Bellevue-Santa Fe Charter School
Solar Panel Installation

Final Report

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Executive Summary

This project covers the design, manufacture, and installation of solar panel frames on a charter school in Avila Beach, CA. Through preliminary research regarding important factors (such as solar movement, ideal panel angle, and site-specific factors), a frame that meets the standards set forth in the California Building Codes was designed. After approval by presiding authorities, parts specified in the design were ordered, inspected upon arrival, and manufactured to the design as necessary. Much of the challenge was related to the installation aspect of the project—coordination with the proper authorities and correct submission of applications was integral to the success of the project. The final installation occurred in May 2014.
Chapter 1, Introduction

Background

For over 6 years Bellevue-Santa Fe Charter School (BSFCS) envisioned solar panels as part of its expansion plan. In 2013 Cal Poly’s IME Professor, Dr. Pan, decided to donate 11 PV solar panels to the elementary school. He recruited two Mechanical Engineering students, Dulce Arroyo Martinez and Moises Quiraz, a Manufacturing Engineering student, Tim Iafrate, as well as an Industrial Engineering student, Henrik Lee to design and install a frame system for the PV panels. BSFCS’s community members Judy Staley and Fred Sisson were also recruited to help the Cal Poly student team in designing of the PV frame system, as they both have extensive experience with solar panel installations.

Problem Statement

BSFCS, a charter school in Avila Beach, handles kindergarten through sixth grade; it plans to expand its facilities to incorporate up-to-date technologies and also hopes to increase its student population to include higher grade levels. Unfortunately, growth of this kind requires larger amount of electrical usage. Therefore, the administration at BSFCS found it advantageous to supplement their power consumption with an alternative energy source.

Objectives

The purpose of this project was to help the BSFCS reduce its electrical bill by installing 16 solar panels on the roof of one of the school buildings. The solar panels were capable of producing about 390 (open-circuit) DC volts.

Our objective was to design frames to hold 16 solar panels on the SciTechatorium’s (47.5 ft x 46 ft) roof without drilling any holes into the roof. Each frame was to be made to accommodate 2 panels. The approximated weight (dead load) for each frame was 111 lbs, approximately 55 lbs per panel. Furthermore, all measures needed to be taken to ensure the electrical circuit was free of electrical hazards and safe to operate. Finally, since the PV panels are located near the beach, corrosion was a concern. Selecting appropriate frame material was key for ensuring long product lifetime. All these specifications were developed from the customer requirements and their consideration was weighed in the QFD table (see Appendix A).
**Project Management**

Having four members in the team allowed us to have every member in our team work on different parts of the project. Dulce Arroyo Martinez and Moises Quiroz (both Mechanical Engineering students) partnered with Tim Iafrate (a Manufacturing Engineering student) to design a frame to hold the PV panels. Adding Tim to the design team ensured the final design was manufacturable. Furthermore, Dulce and Moises were mainly both responsible for executing the calculations necessary to ensure the frames could withstand all the pertinent loads and their associated safety factors, per the current relevant building codes. They also investigated/verified SnapNrack clamps had the necessary strength to hold the frame on the roof. After the design was final all the material needed for 8 frames, 2 panels per frame, were ordered and made available to Tim for machining and manufacturing, although everyone on the team helped and supported Tim in his manufacturing work. As the project progressed, Henrik (an Industrial Engineering student) worked on the pertinent applications and coordination of approval for the design.
Chapter 2, Background

Permits

Upgrades to new or existing structures typically involve city or country permits, in addition to other documentation and inspection required by PG&E. In this case, however, the related governing body was the Department of State Architecture (DSA), due to the fact that the installation site was a school. After looking into the permit requirements for DSA it was determined that this project was exempt, in accordance with IR A-10 section 1.1 (see Appendix B).

Having said that, the document also states that the project was still required to “comply with all currently effective design, construction, and inspection provisions of the California Code of Regulations, Title 24, as adopted by the Division of the State Architect. When authorizing construction of exempt projects described in this interpretation, the school district assumes responsibility to assure compliance with all code provisions.” Furthermore, section 4 of IR A-10 also states, “design professional in responsible charge” or “design professional” shall be the architect, structural engineer, or professional engineer (e.g. mechanical engineer for mechanical-only projects, electrical engineer for electrical-only projects), licensed to practice in California, who is responsible for the completion of the project design work.

Solar Movement

The orientation of photovoltaic modules with respect to the sun is important, as it has a significant effect on the power output provided by the solar panels. Solar panels provide the most power when the solar rays strike the panel at a right angle. Wes Weisenberger, founder of Central Coast Solar, claims that the output falls off with a cosine curve as the angle of incidence changes from a right angle.

Because the location of the sun in relation to the panels changes throughout the day and the path that the sun follows changes throughout the year, the optimum angles, which provide the highest solar radiation, also changes. In an ideal case, the modules would constantly track the sun as to continually orient themselves at a right angle to the sun. Figure 1 (a), as shown below, illustrates the annual and daily sun paths for a location in the northern hemisphere. Based on the figure, the sun is at a higher point in the sky during the summer than in the winter.

Therefore, for a fixed solar panel position to extract the maximum amount of solar radiation using the solar panels, the tilt angle of the panel should be smaller in the summer
than in the winter. Another important angle to consider when looking at solar movement and panel orientation is the azimuth angle. Azimuth is defined as the angle measured clockwise from North to the object of observation. In the case of the solar panel orientation this object of observation is simply the direction the panel is facing. The tilt angle is labeled as $\gamma_p$ in Figure 1 (b). Figure 1 (b) also illustrates the azimuth angle of a solar panel. Finally Figure 1 (c) shows how the solar rays are hitting the solar panel throughout the different times of the year for a fixed position.

![Figure 1(a)](image1.png)

![Figure 1(b)](image2.png)

![Figure 1(c)](image3.png)

**Figure 1: Solar movement throughout the year**

There are multiple solar panel setup techniques currently in use to track the sun, including: fixed position, one axis tracking systems, and two axis tracking systems. Single axis tracking systems rotate the azimuth angle of the panels and attempt to track the sun as it travels from East to West, while two axis-tracking systems track the sun about two axes. They alter the tilt angle and the azimuth angle in an attempt to garner the largest amount of radiation.

Hossein, Keyhani, Javadi, Mobli, Abrinia, and Sharifi, in their article “A review of principle and sun-tracking methods for maximizing solar systems output,” claim that the potential energy gain from a two axis tracking solar array can approach 57%. However their model neglects the effects of earth’s atmospheric interference. Later, the article claims, “In a generally good area, annual gains between 30 and 40% are typical. The gain in any given day may vary from almost zero to nearly 100%”
Additionally, George Helmholz’ article, “Should You Install a Solar Tracker?” presents that a two axis solar array tracking system. “Seasonally in California, gain ranges from 20 to 30 percent in winter (October through March) to between 40 and 55 percent in summer. In general, a tracker adds most to output during the hours when a stationary array produces the least power.” This information seems to be on par with the other sources.

The solar panel output calculator PVWATTS, produced by the National Renewable Energy Laboratory (NREL) is a highly sophisticated calculator that can provide accurate solar panel output estimations for many locations across the continental United States. According to NREL website, “The PVWatts calculator works by creating hour-by-hour performance simulations that provide estimated monthly and annual energy production in kilowatts and energy value. Users can select a location and choose to use default values or their own system parameters for size, electric cost, array type, tilt angle, and azimuth angle. In addition, the PVWatts calculator can provide hourly performance data for the selected location.

Using typical meteorological year weather data for the selected location, the PVWatts calculator determines the solar radiation incident of the PV array and the PV cell temperature for each hour of the year. The DC energy for each hour is calculated from the PV system DC rating and the incident solar radiation and then corrected for the PV cell temperature. The AC energy for each hour is calculated by multiplying the DC energy by the overall DC-to-AC derate factor and adjusting for inverter efficiency as a function of load. Hourly values of AC energy are then summed to calculate monthly and annual AC energy production.” (www.nrel.gov/rredc/pvwatts) The use of this calculator provided the data necessary to complete Figure 2, which are further discussed in the design development section of this report.

This graph (Figure 2) illustrates a comparison of multiple solar panel orientation techniques for the monthly solar output of a 2.5 kilowatt solar array located in Santa Maria, CA. The chart includes a single fixed position orientation in which the panels are oriented with a 180° azimuth angle and a 32° tilt angle. Also, it includes a twin tilt angle orientation where the tilt angle of the panels would be changed twice a year, once in April and once in October to 14° and 54° respectively. The chart also shows twelve tilt angle orientations, where the tilt angle of the panels would be changed 12 times a year. Finally the chart also shows the output of a one axis tracking system and a two axis solar tracking array.
Figure 2. Graphical representation of energy output during various months

The data gathered from NREL's PVWATTS, can be summarized in Table 1.

Table 1: Efficiencies reached by different sun exposures

<table>
<thead>
<tr>
<th>Results From PVWatts Version 1 Santa Maria CA</th>
<th>Solar Radiation Angle(s)</th>
<th>AC Energy Per Year (kWh)</th>
<th>Energy Value Per Year ($)</th>
<th>% Increase from 1 position</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Yearly average (kWh/m²/day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 position</td>
<td>32°</td>
<td>5.96</td>
<td>3936</td>
<td>$492.00</td>
</tr>
<tr>
<td>2 positions</td>
<td>14°, 54°</td>
<td>6.21</td>
<td>4120</td>
<td>$514.99</td>
</tr>
<tr>
<td>12 positions</td>
<td></td>
<td>6.28</td>
<td>4153</td>
<td>$519.99</td>
</tr>
<tr>
<td>1 Axis Tracking</td>
<td>32°</td>
<td>7.50</td>
<td>5016</td>
<td>$627.00</td>
</tr>
<tr>
<td>2 Axis tracking</td>
<td></td>
<td>7.91</td>
<td>5278</td>
<td>$659.75</td>
</tr>
</tbody>
</table>

This data is in accordance to the previously mentioned sources showed that a two axis tracking system can provide 34.1% increase in power output over a single fixed position orientation. The table also showed the savings of such a system, as compared to a fixed orientation, to be $3,355 (where this value is based on a 12.5 cent/kWh value over a 20 year period).
Roof Mounting Set-Up

Since the frame mounting location would be on the roof of one of the BVSFC school’s portable buildings, mainly the building named SciTechatorium, it was also important to consider the type of roof which will hold the solar panel and frame. Since the roof used in this project was a standing seam roof, there was no need to drill any holes on the roof. Instead, Fred Sisson, one of our PV frame design experts, recommended special standing seam roof clamps. In the past, Sisson collaborated in designing special clamps for standing seam roofs. Today, those clamps are being sold through a company called SnapNrack. SnapNrack has two main clamp designs, the wide base seam clamp and the standard base seam clamp (shown in Figures 3 (a) and (b), below). Considering the cross section of the standing seams on the SciTechatorium, the wide base seam clamp was the more appropriate clamp for this project.

Greg McPheeters, Senior Design Engineer at SnapNrack, was in charge of testing the clamps. In an email he stated, “We recommend that design loads on our seam clamps never exceed 200 lbs of uplift, and we only list roofs as compatible if they can demonstrate an 800 lb load capacity in testing.” Furthermore, the clamps are made of 6005 Series extruded aluminum and a stainless 5/16” bolt to secure the clamp. They have a 10 year material and workmanship warranty. An engineering drawing of both the wide and standard base seam clamp is included in the Appendix C for your reference.
Chapter 3, Design Development and Alternatives

Conceptual Design and Selection

Moving forward with the design, the team brainstormed ideas for a frame system to hold the panels in a fixed position, with the potential of an adjustable tilt angle. The final design concept was chosen based on the design requirements (identified in the QFD table found in Appendix A).

The team started the design development process by considering different types of solar panel frames. Having identified the different type of frames the team used the Pugh Matrix method to compare some of the potential frame solutions (see Figure 4 below). The way it works is by using a scoring matrix for concept selection, in which options are assigned scores relative to criteria. The scores include a plus, a minus, and an S. A plus means that the design concept in question is better than the datum. A minus means that it is worse than the datum. Finally, an S indicates that the design in question is the same as the datum for the specified criterion. Once all the designs are given their scores for the entire listed criterion the scores can be added based on the three different scoring possibilities.

