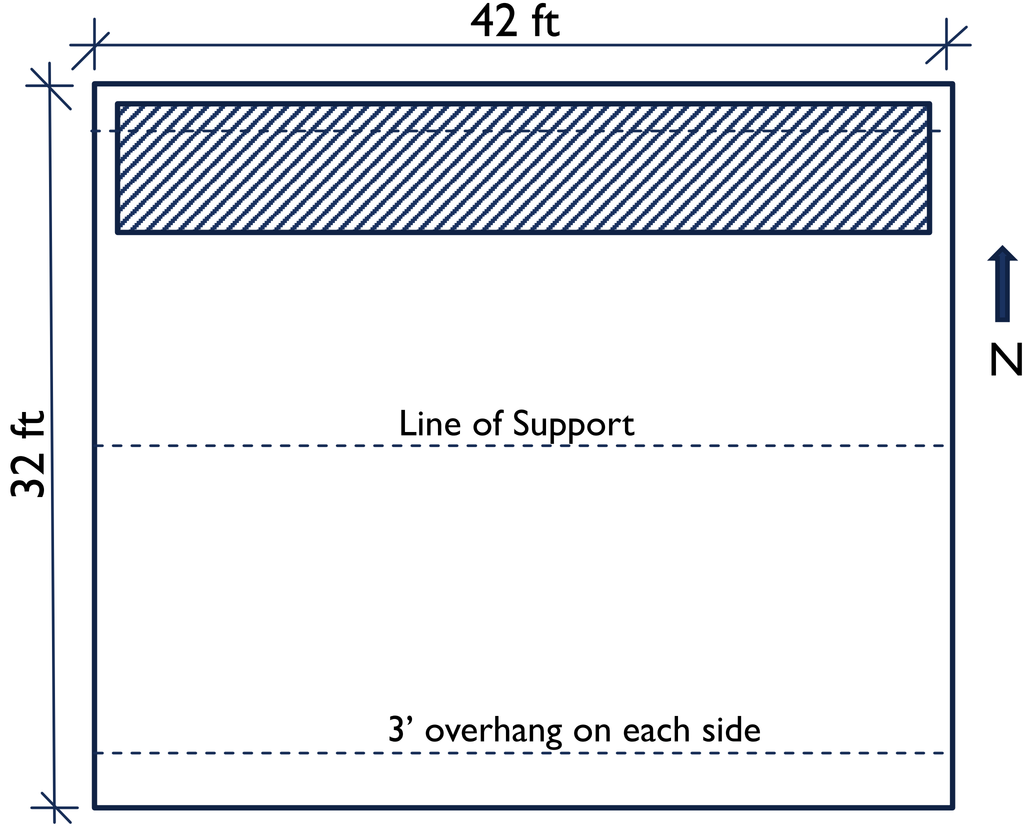
Snow drift for Roof Projections and Parapets (ASCE 7-16 Chp 7.8)

- EXCEPTION: if side of roof projection < 15ft, drift loads are not req'd
- 12 Panels (40"/panel)= 40' > 15' therefore snow drift is req'd