![Figure 4: Pugh Matrix Method for concept selection](image_url)
The concept assessment scores were assigned in the following way: the investment required for a structure, whether it be triangular one or one that tracks the sun, is higher than the investment required for a flat frame. However, a flat frame would be more likely to accumulate water over its members, thus corroding faster than the triangular frame. A flat frame would have lower drag coefficient because the area against the wind would be at a minimum in this position; therefore, it would still have a lower live wind load. The more the panels would be exposed to the radiation of the sun, the more energy they would produce; therefore, a two-axis tracking system would produce more energy than any other frames, but a one-axis tracking system tended to be inherently more stability because frames would supported by not one, as in the case of a two axis tracking system, but two big poles that are encased in concrete and driven into the ground. Corrosion resistance was largely dependent on the material used for the frame, so it was assumed it was the same for all choices. Even though all frames would be easy to use and adjust, the flat frame and the fixed tilt angle frames were the best choices here because once they were installed there would be no need for them to be readjusted. All adjustable frames would be easy to fix because the user would just need to replace basic components, but to fix the tracking systems the user might need more expertise, since it may require replacing electronic devices, motors, sensors, etc. Also, the electronic parts of these systems were more expensive which brings the total cost up for this design. The two biggest players in this design are cost and efficiency. The most cost effective frame (flat) is the least efficient in the production of usable energy. The frame that provided the highest efficiency were the two-axis tracking system, but it they were also the most expensive and complex frame.

Before a final decision was reached further analysis was required to guarantee that our frame selection was the best possible choice, especially when using cost and efficiency as the two most important design criteria. From our discussion before, it was known that the design that would produce the most power is a two-axis tracking system. So, the question was, how cost affective would a two-axis system be? By revisiting Table 1, it can be observed that over the 20 year lifetime of the solar panel frames the savings by implementing two-axis system versus one fixed tilt angle was about $3,355. By researching it was discovered that manufacturer guarantee the tracking systems for approximately 10 years and that the cost of such a system was expensive, see Table 2 for examples of a few approximate costs for various two-axis tracking systems. Furthermore, not only would the cost of the system be expensive, but would also need to be replaced at least once during the 20 years life of the PV system.
Taking everything into consideration, the most cost effective solution would be the fixed position design, since the return on investment for the two-axis tracking is non-existent.

Having reached a decision on the design concept for the frame the team also considered how to test the design. The team recognized that, since the frames are mounted on the roof of the SciTechatorium, the most critical mechanical component of the frame system is the clamps. Therefore, a clamp validation test was performed (please see Chapter 6).

<table>
<thead>
<tr>
<th>Two axis Tracking costs</th>
<th>Qty Needed</th>
<th>Price</th>
<th>Total Price</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wattsun AZ-225 Dual Axis Active Solar PV Panel Tracker Mount to 225sqft</td>
<td>1</td>
<td>$6,895.00</td>
<td>$6,895.00</td>
<td><a href="http://thesolarstore.com">http://thesolarstore.com</a></td>
</tr>
<tr>
<td>Wattsun AZ-225 Dual Axis Tracker 225 sq-ft</td>
<td>1</td>
<td>$5,829.69</td>
<td>$5,829.69</td>
<td><a href="http://www.civicsolar.com">http://www.civicsolar.com</a></td>
</tr>
<tr>
<td>Zomeworks Universal Track Rack UTRF-120 120 sq-ft</td>
<td>2</td>
<td>$2,115.00</td>
<td>$4,230.00</td>
<td><a href="http://www.civicsolar.com">http://www.civicsolar.com</a></td>
</tr>
<tr>
<td>Zomeworks Universal Track Rack UTRF-072 72 sq-ft</td>
<td>4</td>
<td>$1,747.50</td>
<td>$6,990.00</td>
<td><a href="http://www.civicsolar.com">http://www.civicsolar.com</a></td>
</tr>
</tbody>
</table>
Chapter 4, Description of Final Design

Functional Description of Final Design

Optimum Angle

The optimum angle for maximizing the value of energy produced by the solar panels was determined to be 31°. This conclusion was reached using the PVWatts V1 analysis tool developed by the National Renewable Energy Laboratory. Since BSFCS falls under the A-1 Small General Service Electric Schedule it pays $.214 /kWh in the summer months and $.151 /kWh in the winter months. These two utility rates were taken and entered into the solar output calculator. After varying the panel angle from 0° to 54° it was determined that the maximum value of the energy produced for the location of the school occurs at 31° for an estimated value of $1180 per year (see Figure 5 below for a graphical depiction of the 31° conclusion). To achieve this 31° angle, the height of the bar across from the 31° angle needs to be approximately 29 inches long. Furthermore, the adjacent distance along the roof needs to be 48 inches.

![Panel angle vs. Value](image)

*Figure 5: Displays the value of energy output as the solar panel angle is varied*

The design features two cross bars to hold the panels in place. This arrangement makes the panels become the hypotenuse in the triangle model that was used in the static analysis of the frame. Additionally, the final design also features a 20 inch bar spanning two standing seams. This feature required 8 clamps for each frame, two for each leg. This design decision was made for two reasons. The first was to avoid being constrained by the 16 inch distance
between standing seams, while the second was to further reduce the amount of load carried by a single clamp. This second reason was especially important because the clamp feature is critical in the success of this design. Failure of the clamps could be life threatening. Please see Figures 6 (a) and 6 (b) for a 3-D view of the final frame design and Appendix D for final design engineering drawings.

(a)

(b)

*Figures 6: Isometric graphics of frame*
Series Connection Arrangement

A series connection arrangement is advantageous because of the lower current, when compared to a parallel connection. Lower current enables smaller diameter wires to be used. This is beneficial because smaller wires are more cost effective than their larger wire counterparts. Furthermore, the PV panels used in this project have extremely close current values. The series connection arrangement takes advantage of this by facilitating the addition of the DC-voltages from each individual panel.

PV Panel Distribution

The PV panels were positioned on the east side of the SciTechatorium for two reasons. First, we wanted to be as far as possible from the trees located on the South West corner of the building to minimize possible shadowing, since both trees are expected to continue growing during the frame’s design life of 20 years. Second, the east side of the SciTech is much closer to the electrical meter. The shorter the distance between the panels and the meter, the less wire needed to connect the two. This reduced not only the cost for the wire but also the power loss due to long range power transmission. Furthermore, less wire reduced the likelihood of injury or death due to electrical components.

Analysis of Design

Dimensions of Frame Members

Since our frame can be modeled as a triangle, we used trigonometry to find all dimensions needed. The adjacent distance was given by the geometry of the roof. Since the standing seams are separated by a distance of 16 inches the options were reduced to 64 or 48 inches. In the end 48 inches was chosen. The lengths of the other member were calculated using trigonometric relationships (see Appendix D).

Pressure on PV Panels and Force Due to Wind

Because the PV panels are located near the beach, they will frequently experience wind loads. Analysis was conducted to determine what pressure on the panels due to wind speeds as high as 85 mph, based on IR 16-7 (see Appendix E for IR 16-7 and Appendix D for the pressure calculation). The calculated pressure was then turned into a force and used in the static load calculations.

Frame Static Analysis

Static analysis was conducted on the frame to predict reactions at each member. The calculations were computed for the worst case where worst case scenario is when 85 mph winds are applying a force perpendicular to the pane (see Appendix D)
Cross Bars, Distributed Loading (Bending Moment and Shear Stresses)

The frame design used two cross bars to hold the dead load (Weight) of two panels; about 119 lbs. A distributed load across these bars was assumed and the analysis for this member was based on bending moment and shear stress calculations. Furthermore, the maximum bending moment, in addition to a safety factor of three, was used to ensure the member would not bend. Back of the envelope calculations showed the max shear stress, due to the bending moment, was much lower than the yield strength of the material (see Appendix D). By doing this check, the design ensured that the dimensions chosen for our bars are strong enough to hold the weight of the panels.

Opposite Bars, Axial Loaded, Short Columns Calculations for Buckling and Stability

Since the bar across from the 31° is loaded axially, it is treated as a column. Calculations were completed to determine whether the bars were long column, intermediate column, or short column (see Appendix D). Eventually the calculations determined the bar to be a short column and the Secant Column Formula was used to check for buckling (see Appendix D).

Shear Stress on Clamp (Bolt-Nut)

The clamp manufacturer has conducted several tests to rate their clamps, but because it is difficult to confirm these ratings through basic hand calculations, the clamps were tested. We were concerned about the clamps losing grip on the roof seams. Please see Chapter 5 for the basic testing approach that was taken to verify that the clamps will perform as expected. Also, please note that the clamps are made of aluminum and are, therefore, weaker than the bolt, which is made of Stainless Steel. So, the bolt could strip off threads from the clamp and cause the design to fail. Appendix D include calculations for possible shear of V-threads on the clamp nut.

Safety Considerations

As previously mentioned, the frames, especially the clamps, were designed to withstand 85 mph wind speeds. Therefore, the baseline for safety was that the frames do not leave the roof of the building at any point. The second-most pressing safety consideration was exposure of the wires to the environment or, worse, to the students of BSFCS. In addition to casing the wires to withstand the voltage and current running through them, the final implementation ensured that the wires were placed such that environmental factors and student access to high voltage/current wires were not a concern.
Material Selection

The solar frames need to have excellent corrosion resistance as they are going to be subject to a harsh coastal climate for an expected lifetime of 20+ years. In addition, the frames needed to remain as light as possible as they are going to be installed on a rooftop and any excess weight was not and will not be of benefit.

The majority of the frame was constructed using extruded 2in x 1in x .125in 6061 T6 aluminum tube. This material was selected for a number of reasons including the following:

- Excellent corrosion resistance
- Low density
- Good machinability
- High strength to weight ratio
- Low cost

The idea of using hot dipped galvanized steel tubes was heavily considered because of their inherent ability to resist corrosion. Ultimately the decision to avoid using this type of material was because of two reasons: the exposure of raw steel when cut and the increased cost. When galvanized steel is cut to length, the cut face is raw steel which is highly susceptible to rusting and one of the primary goals of the solar frame is to resist corrosion for the entire lifetime of the frames. Also, according to our research the cost of these hot dipped galvanized tubes was more than their aluminum counterparts.

All hardware was made of 18-8 Stainless Steel. 18-8 Stainless offers excellent corrosion resistance and minimum tensile strength of 70,000 psi. This is more than adequate for the loads developed by the solar panel frames under high wind conditions.

The brackets used in this design were machined from 6061 T6511 extruded aluminum to further take advantage of the 6061 alloy properties.
Maintenance and repair considerations

Ideally, there will be no need for maintenance or repair, mainly because the design was created in such a way that there would be no moving parts, instead the design is depending in proper material choose as well as proper assembly and installation. For maintenance considerations, the frames were spaced apart such that no pair of panels will interfere with the power generation of any other pair. This spacing doubles as maintenance spacing for any frame, should it prove necessary. Additionally, the design was comprised of easily accessible and inexpensive parts. Therefore, if parts need to be replaced, the exact same parts, instead of similar parts that had not been analyzed for the design, can be ordered. Appendix D contains a top-level assemble drawing with Bill of Materials (BOM) and Appendix F contains a list of parts, cost, and vendor information. Additionally, Appendix G contains a draft of the final systems single line diagram, provided by Charlie Joy of REC Solar. Also, SnapNrack clamps are rated to last for at least 10 years, so detailed inspections are required after to guarantee the full functionality; otherwise they need to be replaced.

Please note: the final single line diagram by asking the county for a copy of the approved permit for this project.
Chapter 5, Product Realization

Manufacturing of the brackets

After the raw materials for the brackets arrived from Onlinemetals.com they were cut to length on the KAMA Horizontal Band saw. Figure 7, shown below, illustrates the cutting of the raw materials. A material stop was used to ensure that each cut provided a work piece of equal length. The cut pieces were inspected using a pair of digital calipers as they came off the band saw and any deviation over 0.010 in. from the target called for adjustment of the material stop.

Figure 7: Cutting raw stock on horizontal Band saw
After cutting to finished length the pieces of 6061-T6 aluminum were de-burred on a small belt sander. Figure 8 which is shown below, demonstrates the de-burring setup.

![Figure 8: De-burring.](image)

This de-burring method provided a significant time savings in comparison to hand tools. When there are over 64 brackets to make, a savings of two minutes per part adds up quickly!

Note: It took a few iterations before the final design for each type of bracket was finished. Many of the iterations included design changes that attempted to improve the manufacturability of the parts. Ultimately, only one design change made it to the final design. This design change pertained to replacing the 3/16 radius with a chamfer. The geometry of the new roughing tool (provided by Ladd Caine) created a 0.04 in chamfer (see Figure 9).
The addition of this new cutter was also paramount to the drastic increase in machining speed. The previous tool paths which used a 1 in 3-flute carbide insert end mill, a very respectable cutter, followed a 0.100 in step depth, 1.000 step over, at 140 inches per minute feed rate. These feeds were developed from numerous test cuts in scrap material. The limiting factor for this cutter is the step depth of 0.100. Any amount deeper during at full width cut, and the tool begins to chatter.

The original cutter produced a material removal rate of:

\[ MMR = 0.100 \text{ in} \times 1.000 \text{ in} \times 140 \frac{\text{in}}{\text{min}} = 14 \frac{\text{in}^3}{\text{min}} \]

The new Hanita roughing end mill was able remove material at a much faster rate. After performing numerous test cuts, it was determined that a step depth of 0.500, full 1 in slot at 60 IPM resulted in very smooth cutting and 100% spindle load on the Haas VF2 CNC. These were the final numbers used in the Creo CAM tool path design.
The Hanita roughing end mill material removal rate:

\[ MMR = 0.500 \text{ in} \times 1.000 \text{ in} \times 60 \frac{\text{in}}{\text{min}} \]

\[ = 30 \frac{\text{in}^3}{\text{min}} \]

This is over double the material removal rate!

With the addition of the new roughing end mill the total machining time for each of the 64 brackets was reduced from approximately 14 minutes down to 5.

After all the 6061-T6 aluminum pieces had been cut to size and de-burred they were ready to be CNC machined. The CNC machine code was developed using the CAM portion of Creo Parametric 2.0. Please see Appendix H for the machine codes.

Each bracket was manufactured using two operations. In the first operation for the horizontal bracket, see Figure 10, the part of the top section was roughed out and down .500 in to make to reduce the length the drill had to bore because the jobber length U drill used was not long enough to drill the entire length. With this section roughed out. The hole was center drilled using a #3 center drill at a depth of 0.125 in. After the center drilling the hole was drilled using a peck depth of 0.1, feed rate of 30 ipm, retract plane of 0.25, and approximately 300 surface feet per minute cutting speed. The drill was retracted fully after each peck to clear the chips. When the machine was set to 100% rapid these retract moves did not add a significant amount of time and all holes will drilled perfectly.

![Image](image162x110.png)

*Figure 10: Tool path simulation for operation 010 of the horizontal bracket.*
The second operation for the horizontal bracket, Figure 11, started with a roughing operation using the Hanita 1 inch 3 flute roughing end mill at .400 depth, full 1 inch slot, 1500 sfm, at 90 inches per minute feed rate. Flood coolant was essential to keep the cutting edge of the tool cool during this heavy roughing sequence. The parts were not finished machined due to the excessive amount of time that this would require and the lack of a need for a perfect surface finish. The finish provided by the roughing end mill was sufficient enough. The next step was to drill the two mounting holes. The same jobber length U drill was used for this with the same parameters as before only that the pecking cycle was eliminated and the holes drilled straight through at 25 inches per minute.

The final step in the horizontal bracket was the chamfering of the top edges. A 0.500 diameter 45° chamfer tool was used for this at 25 inches per minute. This chamfer tool provided an excellent looking chamfer.

The first operation for the U Bracket included three steps: Facing, center drilling, and drilling. The tool path can be seen in Figure 12 below.
The facing operation utilized a 4 inch 6 tooth carbide face mill. The mill was run a 1500 sfm, 45 inches per minute, full 2 inch width, at 0.300 step depth. After face milling the top of the block off, the thru hole was center drilled and then fully drilled using the same parameters as the horizontal bracket.

The second operation of the U bracket, shown in Figure 13, included the following steps: roughing, drilling, chamfering, rounding. The roughing operation used the same tool and parameters as the other brackets as these seemed to offer excellent material removal rates while not sacrificing tool life and over working the machine. The spindle loads did not exceed 90% on the HAAS VF3. After the roughing operation, the mounting holes were drilled using the same parameters as the horizontal and solid brackets. After the holes were drilled, the top edges were given a 0.040 45° chamfer using the same chamfer tool. After this, four of the corners were rounded off using 0.375 radius rounding cutter. The rounding feature was created using many test cuts on scrap material with the rounding cutter in order to get the radius to blend in with the walls of the part. After the test cuts the exact movement of the cutter was recorded and used to create a trajectory path for the tool to follow in the CAD/CAM software package, Creo Parametric 2.0.

![Figure: 13 Tool path simulation for operation 020 of the U bracket.](image)

The solid base was manufactured nearly identically to the horizontal bracket. The tool path of the first operation is shown in Figure 14 below. The only difference between the two parts was that the solid base did not require the initial roughing sequence in order to create room for the drill because the drill had enough length.
The second operation, Figure 15, used a roughing, chamfering, and drilling sequence using the same parameters and tools as the other brackets and the tool path for this operation is shown below.

The mid clamp used a different cutter than the rest of the brackets for the roughing operation because the Hanita roughing end mill which had previously been lent to the project had already been returned. The first operation faced the top of the work piece, center drilled and then drilled the center hole, and finally put a 0.040 45° chamfer on the edges. The tool path for the first operation is shown in Figure 16 below.
The part was then flipped over for the second operation. The edges were roughed out using a three flute TiN coated carbide insert cutter using: 1500 sfm, and a federate of 90 ipm. Following the roughing, the part was finished using a 0.625 2 flute HSS flat end mill to ensure accurate finished part sized. After finishing, a chamfer was added to the sharp corners using the same tool and parameters as with the other parts.

Additional, the following Figures, 17-19 shows the a work piece in the middle of a machining process, the CNC machine executing the machining, and the bucket of waste material.
Despite this massive amount of material removal much of which was removed using the 1 inch roughing end mill, the tools showed almost no wear and the final parts came out.
with similar dimensions to the initial parts. This provides even further proof that the speeds and feeds used were proper.

The other components of the frame were made from 6061–T6 Aluminum tubing. The top and bottom support rails and frame feet were made from 1 in. x 2 in. x .125 in. tubing. The frame leg supports were built using 1.75 in x .125 in. square tubing. These pieces were cut to length on the same KAMA horizontal band saw that was used to cut the pieces of bar stock for the brackets. All of the tubing components of the frame were designed to be as simple to manufacture as possible, only requiring an initial cut and the drilling of a few holes. Because of the short length (20 in.) of the feet for the frame, the holes were able to be drilled on the HAAS CNC. The remainder of the tubing components required the location of the holes to be scribed and center punched before drilling the holes on a drill press. To aid in this process, a custom jig was manufactured to quickly and accurately locate the center punch to ensure that the spacing of certain holes was carefully controlled. This jig is shown in Figures 20 and 21.

![Figure 20: Custom center punch jig](image-url)
Figure 21: Custom center punch jig

Figure 22: Some of the tools used in the CNC machining
The manufacturing time can be estimated with the following table.

**Table 3: Estimated Machining Time**

<table>
<thead>
<tr>
<th>Part Names</th>
<th>Bandsaw</th>
<th>Machining</th>
<th>Setup</th>
<th>Deburring</th>
<th>Number of parts</th>
<th>Minutes</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brackets</td>
<td>2.5</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>64</td>
<td>928</td>
<td>15.5</td>
</tr>
<tr>
<td>Mid clamps</td>
<td>1.5</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>18</td>
<td>135</td>
<td>2.3</td>
</tr>
<tr>
<td>Leg Supports</td>
<td>1.5</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>16</td>
<td>168</td>
<td>2.8</td>
</tr>
<tr>
<td>Feet</td>
<td>1.5</td>
<td>2</td>
<td>2.5</td>
<td>2</td>
<td>32</td>
<td>256</td>
<td>4.3</td>
</tr>
<tr>
<td>Rails</td>
<td>1.5</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>18</td>
<td>225</td>
<td>3.8</td>
</tr>
<tr>
<td>Modify SnapNrack</td>
<td>0</td>
<td>0.75</td>
<td>1.5</td>
<td>0</td>
<td>64</td>
<td>144</td>
<td>2.4</td>
</tr>
<tr>
<td>clamps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center punch jig</td>
<td>5</td>
<td>60</td>
<td>30</td>
<td>5</td>
<td>1</td>
<td>100</td>
<td>1.7</td>
</tr>
<tr>
<td>CAD/CAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>45.0</td>
<td></td>
</tr>
<tr>
<td><strong>Total (hours)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>77.6</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Machining constraints**

This senior project ran into a major constraint with the limited availability of CNC equipment in the MFGE advanced manufacturing lab. Industrial manufacturing engineering (IME) students working on projects, either for their IME senior projects or for other IME classes, needed the machines to work on their projects. Because IME students in manufacturing classes have priority to use the CNC machines, the manufacturing of the frames was seriously impacted; ultimately, different machines had to be sought out and used. After working with different individuals from both IME and ME departments including IME dept. chair, Jose Macedo, IME lab technician Ladd Caine, Mustang ’60 supervisor Eric Pulse and student CNC tech Will Hilgengerg, a special access to the HAAS VF-3 Machine in the Mustang ’60 machine shop was granted. This is the machine that was used to machine the vast majority of the brackets.

Note: For the consideration of future senior project teams the team would like to suggest a solution to the previously described problem. As it stands now, most engineering students use the machines in the Aero hangar and Mustang ‘60 machine shop for all project work. IME students, however, typically use the manufacturing shops in Cal Poly’s building 41 for projects. Furthermore, non-IME engineering students are advised to, and in some cases required to, go through the introduction and safety tests required to gain access to the shops. No such requirement, or suggestion, is established for IME students. Therefore, the team suggests IME instructors start to require, or incentivize, their students to take the yellow tag test required by the shops. Or a special agreement between departments that would require a practical exam could allow students to use certain machines in all labs.
Chapter 6, Design Verification Plan (Testing)

The Department of State Architecture provides guidelines (see IR 16-8 in Appendix E) for testing of standing seam roofs. It requires two separate tests to be conducted, one that tests the capabilities of the clamps and another that confirms the strength of the roof. Since Bellevue ultimately falls under DSA’s jurisdictions the test plans the team developed were intended to comply with the guidelines for both of these test. Furthermore, the team worked with the Structural Engineer to ensure there would be no expected damage to the roof as a result of testing.

Note: Testing on the roof was unavoidable since the team was unable to find the necessary materials that allows for an accurate model of the roof to be created.

Testing of clamps

After the first test plan was completed and approved by the Structural Engineer, mainly the one concerning capabilities of the clamps, the team took the test plan, the test rig, and a video camera to the project location and tested the roof, as outlined in Appendix I. For the videos of the testing procedure in action using the following links:

Run #1: https://www.youtube.com/watch?v=wPzsCPspGY
Run #2: https://www.youtube.com/watch?v=IFPm1-G2748

The testing rig was created from 2 2x6 boards to prevent the rig from absorbing any of the forces through deformation. This rig was 4 feet long, the fulcrum 10 inches from the side nearest the seam. The loading point was 32 inches from the fulcrum, four times the distance from the chain attached to the clamp. The net weight of the rig on the longer end provided 28.1 lbf upwards on the clamp. The clamp was attached to the roof at a point where one of the clamps for the actual frame was going to be installed. The weights were added to the side opposite the clamp in 15-lb increments, up to 105 lbs; the declination angle from the horizontal position was then recorded using an iPhone application calibrated to zero degrees at the starting horizontal unloaded rig position.

As can be seen below in Figure 23, the first run of this test successfully reached 105 lbs (approximately 450 lbf vertical on the clamp).
The second run followed the same procedure. The testing rig was moved about 4 ft from the previous tested point. This distance represented the space between the panels as it was proposed on the roof’s layout drawing. The second test was not completed successfully because after adding the last weight (105 lbs total), the roof unexpectedly “jump” causing a drastic declination angle on the rig. Below is a table containing the test results from the second test.

Table 4: Clamp’s Performance Data for the Second Run.

<table>
<thead>
<tr>
<th>Weight (lb)</th>
<th>Angle of deformation (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.8</td>
</tr>
<tr>
<td>30</td>
<td>1.4</td>
</tr>
<tr>
<td>45</td>
<td>1.9</td>
</tr>
<tr>
<td>60</td>
<td>2.5</td>
</tr>
<tr>
<td>75</td>
<td>3.2</td>
</tr>
<tr>
<td>90</td>
<td>3.8</td>
</tr>
<tr>
<td>105</td>
<td>Unexpected roof &quot;jump&quot;</td>
</tr>
</tbody>
</table>
All clamp testing was concluded after the “jump.” The team was concerned it might have caused damage to the roof and advised the school to have that area inspected. However, despite that “jump,” the test had definite results with respect to the clamps capabilities. The clamps never slipped or seemed to move. Therefore, they showed to be more than capable of holding the load required by this design.