$\boldsymbol{h_d = 0.6\ ft}\ (60\%\ of\ roof\ width\ at\ drift\ location)$

$\boldsymbol{p_d = 12\ psf}$

$\boldsymbol{w = 2.4\ ft}$



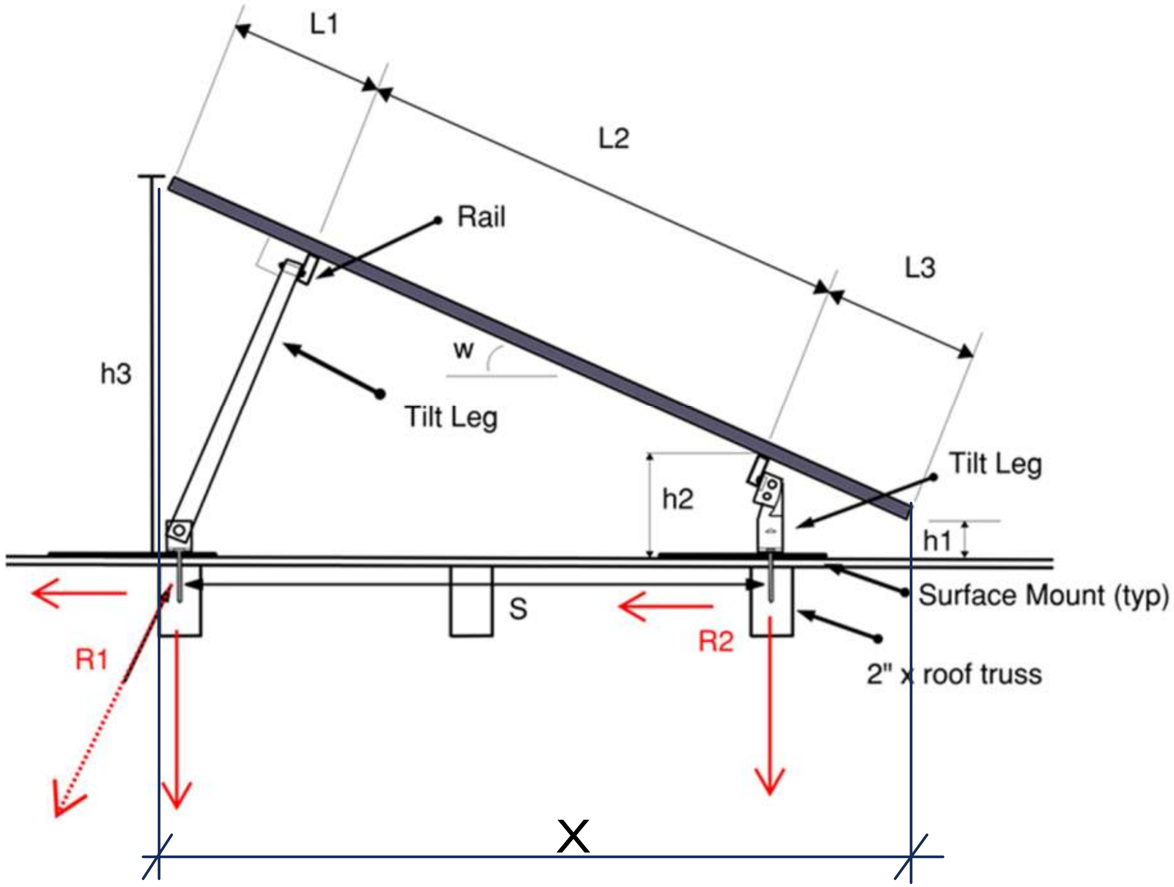
EX. 1 CONTINUED

- Additional Dead Load:

$Panel\ weight = \ 50\ lb$ $A_{panel} = 18.33ft^2$

$DL = 3\text{psf}$

- $TRY\!:\ h_1\ = 4", \omega = 30°, S\ = 4\ ft$
- $h_2 = 37\ in$
- $h_3 = 3.1\ ft$
- $x = 4.76\ ft$



EX. 1 CONTINUED

- Existing Loads

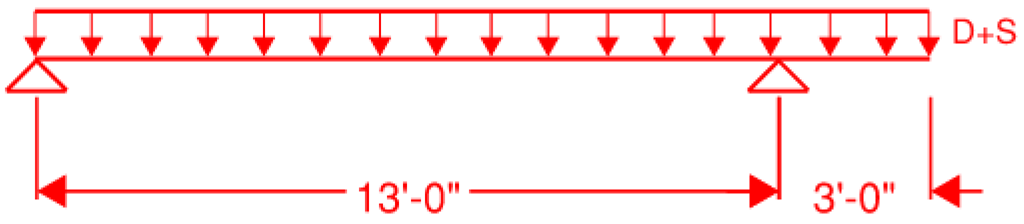
$DL = 15\ psf$

$SL = 40\ psf$

$W\ = 110\ plf\,(\text{ASD})$

$M_{\text{max}} = 1.91k - ft\ (ASD)$

$V_{\text{max}} = 0.86\ k(ASD)$

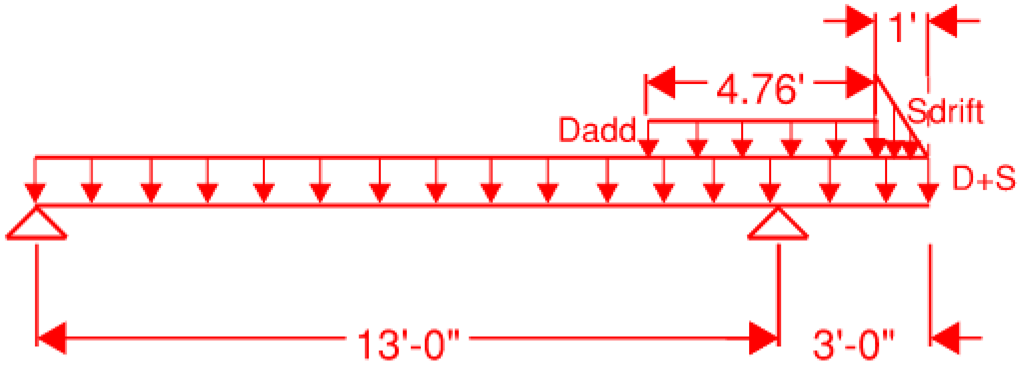


EX. 1 CONTINUED

- Existing + Additional Loads

$DL = 15\, psf,\qquad DL_{add} = 3\, psf$

$SL = 40\, psf,\qquad \mathrm{SL_{drift}} = 12.3\ \mathrm{psf}$



$M_{\max} = 1.928k - ft(ASD)$

$V_{\max} = 0.878\, k(ASD)$

- Stress Increase

$$\frac{1.928\, k - ft - 1.91\, k - ft}{1.91k - ft} = 1\% \; < 10\%\; \boldsymbol{OK}$$

$$\frac{0.878\, k - 0.86\, k}{0.86k} = \; 2\% \; < 10\%\; \boldsymbol{OK}$$

EX. 1 CONTINUED

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$p = q_h(GC_{rn})\ , q_h = 21\ psf\,(ASCE\ 7-16\ Chp\ 26.10)$