**Testing plan for roof**

This test plan was very similar to the testing plan for the clamp. The difference lied in the fact that the rig can no longer be resting on the same roof pan as the seam being tested. Therefore, the testing rig in this case must be designed similar to the one used in Figure 25.

The testing plan can be seen in Appendix J. However, the plan was not because it was never approved by the Structural Engineer.
Chapter 7, Installation

Complying with permit requirements

The team worked with Rick Manderscheid and Anthony Palazzo, Maintenance Supervisor and Director of Building, Planning and Transportation (respectively) for San Luis Coastal Unified School District (SLCUSD) to ensure the project complied with the school districts policies. Furthermore, a certified Structural Engineer, Mr. James Adrian Adams from Solar Roof Check, was hired by the project sponsor to complete all the structural calculations required for the county permits. All the electrical work, for the county permit and PG&E application, was completed by Charlie Joy. Mr. Joy is a Professional Engineer whose job functions included creating an electrical single line diagrams and other electrical work related to solar panel installations. Please see Appendix G for a draft of the final single line diagram. The final single line diagram can be accessed by requesting a copy from the county.

Permit approval and installation

SLCUSD granted approval for the project with the submittal of the county building permit application. Once Mr. Adams completed the structural analysis (see Appendix K) and corroborated that the building was strong enough to withstand design forces produce by winds up to 110 MPH, the application for the permit to the San Luis Obispo County were submitted. On May 21, 2014 the SLO County granted the permit to install 16 solar panels on the roof of SciTechatorium building.

Having obtained the county permit the project was able to move to the next phase, installation. The installation process consisted of two steps: first installation of the mechanical system and second the wiring of the electrical components. The first step took place on May 23. The team started to put some of the parts together in the IME Lab. After working for few hours, the group was able to finish attaching all the brackets to the main bars. The panels were transported the same day to the school, so that the next step, that the second step could take place on the morning of next day. On Saturday May 24, the team met at the Bellevue-Santa-Fe school to start the installation. It was after 7 hours of intense work and with the help of some parents that the team was able to install all the panels, see Figure 29 for snapshots of the installation.
As of project completion date, May 24, 2014, the electrical installation had yet to be completed.

Figure 26: View of the SciTechatorium’s roof after installation was completed
Chapter 8, Conclusion, Recommendations, and Acknowledgments

Conclusion

Given the potential liabilities of this project, the purchasing of parts and materials required for the frames depended on:

- Certified engineering approval/completion of all design drawings and structural calculations (as specified by IR A-10)
- Approval from SLCUSD to move forward with the project
- Approval of PG&E permit as well as electrical components

After the necessary permits and applications had been obtained and filed Dr. Pan submitted purchase orders based on a complete Bill of Materials, part cost, and vendor information (please see Appendix F for a list of part cost and vendor information). Mechanical Installation was completed on May 24th, 2014 and Electrical work was completed before the end of May, 2014.

The team successfully went through all the steps required by the Cal Poly’s mechanical engineering department upon completion of the senior design project. The team designed, analyzed, built, test and ultimately installed 8 frames at the Bellevue-Santa-Fe school. These frames are holding 16 panels that will reduce the high electrical bill produced by the school monthly energy consumption.

Recommendations

Although the project team faced many obstacles and was able to persevere, ultimately finding the resources needed to be able to install all the mechanical components on the project site (as desired by the project sponsor), not all components required by the governing body, DSA, were met. Therefore, it is especially important to highlight one of those challenges, specifically the second test phase called out by IR 16-8 section 2.3.3 (b) (See Appendix E for a copy of IR 16-8). This test is of particular interest because it is needed to verify the roof can hold the load being exerted on it by the panels and the frame. If DSA were ever to inspect the project site and request documentation pertaining to the completion of this test, no such documentation could be provided. At a minimum, this would result in the school being fined. Therefore, it would be prudent to perform this test at the earliest convenience and record the results to more accurately gauge the structural integrity of the roof.
Also, please note Appendix L. It provides a detailed description of many of the challenges faced by the team throughout the project process.

**Acknowledgements**

The team would like to thank the following for their support throughout this project:


There are many other individuals not named here who, in either aiding us in one way or another with the approval processes or helping in the manual labor of mechanical and/or electrical installation, pushed this project to fruition. Their efforts are likewise appreciated.
References


"Series 500 Standing Seam System."


Appendix A: QFD Table
Pg. 43-44
The shown below was used to transform customer requirements into engineering requirements. They were both weighed using a zero to nine scales. The numbers indicate how important the engineering requirements are with respect to each customer requirement. A larger the number indicates a more important engineering requirement.

*Table 1C: Quality Function Deployment (QFD)*

<table>
<thead>
<tr>
<th>Customer Requirements (Whats)</th>
<th>Weighting (1 to 5)</th>
<th>Engineering Requirements (HOWS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Holds panel weight (25 kg)</td>
</tr>
<tr>
<td>Sturdy</td>
<td>5</td>
<td>Pass inspections</td>
</tr>
<tr>
<td>Safe for people</td>
<td>5</td>
<td>Life ≥20 years</td>
</tr>
<tr>
<td>Electrically hazard free</td>
<td>5</td>
<td>Non-corrosive material</td>
</tr>
<tr>
<td>Life ≥20 years</td>
<td>4</td>
<td>Fixed position</td>
</tr>
<tr>
<td>Non-corrosive</td>
<td>4</td>
<td>Uses ≤80% off the shelf parts</td>
</tr>
<tr>
<td>Independent system</td>
<td>5</td>
<td>Does not permeate roof</td>
</tr>
<tr>
<td>No damage to roof</td>
<td>5</td>
<td>Ideal angle for max energy payoff</td>
</tr>
<tr>
<td>Max power payoff</td>
<td>5</td>
<td>Uses minimal wire</td>
</tr>
<tr>
<td>Low maintenance</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Importance Scoring</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Importance Rating (%)</td>
<td>44</td>
<td>88</td>
</tr>
</tbody>
</table>


Appendix B: IR A-10
Pg. 45-47
ALTERATION AND RECONSTRUCTION PROJECTS – DSA APPROVAL EXEMPTION

References: California Code of Regulations (CCR) Title 24
Part 1: California Administrative Code
Sections 4-306, 4-308, 4-309, 4-315, 4-336 & 5-102
California Education Code, Sections 17295 and 81133

Disciplines: Structural
Fire and Life Safety Revised 05-16-13 Revised 11-03-10 Revised 03-17-08
Access Compliance Revised 02-22-13 Revised 07-02-09 Revised 05-29-07
Revised 01-24-12 Revised 12-08-08 Issued 11-16-05
Revised 03-10-11

This Interpretation of Regulations (IR) is intended for use by the Division of the State Architect (DSA) staff, and as a resource for design professionals, to promote more uniform statewide criteria for plan review and construction inspection of projects within the jurisdiction of DSA which includes State of California public elementary and secondary schools (grades K-12 and community colleges), and state-owned or state-leased essential services buildings. This IR indicates an acceptable method for achieving compliance with applicable codes and regulations, although other methods proposed by design professionals may be considered by DSA.

This IR is reviewed on a regular basis and is subject to revision at any time. Please check the DSA web site for currently effective IRs. Only IRs listed in the document at http://www.dgs.ca.gov/dsa/Resources/IRManual.aspx at the time of plan submittal to DSA are considered applicable.

Purpose: The purpose of this Interpretation of Regulations (IR) is to clarify when plans and specifications for alteration or reconstruction projects governed by the California Education Code, Sections 17280-17317, 17365-17374, and 81130-81149, collectively known as the “Field Act,” are required to be submitted to the Division of the State Architect (DSA) for review and approval. Construction projects governed by the Field Act include construction projects at public elementary schools, public secondary schools, and public community colleges.

Per California Education Code, Sections 17295 and 81133, all alteration and reconstruction projects governed by the Field Act shall be submitted to the DSA.

1. Exceptions:

1.1 DSA review and approval is not required for alteration or reconstruction projects to school buildings governed by the Field Act with an estimated construction cost of $39,324.38, or less, for 2013.

1.2 DSA review and approval is not required for alteration or reconstruction projects to school buildings governed by the Field Act with an estimated construction cost greater than $39,324.38, but not in excess of $157,297.53 for 2013, when all of the following conditions are met:

1.2.1 A California registered structural engineer shall examine the project and prepare a written statement certifying that the project does not contain any work of a structural nature. The statement must attest that the work does not cause any alteration or reconstruction of structural elements nor trigger structural rehabilitation per Title 24, Part 1, Section 4-309 (c). This statement shall bear the signature and stamp or seal of the structural engineer and shall be filed with the appropriate DSA Regional Office.

1.2.2 The design professional in responsible charge of the project shall prepare a statement certifying that the plans and specifications (1) contain no work that is regulated by the accessibility standards of Title 24, (2) contain no work that triggers accessibility upgrades to existing buildings or facilities, and (3) meet any applicable fire and life safety standards. This statement shall bear the signature and stamp or seal of the design professional and shall be filed with the appropriate DSA Regional Office.
1.2.3 Within 10 days of the project completion, a DSA-certified project inspector shall sign and submit a verified report to DSA, indicating the completed project is in conformance with the plans and specifications. Form DSA-999 "Inspection Verified Report for Projects Exempt from DSA Approval" is available from the DSA web site at http://www.dgs.ca.gov/dsa/Forms.aspx.

2. Voluntary Submittal: This interpretation does not preclude a design professional or school district from choosing to submit plans and specifications, with the appropriate fee to the DSA for review, even when the project is exempted from DSA plan review requirements as outlined herein.

3. Requirement to Comply: Projects not requiring DSA approval (i.e. exempt projects) shall comply with all currently effective design, construction, and inspection provisions of the California Code of Regulations, Title 24, as adopted by the Division of the State Architect. When authorizing construction of exempt projects described in this interpretation, the school district assumes responsibility to assure compliance with all code provisions.

4. Definition: For this interpretation, “design professional in responsible charge” or “design professional” shall be the architect, structural engineer, or professional engineer (e.g. mechanical engineer for mechanical-only projects, electrical engineer for electrical-only projects), licensed to practice in California, who is responsible for the completion of the project design work.

5. Annual Adjustment of Cost Thresholds: Construction cost thresholds cited in this interpretation are based on January, 1999 figures of $25,000 and $100,000 and are adjusted annually per the California Education Code. Annual adjustments are calculated using the first January issue of Engineering News-Record’s U.S. 20 City Construction Cost Index.

6. Project Cost Determination: For purposes of this Interpretation, the estimated construction cost shall be determined at the completion of project design. Effective July 1, 2013, for the purpose of determining estimated project cost, the scope of the project shall be limited to construction on one site only.

In accordance with Education Code Section 17280, the estimated construction cost used in determining exemption from DSA review shall not include the cost of air-conditioning equipment¹ and insulation materials², and installation cost of such equipment and materials, when such installation does not cause structural alterations³ to a school building (i.e. affects primary or secondary framing members). In cases where such installation causes structural alterations to a school building, the provisions of Title 24, Part 1, Section 4-309 will apply and the project may require DSA review and approval.

¹ For purposes of this provision, air conditioning (AC) equipment includes heating, ventilation and air conditioning (HVAC), AC units, heating units, or ventilation units, and does not include ductwork or utility services (i.e. electrical and/or gas service) to the equipment.

² For purposes of this provision, insulation materials must be of the same type as previously installed in accordance with building standards.

³ For purposes of this provision, the exclusion of HVAC related cost is valid only when a determination of no structural alteration is made by a California registered structural engineer in accordance with requirements of Section 1.2.1 of this IR.

7. Subdivision of Projects Prohibited: Construction projects shall not be subdivided for the purpose of obtaining exemption from DSA review and approval.
Appendix C: SnapNrack Clamp Drawing
Pg. 48-49
6005-T5 Aluminum

Top Surface of Both Clamp Styles is 1.75" x 1.75"
Appendix D: Design Calculations and Design Drawings

Pg. 50-76
BSFCS Frame Design Drawings and Calculations

Provided by: Cal Poly senior engineering students

Approved by: James A. Adams, SE

6/4/2014
<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>QTY.</th>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>Material</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>001</td>
<td>Cross Bar</td>
<td>6061-T6 (SS)</td>
<td>5.46</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>006</td>
<td>Axial Loaded Bar</td>
<td>6061-T6 (SS)</td>
<td>2.29</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>005</td>
<td>U Base bracket to hold the Solid Base</td>
<td>6061-T6 (SS)</td>
<td>0.63</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>004</td>
<td>U Base bracket to hold the stoper</td>
<td>6061-T6 (SS)</td>
<td>0.59</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>003</td>
<td>Solid Based Stoper</td>
<td>6061-T6 (SS)</td>
<td>0.87</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>002</td>
<td>Bottom Rail</td>
<td>6061-T6 (SS)</td>
<td>1.33</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>007</td>
<td>Holds down panels at the middle</td>
<td>1060 Alloy</td>
<td>0.132</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>Unirac SolarMount-I End Clamp E</td>
<td>Holds down panels at each corner</td>
<td>1060 Alloy</td>
<td>0.046</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>Solar Panel</td>
<td>Solar panel</td>
<td>Silicon</td>
<td>63.028</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>SnapNrack Assembly Clamp</td>
<td>1065 Aluminum</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>HBOLT 0.3125-24x3.5x0.875-S</td>
<td>Stainless Steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>20</td>
<td>HBOLT 0.3125-24x2x0.875-S</td>
<td>Stainless Steel</td>
<td></td>
<td></td>
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<tr>
<td>13</td>
<td>4</td>
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<td>Stainless Steel</td>
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<td></td>
</tr>
<tr>
<td>14</td>
<td>28</td>
<td>HNUT 0.3125-24-D-N</td>
<td>Stainless Steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>36</td>
<td>Preferred Narrow FW 0.3125</td>
<td>Stainless Steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>2</td>
<td>HBOLT 0.3125-18x4.5x0.875-S</td>
<td>Stainless Steel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Note
All chamfer on top face are .04
Note
All chamfer on top face are .04

2X φ .368

.50 3.55

.995 .40 1.76 4.55

2X1.00

1.60

.40

.60 2.00

1.00

2.00
Note
All chamfer on top face are .05
Note
All chamfers are .04, 45°
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SPACING BETWEEN PANELS

Panel Length = 78 in
θ = 31° optimum angle (year-round)

\[ \tan \theta = \frac{Y}{X} \]
\[ Y = \tan(31°)(48) = 29 \text{ in} \]
\[ \sin \theta = \frac{Y}{h} \]
\[ h = \frac{29}{\sin(31°)} = 56 \text{ in} \]

SPACING ON THE ROOF

Distance between the panels should be 48 inches.

This distance separates the panels so that the first row does not block second row, and so forth...

Tree

48 in

47.5 ft

46 ft

46 ft

39 ft

30 ft

30 ft

2 ft

5 ft

8 ft

Usable Space
Known:

\[ V = 110 \text{ mph} \]
\[ b = 3.261 \text{ ft} \]
\[ h = 6.519 \text{ ft} \]

Elementary School  \[ C_d = 2 \]

Find: Pressure created by wind on PV panels and the force created by wind

Solve:

\[ P_{net} = g \beta k_t C_{net} [I \eta] 0.6 \]

where:

\[ g = 31.0 \frac{\text{ft-lb}}{\text{sec}^2} \]

\[ k_t = 2.01 \left( \frac{15}{2g} \right) \text{ when } z \geq 15 \text{ and } \beta = 900, \text{ and } \eta = 7 \]

From ASCE Table 6-2

\[ k_t = 0.85 \]

\[ C_{net} = 1.0 \text{ from Table 2 of IR-16-2} \]

\[ I = 1.15 \text{ from ASCE Table 6-1} \]

\[ \eta = 1.0 \text{ from ASCE section 6.5.2.2} \]

\[ P = (31.0 \frac{\text{ft-lb}}{\text{sec}^2}) (0.85) (1) (1.15) (1) (0.6) \]

\[ P = 18.2 \frac{\text{ft-lb}}{\text{sec}^2} \]

\[ F_{w, a} = \frac{A P C_{d}}{\eta} \]

\[ A = (6.519 \text{ ft}) (3.261 \text{ ft}) y^2 \]

\[ (18.2) (0.6) \]

\[ = 15.46 \text{ lb} \]
Known: \( P_{net} = 18.06 \text{ lb/ft}^2 \)

\( h = 19.87 \text{ mm} = 6.519 \text{ ft} \)

\( b = 9.94 \text{ mm} = 3.261 \text{ ft} \)

\( W = 40 \text{ lb/panel} \)

\( F_w = 1.66 \) \( (F_{net}) = 25.65 \)

Find: Reaction on Frame due to two solar panels.

Solve:

\[ F_{w} \]

\[ \begin{array}{c}
\theta = \tan^{-1} \left( \frac{29/12}{h} \right) = 31^\circ \\
\end{array} \]

\( \theta = \tan^{-1} \left( \frac{29/12}{h} \right) = 31^\circ \)

\[ \sum F_x = 0 \quad F_{x1} = F_w \cos \theta = 21.95 \text{ lb} \]

\[ \sum M_{F_{y1}} = 0 \quad F_{y2} (x) - 2W \left( \frac{x}{2} \right) + F_w \cos \theta \left( \frac{x}{2} \right) + F_w \sin \theta \left( \frac{h}{2} \right) = 0 \]

\[ \Rightarrow F_{y2} = \frac{W(x) - F_w \left( \frac{x}{4} \right) \left( x \cos \theta + h \sin \theta \right)}{x} \]

\[ \Rightarrow F_{y2} = -14.38 \text{ lb} \]

\[ \sum F_y = 0 \quad F_{y2} + F_{y1} - 2W + F_w \sin \theta \]

\[ \Rightarrow F_{y1} = 2W - F_w \sin \theta - F_{y2} \]

\[ \Rightarrow F_{y1} = 23.2 \text{ lb} \]
Known: \( W = 60 \text{ lb/panel} \), \( b = 3.261 \text{ ft} \)

Find: Moment and shear diagrams for cross bars. 

Diagram:

Assumption: Crossbars are identical and weight is distributed evenly.

FBD of Bars 1 and 2

\[
\sum M_{A_i} = 0 \\
-W(1.7 - 1.4) \text{ ft} - W(1.7 + 3.344 - 1.4) \text{ ft} \\
+ R_z(1.7 + 3.344 - 1.4) \text{ ft} = 0 \\
\Rightarrow R_z = \frac{W(1.7 - 1.4 + 1.7 + 3.344 - 1.4)}{2(1.7) + 3.344 - (1.4)^2} \text{ ft} = \frac{W}{R_1} \\
\]

\( W = 120 \text{ lb} \) \( \Rightarrow x = \frac{W}{b} = \frac{120}{3.261 \text{ ft}} = 36.8 \text{ lb/ft} \)
\[ -\left(36.8 \text{ lb/ft}\right) (1.4 \text{ ft}) = -49.16 \text{ lb} \]

\[ 120 \text{ lb} - 49 \text{ lb} = 71 \text{ lb} \]

\[ 71 \text{ lb} - 36.8 \text{ lb/ft} \left(3.261 + \frac{1}{12} - 1.4\right) \text{ ft} = 0 \]

\[ -36.8 \text{ lb/ft} \left(3.261 + \frac{1}{12} - 1.4\right) \text{ ft} = 71 \text{ lb} \]

\[ (120 - 71) \text{ lb} = 49 \text{ lb} \]

\[ 49 \text{ lb} - 36.8 \text{ lb/ft} \left(1.4 \text{ ft} - 0.07 \text{ ft}\right) = 0 \]
\[ -4916 \left( 1.4 - 0.07 \right) \text{ ft} = -65.2 \text{ ft} \]

\[ 7116 \left( 3.261 + \frac{1}{12} - 1.4 \right) \text{ ft} = 138 \text{ ft} \]

\[ 13816 \text{ ft} - 65.2 \text{ ft} = 73.16 \text{ ft} \]
Find: will top bar buckle?

Cross-section of Top bar

\[ I = \frac{b(h^2 - h_1^2)}{12} \]

\[ = \left( \frac{2}{12} \right) \left( \frac{1}{12} \right)^2 - \frac{1}{12} \left( \frac{0.75}{12} \right)^2 \] ft^4 = \frac{5.67 \times 10^{-6}}{12} \text{ ft}^4

\[ \gamma_{max} = \frac{MC}{I} = \left( \frac{73 \text{ lb} \cdot \text{ft}}{12 \text{ in.}} \right) \left( \frac{0.5}{12} \right) \left( \frac{1}{12 \text{ ft}} \right)^2 = \frac{4166}{5.67 \times 10^{-6} \text{ ft}^4} \text{ lb/in}^2 = 4.17 \text{ kpsi} \]

For Aluminum Alloy 6005-T5

\[ s_y = 35 \text{ kpsi} \]

\[ s_y > \gamma_{max} \text{, cross-section will not buckle} \]
Find: Slenderness ratio $L/k$ short column.

Solve:

$L = 2.9 \text{ m}$
$C = 1$
$E = 10.4 \text{ Mpsi}$
$s_y = 3.5 \text{ Kpsi}$

\[ I = \frac{bh^3 - b^2h^2}{12} = \frac{(2)(1.25) - (1.75)(1.75)^2}{12} = 0.55 \text{ in}^4 \]

\[ A = bh - bh = [2(1.25) - (1.75)(1.75)] \text{ in}^2 = 0.9375 \text{ in}^2 \]

\[ k = \sqrt{\frac{I}{A}} = \sqrt{\frac{0.55 \text{ in}^4}{0.9375 \text{ in}^2}} = 0.767 \text{ in} \]

\[ \frac{L}{k} = 0.282 \left( \frac{AE}{P_{cr}} \right)^{1/2} = 0.282 \left( \frac{2}{s_y} \right)^{1/2} \]

\[ \left( \frac{L}{k} \right)^2 = 0.282 \left[ \frac{2}{35 \times 10^6 \text{ psi}} \right] \left( 10.4 \times 10^6 \text{ psi} \right) \left( 1.75 \right) \left( 1.75 \right) = 6.87 \]

\[ \left( \frac{L}{k} \right) \approx 37.8 \]

\[ \left( \frac{L}{k} \right) > \left( \frac{L}{k} \right)_s \implies \text{ short column, secant column formula} \]
Find: will back legs buckle? Where $T_{max} = 9.17 \text{ kips}$.

Solution:

\[ T = \frac{P}{A} \left( 1 + \frac{Ec}{k^2} \text{ sec} \left( \frac{L}{2k} \sqrt{\frac{P}{EA}} \right) \right) \]

\[ T_{cr} = \frac{S_t}{2} \left( 1 + \frac{Ec}{k^2} \text{ sec} \left( \frac{L}{2k} \sqrt{\frac{S_t}{2E}} \right) \right) \]

For short column use secant formula.

Where

- $E = 1.075 \text{ in}$
- $S_t = 35 \times 10^3 \text{ psi}$
- $C = 1 \text{ in}$
- $k = 0.767 \text{ in}$
- $E = 10.4 \times 10^6 \text{ psi}$
- $L/k = 6.87$

\[ \sigma_{cr} = \frac{35 \times 10^3}{2} \left( 1 + \frac{(1.075 \times 10^3)(1)}{(0.767)^2} \right) \text{ sec} \left( \frac{4}{(4)(6.87)} \sqrt{\frac{25 \times 10^3 \text{ psi}}{(10.4 \times 10^6)}(2) \text{ psi}} \right) \]

\[ \sigma_{cr} = 49 \text{ kips} \]

\[ \sigma_{cr} > T_{max} \text{ - Back legs will not buckle} \]
Find: Does the member which spans two seams buckle?