$L_b = \min(0.4((13ft)(42\ ft))^{0.5}, 13\ ft, 32ft) = 9.35ft$

$A = \frac{(66in)(40in)}{144} = 18.33ft^2, A_n = \left(\frac{1000}{[\max(9.35,15)^2]}\right)A = 81$

$(GC_{rn})_{nom} = 1.59$

$\gamma_p = \min\left(1.2, 0.9 + \frac{h_{pt}}{h}\right) = 0.9$

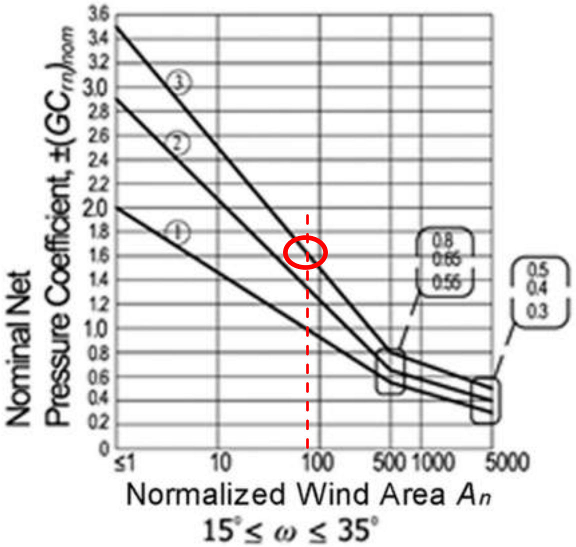
$\gamma_c = \max\left(0.6 + 0.06L_p, 0.8\right) = 0.93$

$\mathrm{d_1 = 26.24\ ft, d_{1min} = \max\left(4, 2\left(h_2 - h_{pt}\right)\right) = 6.17\ ft < 26.24\ ft}$ **OK**

$\mathrm{0.5h = 6.5\ ft < d_1 therefore\ exposed}$

$1.5L_p = 8.25\ ft, \frac{(8.25ft)(12)}{40in} = 2.5\ panels = first\ 3\ panels$

$\gamma_E = 1.5\ first\ 3\ panels\ and = 1.0\ for\ remainder$



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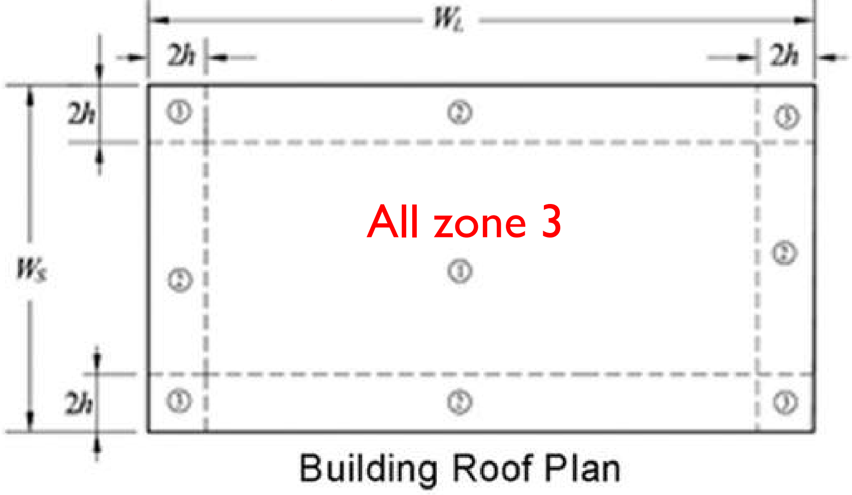
2h = 26 ft, 2*2h =52 ft > roof dims