Know: \[ I = 5.07 \times 10^{-6} \text{ ft}^4 \]
\[ C = 0.5 \text{ in}^2 \]

Solve: \[ P = 779 \text{ lb} \]

Because of symmetry, \( R_1 = R_2 = \frac{P}{2} = 389.5 \text{ lb} \)

\[ A_1 = A_2 = (8 \text{ in}) \left( 389.5 \text{ lb} \right) = 3116 \text{ in}^2 \]

\[ \sigma_{max} = \frac{M C}{I} = \frac{(3116 \text{ in}^2 \cdot \text{lb}) (0.5 \text{ in})}{(5.07 \times 10^{-6} \text{ ft}^4)} \]
\[ \sigma_{max} = 14.8 \text{ kpsi} \]

\[ S_t \geq \sigma_{max} \]

\[ 35 \text{ kpsi} \geq 14.8 \text{ kpsi} \text{, will not buckle.} \]
STRESS CONCENTRATION

- MATERIAL
  6061-T6 ALUMINUM
  $\sigma_{\text{max}} = 35 \text{ kips}$

\[
\frac{D}{d} = \frac{2.275}{.4} = 5.69
\]
\[
\frac{y}{d} = \frac{.1875}{.4} = .469
\]

Table A-15 (Figure A-15-5) Pg (1027)
Shingley's Mechanical Engineering Design.

\[
\sigma_0 = \frac{F}{d \cdot t} = \frac{389.5 \text{ lbs}}{(0.9 \times 2) \text{ in}^2} = 487 \text{ psi}
\]

\[
\sigma_{\text{avg}} = \frac{\sigma_{\text{max}}}{K_t} = \frac{35}{1.6} = 21.88 \text{ kips}
\]

$\sigma_{\text{avg}} > \sigma_0$

21.88 kips $> 487$ psi, GOOD
**STRESS CONCENTRATION (HOLE)**


- **Circular Fillet**
  - Stress Concentration Factor
  
  \[ K = \frac{\sigma_{\text{max}}}{\sigma_{\text{avg}}} \]

- **Stress Concentration Factor**
  
  \[ K = 2.46 \]

- **\( P_{\text{critical}} \) = 779 lbs**

- **Hole \( d = .368 \text{ in} \)**

- **\( \sigma_{\text{max}} = 35 \text{ Kips ALUMINUM 6061-T6} \)**

\[
\frac{\frac{.368}{2}}{d} = .184
\]

From Figure 2.60, Pg (116)

\[ K = 2.46 \]

\[ \sigma_{\text{ave}} = \frac{35 \text{ Kips}}{2.46} = 14.3 \text{ Kips} \]

\[ A = (.4)(2 - .368) = .6528 \text{ in}^2 \]

\[ \sigma_{\text{ave}} = \frac{P_{\text{allow}}}{A} \]

\[ P_{\text{allow}} = \sigma_{\text{avg}} A \]

\[ = (14.3 \text{ Kips})(.6528 \text{ in}^2) \]

\[ = 9.35 \text{ Kips} \]

\[ P_{\text{allow}} > P_{\text{critical}} \]

\[ 9.350 \text{ lbs} > 3.98 \text{ lbs} \]

**GOOD**
DISTORTION ENERGY (DE)

\[ F = 2193 \text{ lbs} \]

STRESS CONCENTRATION

\[ f = \frac{F}{A}, \quad \sigma = \frac{Mc}{I} \]

\[ F_1 = \frac{F}{2} = 1098 \text{ lbs} \]

\[ A = (0.4)(1.75) = 0.7 \text{ in}^2 \]

\[ I = \frac{6a^3}{12} = \frac{(1.75)(0.4)^3}{12} = 0.009333 \text{ in}^4 \]

\[ M = (0.5)(1098) \text{ lbs} \cdot \text{in} = 549 \text{ lbs} \cdot \text{in} \]

\[ \sigma = \frac{Mc}{I} \left(\frac{549 \text{ lbs} \cdot \text{in}}{0.009333 \text{ in}^4}\right) = 11.8 \text{ Kips} \]

\[ \text{SHEAR STRESS} = 11.8 \text{ Kips} \leq 35 \text{ Kips} \quad \checkmark \quad \text{GOOD} \]

\[ J = \frac{F}{A} = \frac{1098 \text{ lbs}}{0.7 \text{ in}^2} = 1578 \text{ Kips} \]

\[ \text{VON MISES STRESS} \quad (Pg-224) \]

\[ \bar{\sigma} \geq \sigma \quad \text{For Yielding} \]

\[ \bar{\sigma} = \left( \sigma_x^2 + 3 \sigma_y^2 \right)^{\frac{1}{2}} \]

\[ \left[ (11764)^2 + 3(1569)^2 \right]^{\frac{1}{2}} = 12 \text{ Kips} \leq 35 \text{ Kips} \quad \checkmark \quad \text{GOOD} \]
STRESS ANALYSIS

\[ F = 2565 \text{ lbs, Wind Force} \]
\[ F = \frac{2565 \text{ lbs}}{2} = 1283 \text{ lbs Per Panel} \]
\[ F_1 = F_2 = \frac{1283 \text{ lbs}}{2} = 310 \text{ lbs} \]
\[ F_{max} = 35 \text{ kips, 6061-16 ALUMINUM} \]

\[ M = F \cdot I \rightarrow (310 \text{ lbs})(0.5\text{ in}) = 155 \text{ lbs-in} \]

\[ \sigma = \frac{Mc}{I} = \frac{155 \text{ lbs-in})(0.2185) \text{ in}}{0.0067041 \text{ in}^4} = 5.05 \text{ kips} \]

VON MISES STRESS
\[ \sigma' \geq \sigma_y \text{ For Yielding} \]

\[ \sigma' = \sqrt{\sigma_x^2 + 3 \sigma_y^2} = \sqrt{6051^2 + 3(736)^2}^{1/2} = 5.21 \text{ kips} \]

\[ \sigma' \leq \sigma_y \text{ Check} \]

5.21 kips \leq 35 kips \text{ NO YIELD} \]

GOOD
BOLT 5/16 - 18

MATERIAL 18-8 STAINLESS

NUT

SEAM CLAMP INSERT

MATERIAL 6005 SERIES ALUMINUM-T6

HEXAGONAL NUT

Table A-31 (Dimensions of Hexagonal Nuts)

<table>
<thead>
<tr>
<th>Normal Size, in</th>
<th>Width, in W</th>
<th>Regular Hexagonal, in H</th>
<th>Thick or Slotted, in</th>
<th>Jam in</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/16</td>
<td>1/2</td>
<td>1/2</td>
<td>2 1/4</td>
<td>3 1/4</td>
</tr>
</tbody>
</table>

Table 5-2 (Diameters and Area of Unified Screw Threads UNC)

<table>
<thead>
<tr>
<th>Size Designation, in</th>
<th>Nominal Major Diameter, in</th>
<th>Threads Per inch, N</th>
<th>Tensile Stress Area (A), in²</th>
<th>Minor Diameter Area (A), in²</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/16</td>
<td>0.3125</td>
<td>18</td>
<td>0.0524</td>
<td>0.0454</td>
</tr>
</tbody>
</table>
SHEER OF V-THREADS  (unified and ISO)

Standard nut thickness (by design)

\[ t = \frac{7}{8} D \]

D → Nominal Screw size (Table A-31)

\[ D = \frac{5}{16} \text{ or } 0.3125 \text{ in} \]

Area of nut threads strip by the screw threads

\[ A_0 = \pi D \left( \frac{D - \frac{D}{8}}{8} \right) = \pi D \frac{7}{8} t \]

\( n_p \) → Total no. of threads in nut (t)

\[ t = .345 \text{ in} \]

\( n_p \frac{7}{8} \rightarrow \) Number of spaces between threads at points of failure

SHEAR STRENGTH OF NUT MATERIAL

\[ S_{0x} = 0.58 S_y \]

6005-T5 Series Aluminum Yielding strength

\[ S_y = 35 \text{ ksi} \]

F = \( \pi D \left( \frac{7}{8} t \right) \left( 0.58 S_y \right) \)

\[ F = (\pi)(0.3125)(\frac{7}{8} \cdot .345)(0.58)(35 \times 10^3) \]

\[ = 6012 \text{ lbs} \]

MAXIMUM FORCE APPLIED

\[ F = 390 \text{ lbs} \]

\[ F_{allow} > F_{applied} \] FAILURE CHECK

6012 lbs > 390 lbs GOOD
Appendix E: IR 16-7 and IR 16-8
Pg. 77-104
This Interpretation of Regulations (IR) is intended for use by the Division of the State Architect (DSA) staff, and as a resource for design professionals, to promote more uniform statewide criteria for plan review and construction inspection of projects within the jurisdiction of DSA which includes State of California public elementary and secondary schools (grades K-12), community colleges, and state-owned or state-leased essential services buildings. This IR indicates an acceptable method for achieving compliance with applicable codes and regulations, although other methods proposed by design professionals may be considered by DSA.

This IR is reviewed on a regular basis and is subject to revision at any time. Please check the DSA website for currently effective IRs. Only IRs listed in the document at http://www.dgs.ca.gov/dsa/Resources/IRManual.aspx at the time of plan submittal to DSA are considered applicable.

**Purpose:** This Interpretation of Regulations (IR) provides a simplified method to determine wind loads from that given in California Building Code (CBC), Section 1609A.1 and ASCE 7, Section 6.5 – Method 2. For projects submitted to DSA for review under the 2010 CBC, refer to 2010 CBC Section 1609A.6 (1609.6*), where the alternative method described in this IR has been adopted into regulations.

(* Indicates an alternative 2010 CBC section that may be used by community colleges, per 2010 CBC, Section 1.9.2.2.)

**Background:** A Tri-State Wind Code Committee consisting of delegates from the Structural Engineering Associations of California, Oregon and Washington developed the following alternate wind design procedure. This alternate procedure is formatted similar to the 1997 UBC, but includes the basic approach, nomenclature and latest wind design knowledge of the ASCE 7 Standard. This procedure combines the internal and external pressures on each external surface of a building into a single Net Pressure Coefficient, \( C_{net} \). The \( C_{net} \) coefficients are used in the equation for obtaining the design wind pressure, \( P_{net} \), for each external surface of the building.

For additional background and commentary, see the Appendix.

**Policy:** The following Alternate Wind Design Procedure is not mandatory, but will be accepted by DSA as an alternate to Section 1609A.1 of the 2007 CBC for projects under the jurisdiction of DSA.

1. **Alternate Wind Design Procedure:** The following wind load provisions are permitted by DSA as an alternative to Section 6.5 Method 2 – Analytical Procedure of ASCE 7, as mandated in Section 1609A.1 of the 2007 (CBC).

2. **Limitations:** Buildings or other structures whose design wind forces are allowed to be determined in accordance with this IR shall meet the following requirements:

   2.1 The building or other structure shall have no unusual geometric irregularity or spatial form.

   2.2 The building or other structure does not have response characteristics making it subject to across wind loading, vortex shedding, instability due to galloping or flutter; and does not have a site location for which channeling effects or buffeting in the wake of upwind obstructions warrant special consideration.
2.3 A building or other structure greater than 100 feet (30480 mm) in height shall be limited to a height-to-least-width ratio of 4 or less, and with a fundamental natural period less than or equal to one second.

Commentary: The starting assumption of the procedure is that the structures are "rigid," which is defined as having a fundamental natural period of at least one Hz (period of less than one second). Item 2.3 is intended to define that item. Structures less than 100 ft can generally be considered rigid, at least for the approximate period in ASCE Section 12.8.2.1 (these are similar period calculations as 2001 CBC Section 1630A.2.2). Thus the flexible structure requirements in ASCE 7 Chapter 6 can be ignored.

3. Modifications to ASCE 7: The text of ASCE 7 shall be modified as follows:

3.1 Symbols and notations: Symbols and notations are specific to this section in conjunction with Symbols and notations in ASCE 7, Section 6.3.

- **B** = Horizontal dimension of building measured normal to wind direction
- **B_{MWFRS}** = Maximum horizontal distance between vertical elements of MWFRS resisting wind forces in any given direction.
- **C_{net}** = Net-pressure coefficient based on \( K_d \ [G_C \rho - (G_{C_p})] \), see Table 2
- **G** = Gust effect factor equal to 0.85 for rigid buildings as defined in ASCE 7, Section 6.5.8.1
- **I** = Importance factor in ASCE 7 Table 6-1
- **K_d** = Wind directionality factor as defined in ASCE 7, Section 6.5.4.4.
- **P_{net}** = Design wind pressure used to determine wind loads on buildings or other structures, or their components and cladding, in lb/ft² (N/m²)
- **q_s** = Wind velocity pressure in lb/ft² (N/m²), Table 1

3.2 Design wind pressures: When using the Alternate Wind Design Procedure, the Main-Wind-Force-Resisting System, (MWFRS) and Components and Cladding of every building or structure shall be designed to resist the effects of wind pressures on the building envelope. The net pressure on exterior building surfaces shall be determined as follows:

\[
P_{net} = q_s K_z C_{net} [I K_{zt}] \tag{Equation 1}
\]

Design wind forces for the MWFRS shall not be less than 10 lb/ft² (0.48 kN/m²) multiplied by the area of the building or structure projected on a plane normal to the wind direction under consideration. See ASCE 7 Section 6.1.4 for criteria. Design wind pressure for components and cladding shall not be less than 10 lb/ft² (0.48 kN/m²) acting in either direction normal to the surface.

3.3 Design procedure: The MWFRS of every building or other structure shall be designed for the combination of the windward and leeward net pressure, \( P_{net} \), using Equation 1. Components and claddings of every building or structure shall be designed for the critical net pressure, \( P_{net} \), using Equation 1.
3.3.1 **Main wind force resisting systems:** The MWFRS shall be designed for the wind load cases as defined in ASCE 7 Figure 6-9.