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EX. I CONTINUED

$GC_{rn} = 1.99\ (\gamma_E = 1.5) or\ 1.33 (\gamma_E = 1.0)$

$p = 42\ psf\ \ (first\ 3\ panels)$

$p = 28\ psf\ \ (remainder)$

Spacing of legs: 4ft OC

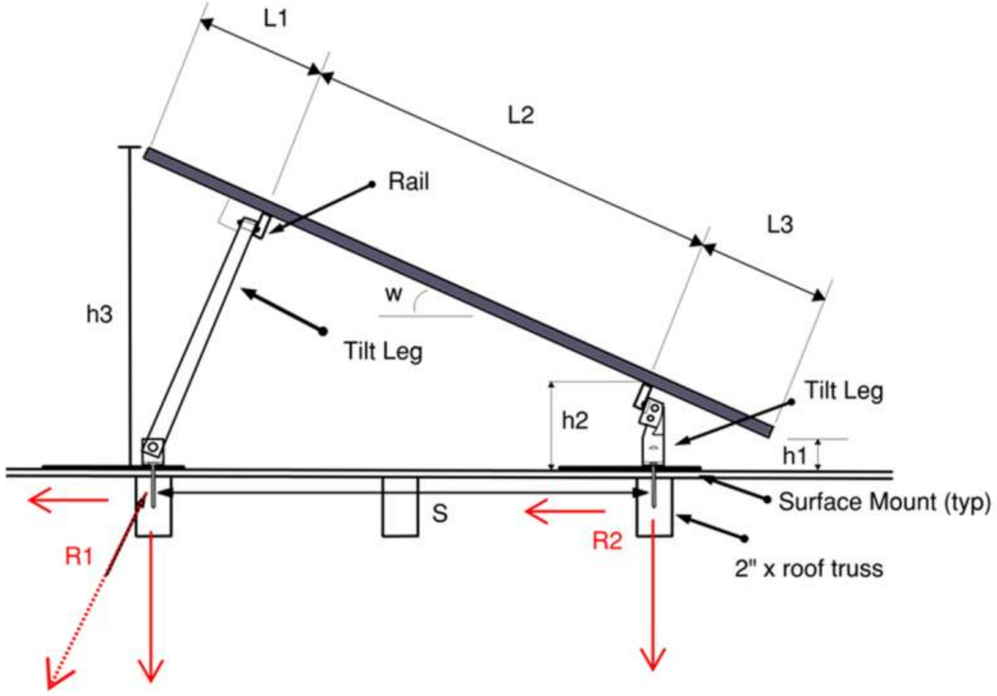
- Anchorage of first 3 panels, solve for reactions:

  $R_{1x} = 171\ lbs, R_{1y} = 297\ lbs, R_{2x} = 105\ lbs, R_{2y} = 182\ lbs$

  Try #14 screws with 2.5 in embedment

  $V_a = 227 \frac{lb}{screw}, T_a = 313 \frac{lb}{screw}\quad (C_p = 1, F.S. = 3)$

  $\frac{R_{1x}}{V_a} + \frac{R_{1y}}{T_a} = 1.7{\sim}2\ screws, \frac{R_{2x}}{V_a} + \frac{R_{2y}}{T_a} = 1.04 \sim 2\ screws$



2-#14 screws with 2.5in embedment required per leg base with legs spaced at 48in along rail

EX. 1 CONTINUED

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- Anchorage of remainder panels, solve for reactions:

$R_{1x} = 114\ lbs, R_{1y} = 197\ lbs, R_{2x} = 70\ lbs, R_{2y} = 121\ lbs$

Try #14 screws with 1.5 in embedment

$V_a = 141 \frac{lb}{screw}, T_a = 178 \frac{lb}{screw} \quad (C_p = 0.62, F.S. = 3)$

$\frac{R_{1x}}{V_a} + \frac{R_{1y}}{T_a} = 1.9 \sim 2\ screws, \frac{R_{2x}}{V_a} + \frac{R_{2y}}{T_a} = 1.2 \sim 2\ screws$

2-#14 screws with 1.5in embedment required per leg base

with legs spaced at 48in along rail

EXAMPLE 2. SLOPED ROOF

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EXAMPLE 2.

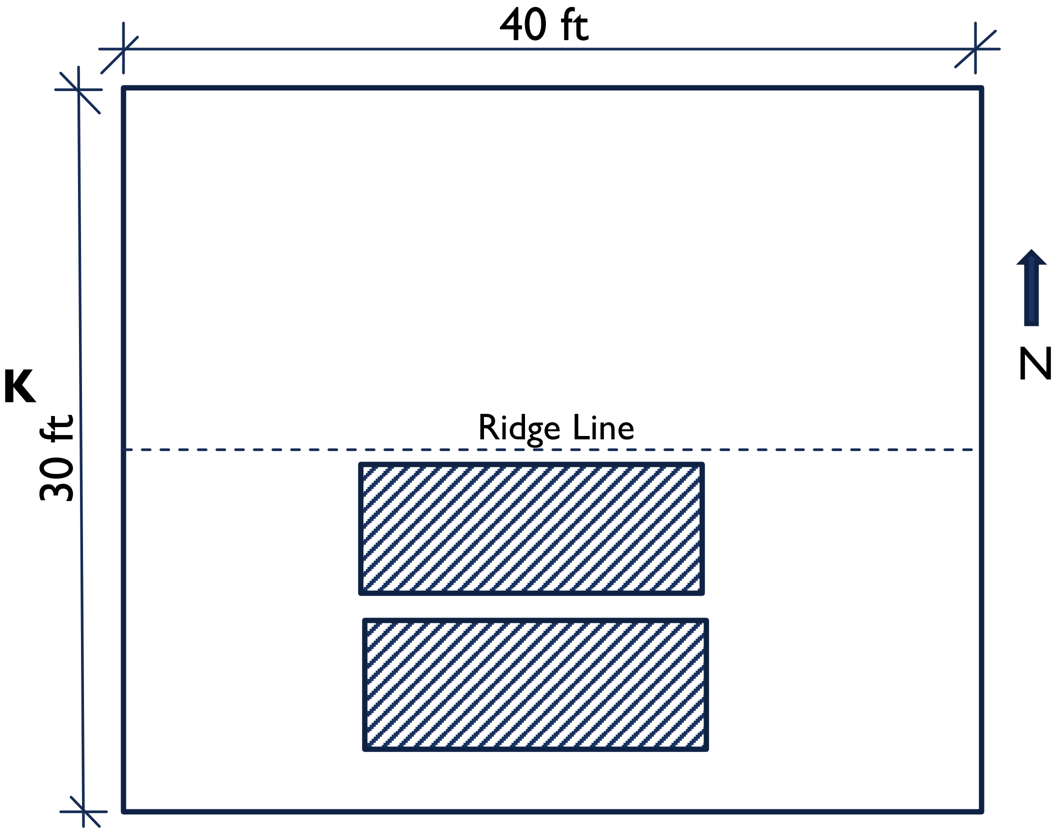
- 2 rows of 4 panels are to be installed on a 30'x40' 25° sloped roof of an enclosed building. The roof elevation is 12'. V = 155 mph and Pg = 50 psf. Roof framing is assumed to be at 16" O.C. and the panels are to be placed 1' from the ridge line on the south side of the roof.

Additional Dead Load:

$Panel\ =\ 50\ lb$ $\qquad A_{panel} = 18.33ft^2$

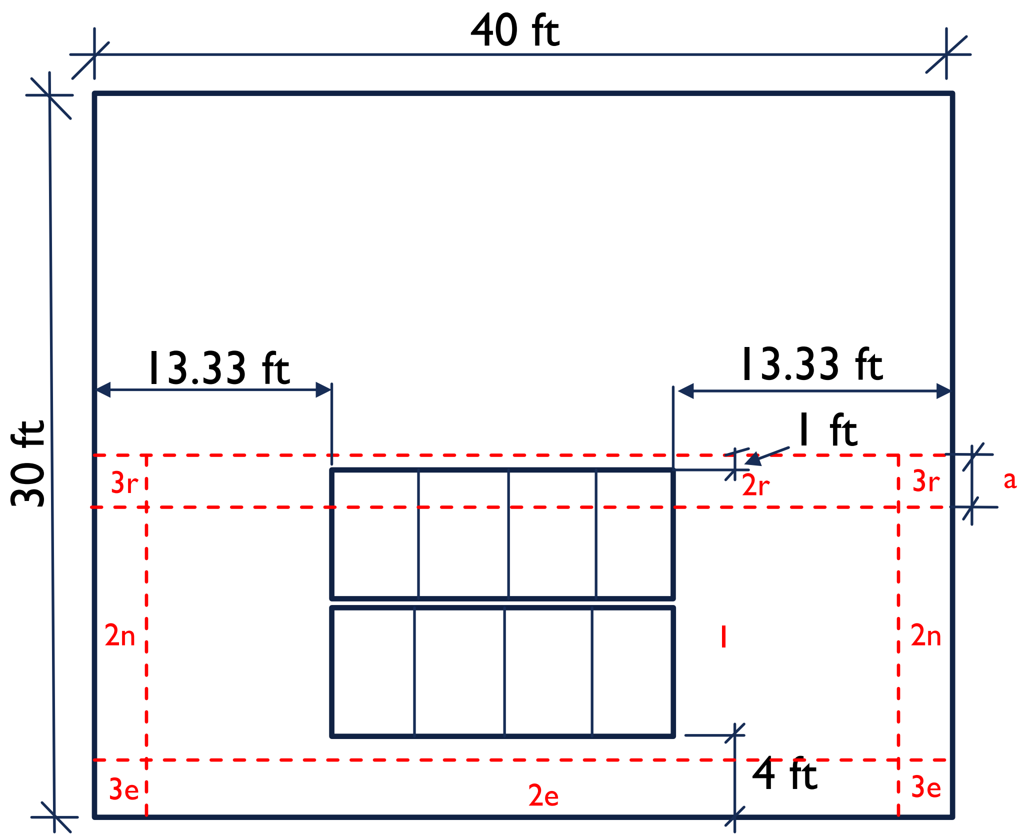
$DL = 3\text{psf}$

$15\ psf\ +\ 40\ psf\ = 55\ psf\ (3\ psf\ added\ {\sim}5\%\ stress\ increase)$ **OK**



EX. 2 CONTINUED

- $h_1 = 2"$
- $h_2 = 4.99\ in < 10\ in\ \boldsymbol{OK}$
- $12\ in\ from\ roof\ rige > 2(h_2) = 10\ in\ \boldsymbol{OK}$
- $a = min(0.1W_s, 0.4h) = 3\ ft \geq 3ft\ or\ 0.04W_s\ \boldsymbol{OK}$
- $A_{eff} = 18.33\ ft^2 = A_p$



Zones are from ASCE 7-16 Figure 30.3-2C (20°<θ<=27°)