**Exceptions:**

1. One-story buildings with \( h \) less than or equal to 30 ft, buildings two stories or less framed with light-frame construction, and buildings two stories or less designed with flexible diaphragms need only be designed for Load Case 1 and Load Case 3 in Fig. 6-9.

2. Where the ratio \( B_{MWFRS}/B \) exceeds 0.7, only Load Case 1 and Load Case 3 in Fig. 6-9 need be considered, provided the design wind load is increased 20% for the vertical elements of the MWFRS closest to the perimeter, for those lateral lines which resist less than 50% of the total wind force at that story.

**Commentary:** Section 3.3.1 of the IR is different than the code change proposal by SEA. The original ASCE 7 requirement to use the load cases in Figure 6-9 was put back into the procedure. Exception 1 is directly from ASCE 7. The proposal by SEA to simplify the torsion was included as Exception 2. However, since there is an increase to some of the vertical elements in the MWFRS due to the torsion load case, the 20% increase was included for the perimeter lines of resistance. When using Exception 2, wall lines that resist more than 50% of the lateral load at that story will not see an increase due to the torsional load cases.

3.3.2 **Determination of \( K_z \) and \( K_{zt} \):** Velocity pressure exposure coefficient, \( K_z \), shall be determined in accordance with ASCE 7 Section 6.5.6.6; and Topography Factor, \( K_{zt} \), shall be determined in accordance with ASCE 7 Section 6.5.7.

1. For windward side of a structure, \( K_z \) and \( K_{zt} \) shall be based on height \( z \).

2. For leeward side and side walls, and for windward and leeward roofs, \( K_z \) and \( K_{zt} \) shall be based on mean roof height \( h \).

\[ K_z \text{ for exposure } C = 2.01(z/900)^{0.21} \] where \( z \) is the height in ft and \( z \geq 15 \text{ ft} \). For other exposures, see ASCE 7 Table 6-3.

3.3.3 **Determination of net pressure coefficient \( C_{net} \):** For the design of the main wind force resisting system and for components and cladding, the net pressure shall be as follows:

1. The net pressure coefficient, \( C_{net} \) for walls and roofs shall be determined from Table 2.

2. Where \( C_{net} \) may have more than one value, the more severe wind load combination shall be used for design.

3.4 **Application of wind pressures:** When using Alternate Wind Design Procedure, wind pressure shall be applied simultaneously on, and in a direction normal to, all building envelope wall and roof surfaces.

3.4.1 **Components and cladding:** Wind pressure for each component or cladding element is applied using \( C_{net} \) values based on the effective wind area, \( A \), contained within the zones in areas of discontinuity of width and/ or length “a”, “2a” or 4a” at: corners of roofs and walls; edge strips for ridges, rakes and eaves; or field areas on walls or roofs as indicated in Table 2, and shall meet the following requirements:
1. Calculated pressure at local discontinuities acting over specific edge strips or corner boundary areas.

<table>
<thead>
<tr>
<th>Basic Wind Speed, V (mph)</th>
<th>85</th>
<th>90</th>
<th>95</th>
<th>100</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure, q_s (lb/ft²)</td>
<td>18.5</td>
<td>20.7</td>
<td>23.1</td>
<td>25.6</td>
<td>31.0</td>
<td>36.9</td>
<td>43.3</td>
<td>50.2</td>
<td>57.6</td>
</tr>
</tbody>
</table>

2. Include “field” (Zones 1, 2 or 4 as applicable) pressures applied to areas beyond the boundaries of the areas of discontinuity.

3. Where applicable, calculated pressures at discontinuities (Zones 2 or 3) shall be combined with design pressures on rake or eave overhangs.

**TABLE 1**

**WIND VELOCITY PRESSURE (q_s) AT STANDARD HEIGHT OF 33 FEET**

- a. For wind speeds not shown, use q_s = 0.00256 V^2
- b. Multiply by 1.61 to convert to km/h
- c. Multiply by 0.0478 to convert to kN/m²

**TABLE 2**

**NET PRESSURE COEFFICIENT, C_net**

<table>
<thead>
<tr>
<th>STRUCTURE OR PART THEREOF</th>
<th>DESCRIPTION</th>
<th>C_net FACTOR^{a, b}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Main Wind Force Resisting System</td>
<td>Walls:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Windward wall</td>
<td>Enclosed: 0.43</td>
</tr>
<tr>
<td></td>
<td>Leeward wall</td>
<td>Partially enclosed: 0.11</td>
</tr>
<tr>
<td></td>
<td>Side wall</td>
<td>-0.51</td>
</tr>
<tr>
<td></td>
<td>Parapet wall Windward</td>
<td>-0.66</td>
</tr>
<tr>
<td></td>
<td>Parapet wall Leeward</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>Roofs:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind perpendicular to ridge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leeward roof or flat roof</td>
<td>-0.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.97</td>
</tr>
<tr>
<td>Windward roof slopes:</td>
<td>Slope ≤ 2:12 (or 10º) Case 1</td>
<td>-1.09</td>
</tr>
<tr>
<td></td>
<td>Case 2</td>
<td>-1.41</td>
</tr>
<tr>
<td></td>
<td>Slope 4:12 (or 18º) Case 1</td>
<td>-0.73</td>
</tr>
<tr>
<td></td>
<td>Case 2</td>
<td>-1.05</td>
</tr>
<tr>
<td></td>
<td>Slope 5:12 (or 22º) Case 1</td>
<td>-0.59</td>
</tr>
<tr>
<td></td>
<td>Case 2</td>
<td>-0.90</td>
</tr>
<tr>
<td></td>
<td>Slope 6:12 (or 27º) Case 1</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Case 2</td>
<td>-0.29</td>
</tr>
<tr>
<td></td>
<td>Slope 7:12 (or 30º) Case 1</td>
<td>-0.47</td>
</tr>
<tr>
<td></td>
<td>Case 2</td>
<td>-0.79</td>
</tr>
<tr>
<td></td>
<td>Slope 8:12 (or 35º) Case 1</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Case 2</td>
<td>-0.25</td>
</tr>
<tr>
<td></td>
<td>Slope 9:12 (or 37º) Case 1</td>
<td>-0.37</td>
</tr>
<tr>
<td></td>
<td>Case 2</td>
<td>-0.68</td>
</tr>
<tr>
<td></td>
<td>Slope 10:12 (or 40º) Case 1</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>Case 2</td>
<td>-0.58</td>
</tr>
<tr>
<td></td>
<td>Slope 12:12 (or 45º) Case 1</td>
<td>-0.15</td>
</tr>
<tr>
<td></td>
<td>Case 2</td>
<td>-0.47</td>
</tr>
<tr>
<td></td>
<td>Slope 21:12 (or 60º) Case 1</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>Case 2</td>
<td>-0.18</td>
</tr>
<tr>
<td></td>
<td>Slope &gt; 21:12 (or 60º)</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>Wind parallel to ridge or flat roofs</td>
<td>-1.09</td>
</tr>
</tbody>
</table>

^{a, b} For wind speeds not shown, use q_s = 0.00256 V^2

Multiply by 1.61 to convert to km/h

Multiply by 0.0478 to convert to kN/m²
2. Components and cladding - Walls

<table>
<thead>
<tr>
<th>Affected zone</th>
<th>4</th>
<th>4</th>
<th>5</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall elements h ≤ 60 ft.</td>
<td>1.00</td>
<td>-1.09</td>
<td>1.00</td>
<td>-1.34</td>
</tr>
<tr>
<td>≥ 500 sf</td>
<td>0.75</td>
<td>-0.83</td>
<td>0.75</td>
<td>-0.83</td>
</tr>
<tr>
<td>Wall elements h &gt; 60 ft.</td>
<td>0.92</td>
<td>-0.92</td>
<td>0.92</td>
<td>-1.68</td>
</tr>
<tr>
<td>≤ 20 sf</td>
<td>0.66</td>
<td>-0.75</td>
<td>0.66</td>
<td>-1.00</td>
</tr>
<tr>
<td>≥ 500 sf</td>
<td>2.53</td>
<td>-1.94</td>
<td>3.38</td>
<td>-2.19</td>
</tr>
<tr>
<td>Parapet walls h ≤ 60 ft</td>
<td>2.87</td>
<td>-1.68</td>
<td>3.64</td>
<td>-2.45</td>
</tr>
<tr>
<td>Parapet walls h &gt; 60 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Components and cladding - Roofs

<table>
<thead>
<tr>
<th>Affected zone</th>
<th>1</th>
<th>1</th>
<th>2</th>
<th>2</th>
<th>3</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof for h &gt; 60 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope ≤ 2:12 (or 10º)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 10 sf</td>
<td>-1.34</td>
<td>-2.11</td>
<td>-2.87</td>
<td>-2.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 500 sf</td>
<td>-1.00</td>
<td>-1.51</td>
<td>-2.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gable and Hipped Roof h ≤ 60 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope ≤ 6:12 (or 27º)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 10 sf</td>
<td>0.58</td>
<td>0.58</td>
<td>1.68</td>
<td>0.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 100 sf</td>
<td>0.41</td>
<td>0.41</td>
<td>1.70</td>
<td>0.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhang</td>
<td>-1.45</td>
<td>-1.87</td>
<td>-3.15</td>
<td>-2.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 10 sf</td>
<td>-1.36</td>
<td>-1.87</td>
<td>-3.15</td>
<td>-2.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 100 sf</td>
<td>-1.53</td>
<td>-1.53</td>
<td>-1.53</td>
<td>-1.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope 6:12 to 12:12 (or 27º to 45º)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 10 sf</td>
<td>0.92</td>
<td>0.92</td>
<td>1.17</td>
<td>0.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 100 sf</td>
<td>0.83</td>
<td>0.83</td>
<td>1.00</td>
<td>0.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhang</td>
<td>-1.70</td>
<td>-1.70</td>
<td>-1.70</td>
<td>-1.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 10 sf</td>
<td>-1.53</td>
<td>-1.53</td>
<td>-1.53</td>
<td>-1.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 100 sf</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monoslope Roof h ≤ 60 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope ≤ 7:12 (or 30º)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 10 sf</td>
<td>0.49</td>
<td>0.49</td>
<td>1.51</td>
<td>0.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 100 sf</td>
<td>0.41</td>
<td>0.41</td>
<td>1.43</td>
<td>0.41</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 4. Chimneys, tanks and solid towers

<table>
<thead>
<tr>
<th>Height / depth or diameter (h/D)</th>
<th>1</th>
<th>7</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square (wind normal to face)</td>
<td>0.99</td>
<td>1.07</td>
<td>1.53</td>
</tr>
<tr>
<td>Square (wind along diagonal)</td>
<td>0.77</td>
<td>0.84</td>
<td>1.15</td>
</tr>
<tr>
<td>Hexagonal or Octagonal</td>
<td>0.81</td>
<td>0.97</td>
<td>1.13</td>
</tr>
<tr>
<td>Round</td>
<td>0.65</td>
<td>0.81</td>
<td>0.97</td>
</tr>
</tbody>
</table>

5. Open sign and lattice frameworks

<table>
<thead>
<tr>
<th>Ratio of solid to gross area</th>
<th>&lt; 0.1</th>
<th>0.1 to 0.29</th>
<th>0.3 to 0.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>1.45</td>
<td>1.30</td>
<td>1.16</td>
</tr>
<tr>
<td>Round</td>
<td>0.87</td>
<td>0.94</td>
<td>1.08</td>
</tr>
</tbody>
</table>

6. Solid Freestanding Wall

<table>
<thead>
<tr>
<th>Horizontal to vertical dimension (B/s)</th>
<th>0 to s</th>
<th>s to 2s</th>
<th>≥ 3s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case A and Case B (all B/s)</td>
<td>1.45</td>
<td>1.45</td>
<td>1.45</td>
</tr>
<tr>
<td>Case C (2 ≤ B/s ≤ 5)</td>
<td>2.24</td>
<td>1.45</td>
<td>1.45</td>
</tr>
<tr>
<td>Case C (B/s &gt; 5)</td>
<td>3.10</td>
<td>1.88</td>
<td>1.45</td>
</tr>
</tbody>
</table>

---
a. Linear interpolation between tabulated C_{net} values and between tabulated slope or effective wind areas is acceptable.
b. Overhang values are for both enclosed and partially enclosed buildings. For other than overhangs, component and cladding values are for enclosed buildings. For partially enclosed buildings, algebraically add or subtract 0.32 to increase values on table.
c. Use wall element values for slopes greater than 21:12 (60º).
d. Refer to ASCE 7 Figure 6-11-A through Figure 6-17 for affected zone designations.
e. For roof slope > 2:12 (or 10º), use coefficients tabulated for gable and hipped roof h ≤ 60 ft.
Open structures can conservatively use the values for “enclosed structures” except for a MWFRS mono-slope windward roof, which must add +0.15 to the Case 2 $C_{net}$ factor.