EX. 2 CONTINUED

- $GC_{p1} = -1.5, GC_{p2r} = -2.2\ (Figure\ 30.3 - 2C)$

$d_1 = 16\ ft\ (zone\ 2r), d_1 = 13.33\ ft\ (zone\ 1)$

$0.5h = 6\ ft < d_1\ therefore\ exposed, 1.5L_p = 8.25\ ft$

$first\ 3\ panels\ \gamma_E = 1.5, remainder\ \gamma_E = 1.0$

$\gamma_a = 0.7$

- $p = q_h(GC_p)(\gamma_E)(\gamma_a), q_h = 29.8\ psf\ (ASCE7 - 16\ Chp\ 26.10)$

$p_{zone1} = 31\ psf$

$p_{zone2r} = 46\ psf$

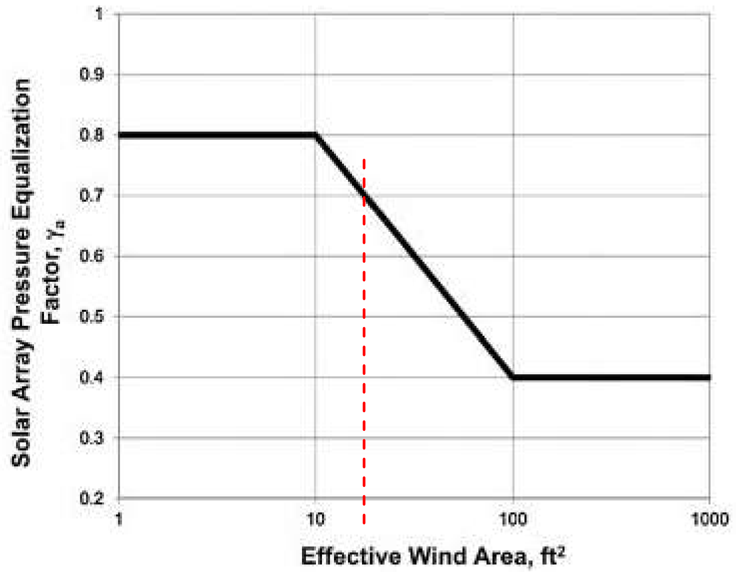


Figure 29.4-8 Solar panel pressure equalization Factor γ_a, for enclosed and partially enclosed buildings of all heights

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EX. 2 CONTINUED

Spacing of legs: 4ft OC

- Anchorage of northern most panels (zone 2r):

  $R_{wind} = 303\ lbs, R_{dead} = 30\ lbs, R_x = 12.7\ lbs, R_y = 27\ lbs$

- Try #14 screws with 3 in embedment

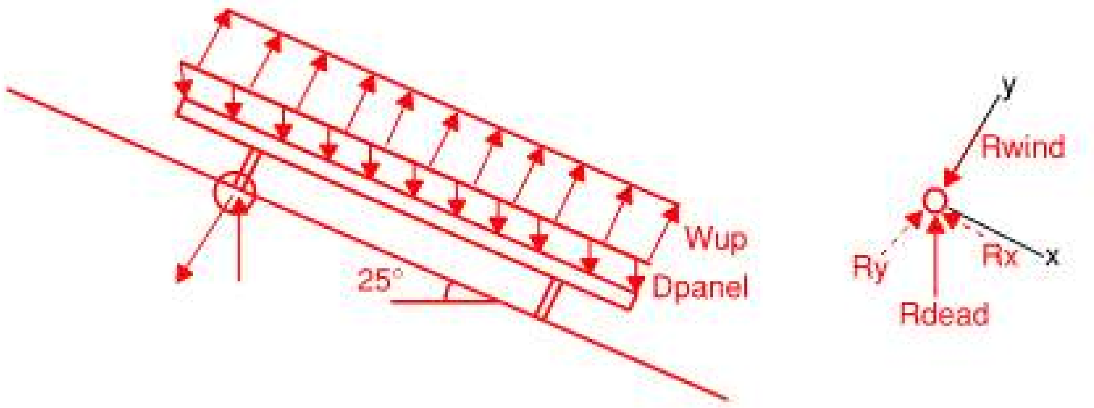
  Tension Capacity:

$$T_a = 381 \frac{lb}{screw} > R_{wind} = 303\ lbs\ \boldsymbol{OK}$$

  Shear Capacity:

$$V_a = 227 \frac{lb}{screw} \left(C_p = 1, F.S. = 3\right) > R_x = 12.7\ lbs\ \boldsymbol{OK}$$

$$\frac{R_x}{V_a} + \frac{R_w}{T_a} = 0.85$$



1-#14 screws with 3in embedment required per leg base with legs spaced at 48in along rail

EX. 2 CONTINUED

- Anchorage of southern most panels (zone 1):

  $R_{wind} = 207\ lbs, R_{dead} = 30\ lbs, R_x = 12.7\ lbs, R_y = 27\ lbs$

- Try #14 screws with 2 in embedment

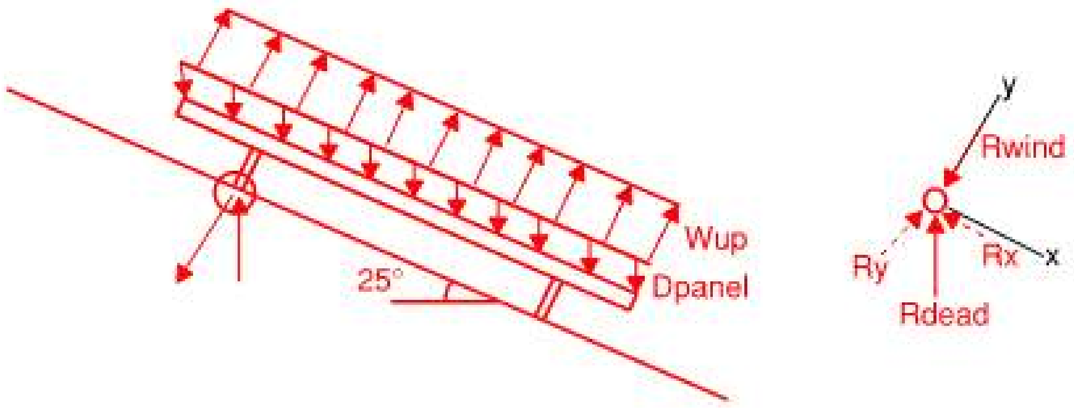
  Tension Capacity:

$$T_a = 245 \frac{lb}{screw} > R_{wind} = 207\ lbs\ \boldsymbol{OK}$$

  Shear Capacity:

$$V_a = 186 \frac{lb}{screw} \left(C_p = 0.82, F.S. = 3\right) > R_x = 12.7\ lbs\ \boldsymbol{OK}$$

$$\frac{R_x}{V_a} + \frac{R_w}{T_a} = 0.91\ \boldsymbol{OK}$$



1-#14 screws with 2in embedment required per leg base with legs spaced at 48in along rail

ROOFTOP AND ARRAY CONFIGURATIONS NOT IN CODE

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SLOPED ROOF AND TILTED PANEL

Calc and compare pressures from Rooftop Solar Panels on Flat Roofs and Rooftop Structures and Equipment for Buildings, use maximum.

- Flat Roof Wind Loads (ASCE 7-16 Chp 29.4.3)

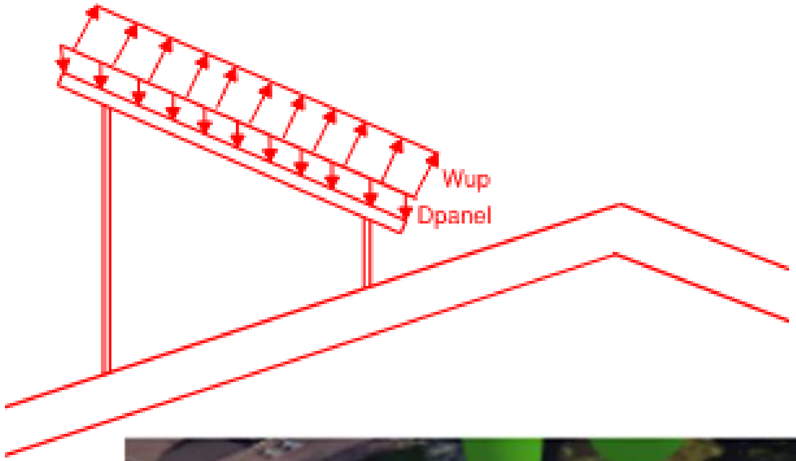
$First\ 3\ panels\ - p = \mathbf{63\ psf}$

$Remainder - p = \mathbf{42\ psf}$

- Rooftop Structures and Equipment for Buildings (ASCE 7-10 Chp 29.5.1)

$$Vertical\ uplift\ force\ F_v = 866\ lbs, \frac{866lbs}{A_p} = \mathbf{47psf}$$

Flat Roof Wind Load 63 psf governs for first 3 panels on each end, and Rooftop Structures and Equipment for Buildings, 47 psf, governs for the panels remaining.



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GROUND MOUNTED SOLAR ARRAY

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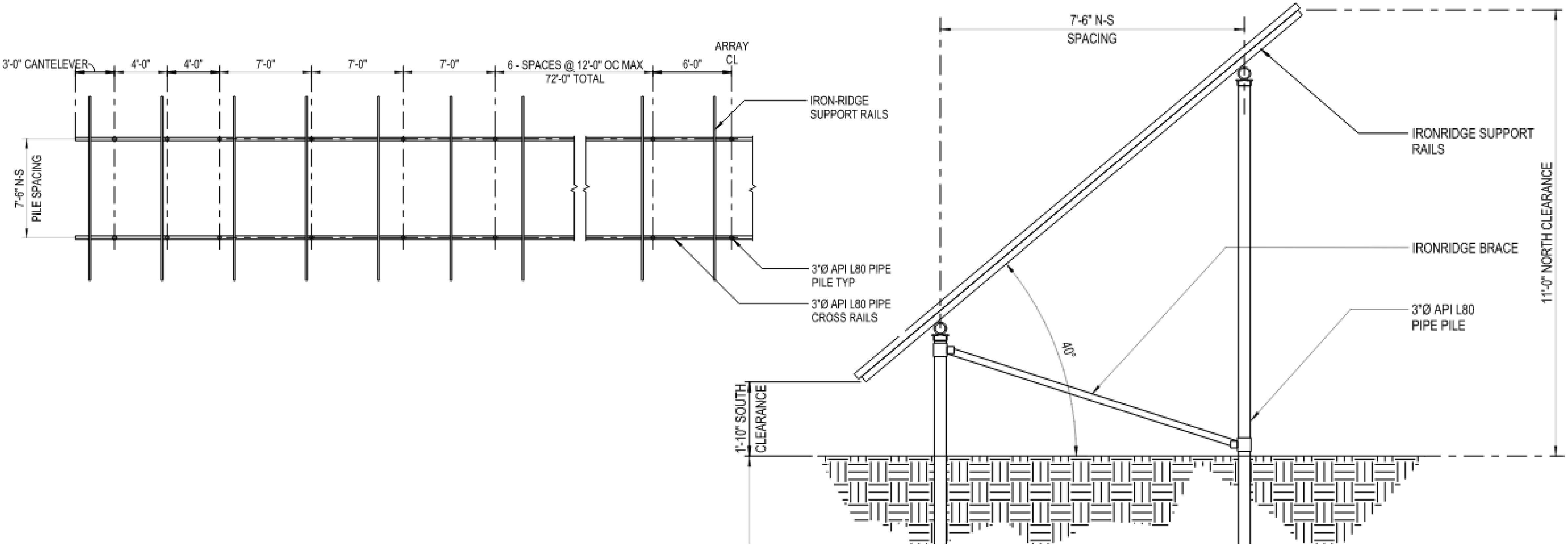
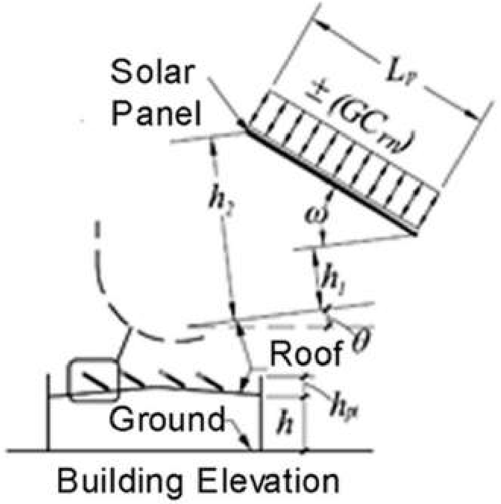
GROUND MOUNTED ARRAYS

- 140 ground mounted solar panels (220 ft total)



METHODS TO DETERMINE WIND PRESSURE

- Flat Roof (ASCE 7-16 Chp 29.4.3)
  - Act as large roof (i.e.1000' x 500')
  - $P = \mathbf{68\ psf}$



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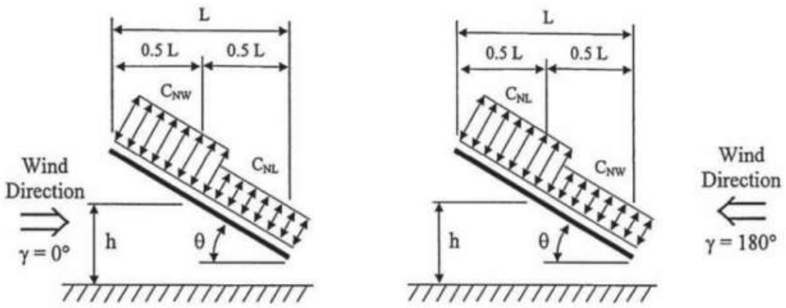
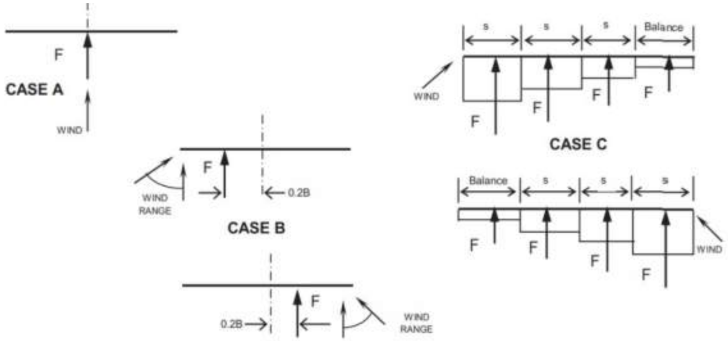
- Open Bldg. with Monoslope, Pitched, or Troughed Free Roofs (ASCE 7-16 Chp 27.3.2)
  - Case A: Cnw Cnl
    - $\gamma_{0°} = \mathbf{-50\ psf, -52\ psf}$
    - $\gamma_{180}° = \mathbf{61\ psf, 66\ psf}$
  - Case B: Cnw Cnl
    - $\gamma_{0°} = \mathbf{-68\ psf, -18psf}$
    - $\gamma_{180}° = \mathbf{76\ psf, 35\ psf}$



Copywrite ASCE 7-16 Figure 27.3-4

- Solid Freestanding Walls and Solid Signs (ASCE 7-16 Chp 29.3)
  - Case A:
    - $P = \mathbf{41.8\ psf}$ (45′and remainder to center)
  - Case C:
    - $0 - 9', p = \mathbf{118\ psf}$
    - $9' - 18', p = \mathbf{74\ psf}$
    - $18' - 27', p = \mathbf{57\ psf}$
    - $27' - 36', p = \mathbf{47\ psf}$
    - $36' - 45', p = \mathbf{44\ psf}$



Copywrite ASCE 7-16 Figure 29.3-1

THANK YOU!
QUESTIONS?