Commentary: Many of the Figures in ASCE include multiple $C_p$ pressure values that are not included in Table 2. For example, in Figure 6-6, the wall pressure coefficient $C_p$ varies depending on the L/B ratio. The L/B ratio with a $C_p$ value that results in the largest $C_{net}$ value was used in Table 2. The same logic was used for other ratios not included in Table 2, such as the h/L values for the MWFRS roof values. Also, the reduction factor for the MWFRS roof values based on area were ignored.

Appendix 1 – Additional Background and Commentary

**Reason for Developing the Alternate Method:** The following is an excerpt from the SEAOC presentation to the IBC requesting the addition of the Alternate Method into the IBC model code.

In response to concerns from design engineers on the complexity of wind design procedures, this proposal provides for an alternate design procedure to Method 2 of ASCE 7.

In using 2006 IBC and ASCE 7, engineers have found that, except for low rise light framed buildings, lateral force design of most structures tends to be controlled by seismic forces in the western states. While ASCE 7 includes a simplified procedure under Method 1 for buildings not greater than sixty feet in height, the procedure includes various limitations such as simple diaphragm, low rise building with no unusual geometrical irregularity, and requires an engineer to refer to numerous relatively complicated charts. The complexity of the detailed Analytical Procedure has daunted even the most experience engineers. The need for wind design procedure in the IBC similar to that which was in the 1997 UBC has been echoed throughout most of the United States.

The Structural Engineers Association of California established a Wind Ad Hoc Committee in late 2006. The group was charged to develop alternate wind design procedures for all height buildings in conjunction with the Tri-state (California, Oregon and Washington) Wind Committee. The Tri-state Wind Committee, with representatives appointed by each of the three states’ structural engineers’ associations, all of whom are experienced structural engineers, was active in code development for the 1991 UBC using ASCE 7-88 standard as the source document, and also took a primary roll in developing the basic format of the wind design provisions in the 1997 Uniform Building Code, which is still being used in several states.

This proposed alternate design procedure is developed for the most common type of buildings that are not subjected to dynamic response with further limitations for building or other structure over 100 feet. The alternate method follows closely with design requirements Chapter 6 of ASCE 7. Simplification is accomplished by generating a table of net pressure coefficients ($C_{net}$), combining a number of parameters in a simple and yet conservative manner. Application of the net pressure coefficients meets the intent to reduce the number of steps required for performing a wind loading analysis on buildings that satisfy the criteria prescribed under the limitations statement, resulting in net forces which meet or exceed those calculated based on Method 2. The reduction of design effort should be helpful in the determination of wind forces for the main wind force resisting system; and should be substantial for components and cladding. The procedure has been designed to give results equal to or more conservative than the present provisions in ASCE 7.

While the proposed code change by SEAOC Wind Ad Hoc Committee has been developed in concert with the Tri-state Wind Committee proposed document, this proposal has some uniqueness in addressing buildings of all heights and the table
developed for $C_{\text{net}}$ coefficient has been arranged in a format similar to the 1997 Uniform Building Code, which most engineers preferred in the past. Given the substantial time savings using this proposed alternate design procedure, and given that the next edition of ASCE wind standard will not be published until after 2010, we respectfully request that this proposed change be adopted into the IBC as an alternative procedure until such time as the next edition of ASCE wind standard can incorporate this alternate design method.

Appendix 2 - Additional Commentary on Design Wind Pressure

The simplification of this procedure is to combine some of the factors in the wind equations to reduce the number of computations required.

For example, the ASCE 7 formulas for the MWFRS are:

$q_z = 0.00256 K_z K_{zt} K_d V^2 I \quad \text{Equation 6-15}$

$p = q G C_p - q_i (G C_{pi}) \quad \text{Equation 6-17}$

Combining the two above equations,

$p = 0.00256 K_z K_{zt} K_d V^2 I G C_p - 0.00256 K_z K_{zt} K_d V^2 I (G C_{pi})$

or

$p = (0.00256 V^2) K_z K_d (G C_p - (G C_{pi}))(I K_{zt})$

With the following new terms:

$q_s = 0.00256 V^2$

$C_{\text{net}} = K_d [G C_p - (G C_{pi})]$

Then the pressure $p = (0.00256 V^2) K_z K_d (G C_p - (G C_{pi}))(I K_{zt})$ can be rewritten as:

$p_{\text{net}} = q_s K_z C_{\text{net}} [I K_{zt}]$

Therefore, the simplification is in the $C_{\text{net}}$ value combining the $K_d$, $G C_p$ and $G C_{pi}$ terms into a single value in Table 2.

**Gust Effect Factor G:** ASCE Section 6.5.8.1 allows the designer to use $G = 0.85$ or calculate $G$ according to Formula 6-4. As the building projected wind area becomes very large, the $G$ factor in Formula 6-4 is reduced. For example, a 50 foot high building that is 200 feet wide has a $G$ just below 0.85, but a 50 foot high building that is 500 feet wide has a $G$ of 0.81. The values in Table 2 are based on the maximum $G = 0.85$.

**ASCE 7 Section 6.5.12.2.1:** For the MWFRS, Equation 6-17 is permitted to be used for buildings of all heights per ASCE Section 6.5.12.2.1. Section 6.5.12.2.1 is the basis for Table 2 in this IR. ASCE Section 6.5.12.2.2 provides an alternate method for low rise buildings in Equation 6-18 and Figure 6-10, but this alternate was not used and therefore the load cases in Figure 6-10 are not required.

**MWFRS Walls:** ASCE Figure 6-5 for the $G C_{pi}$ values requires that two load cases must be considered. Case 1 is positive internal pressure applied to all internal surfaces and Case 2 is negative internal pressure applied to all internal surfaces.
For the MWFRS, the authors used the positive internal pressures. This results in reducing the windward values and increasing the leeward values. It is more conservative to use the positive internal pressures because the leeward pressure is based on the full height of the building, where the windward pressure is based on the height going up the structure. At the top of the structure, you have maximum positive and maximum negative pressures. As you go down the structure, you continue to use the maximum negative pressure (leeward), but use a reduced positive pressure (reduced windward with respect to the maximum). Since positive internal pressure results in increased negative values, the resulting sum of the forces will be higher with positive internal pressures.

**MWFRS Roof:** For the MWFRS roof, there are two load cases in Figure 6-6. Case 1 for the maximum wind uplift force occurs when the maximum negative windward pressure is combined with the maximum negative leeward pressure. The maximum external negative pressures are increased with a positive internal pressure. Positive internal pressures were used for Table 2. Case 2 for the maximum horizontal wind shear force occurs when the maximum positive windward pressure is combined with the maximum negative leeward pressure. However, when combining windward and leeward loads, the same internal pressure is used. The positive internal pressure is used in Table 2 to reduce the MWFRS windward pressure since the leeward roof and leeward walls are both based on positive internal pressure.

**Components and Cladding:** For components and cladding, the authors used the internal pressure (positive or negative) that would result in the greatest total pressure on the element.

**Determination of q_i:** In Section 6.5.12.2.1, \( q = q_z \) for windward walls, \( q = q_h \) for leeward and side walls. The simplified formula uses \( q_i \) based on the height used for the external pressure, which results in \( q_i = q_z \) for windward walls and \( q_i = q_h \) for leeward and side walls. The \( q_i = q_z \) for windward walls is conservative since it results in a higher windward pressure by subtracting a smaller inward pressure. With \( q_i = q_h \) for leeward and side walls, this matches the ASCE 7 language since windward and side walls are required to use \( q_h \).

**Open Structures** were not included in Table 2. Open structures have no internal pressure so there is no simplification of combining external and internal pressures. Open structures can conservatively use the “enclosed structure” values, except for the MWFRS windward pressures on mono-slope roofs. The internal pressure cancels out when combining windward and leeward pressures on walls and roofs for the MWFRS. An open structure with only a mono-slope roof will not cancel out the internal pressure where there is no leeward wall.
SOLAR PHOTOVOLTAIC AND THERMAL SYSTEMS REVIEW AND APPROVAL REQUIREMENTS

References:
- California Education Code
  - Section 17282.5
- California Code of Regulations (CCR), Title 24
  - Part 2, California Building Code, Sections 1609A, 1609*, 1613A and 1613*
- California Code of Regulations (CCR), Title 24
  - Part 3, California Electrical Code, Articles 250, 310, and 690
- California State Fire Marshal Photovoltaic Installation Guideline dated April 22, 2008

Discipline: All

This Interpretation of Regulations (IR) is intended for use by the Division of the State Architect (DSA) staff, and as a resource for design professionals, to promote more uniform statewide criteria for plan review and construction inspection of projects within the jurisdiction of DSA which includes State of California public elementary and secondary schools (grades K-12, community colleges), and state-owned or state-leased essential services buildings. This IR indicates an acceptable method for achieving compliance with applicable codes and regulations, although other methods proposed by design professionals may be considered by DSA.

This IR is reviewed on a regular basis and is subject to revision at any time. Please check the DSA web site for currently effective IRs. Only IRs listed in the document at http://www.dgs.ca.gov/dsa/Resources/IRManual.aspx at the time of plan submittal to DSA are considered applicable.

Purpose: This Interpretation of Regulations (IR) describes the Division of the State Architect (DSA) requirements for review and approval of solar photovoltaic (PV) and solar thermal systems used in construction projects under the jurisdiction of DSA. This IR also describes and clarifies the requirements for projects not subject to DSA review.

Scope: This IR clarifies the requirements for structural support, and anchorage of panels and balance-of-system (BOS) equipment. It also addresses the basic requirements of the California Building Code (CBC) for Fire-Life Safety, Access Compliance, certain electrical requirements, excluded solar projects, and projects exempt from DSA review.

Photovoltaic roofing systems (such as tiles) that incorporate photovoltaic technology physically integrated into the roof covering materials are outside the scope of this IR, except those addressed in Section 2.5 of this IR.

Background: Typical photovoltaic (PV) or solar thermal systems consist of solar panels and BOS equipment. The BOS equipment includes factory assembled foundations or support structures, DC-to-AC inverters, electrical wiring, electrical protection, monitoring, and safety equipment.

Photovoltaic panels are anchored to building structures, or ground mounted. Anchoring relies on various attachment systems such as support frames (Section 2.2, below), ballast (Section 2.4, below), or adhered systems (Section 2.5, below).

Solar thermal panels are typically anchored by support structures.

1. SOLAR PROJECT COMPONENTS SUBJECT TO DSA REVIEW: DSA Structural Safety reviews the anchorage of solar panels and their BOS equipment to the building structure or foundation. The anchorage design for solar panels and their BOS equipment must meet the wind force requirements of the CBC, Section 1609A (1609*) and the seismic requirements of the CBC, Section 1613A.

Manufacturer’s support frames will also be reviewed by DSA. The building’s vertical and lateral load resisting systems will also be evaluated for the additional loads from the solar panels and BOS equipment.
See Sections 3.1, 3.2 and 3.3 below for design and/or submittal requirements for Access Compliance, Fire-Life Safety, and Electrical, respectively.

DSA does not review the design and construction of the panels and the BOS equipment. However, the panels and BOS equipment must be designed and constructed to meet the requirements of Title 24.

2. BASIC STRUCTURAL SAFETY DESIGN REQUIREMENTS FOR SOLAR PROJECTS:

2.1 General Design Requirements:

2.1.1 Requirements for Dead Load. The dead load of solar panels shall be considered in the design of the structure. For installations on existing roofs, the additional dead load may be offset by the roof live load per Section 2.1.2, provided the roof design is adequate for the concentrated loads from solar panel support frames. The increase in effective seismic weight of the structure shall be evaluated per Title 24, Part 1, California Administrative Code (CAC), Section 4-309.

2.1.2 Requirements for Live Load. It is not necessary to include roof live load (20 psf, 300 lb point load) in the area(s) covered by the panels when these area(s) are inaccessible, or signs are posted prohibiting storage under the panels. Areas where the clear space between the panels and the rooftop is 24 inches or less are considered inaccessible. Where the solar panels do not cover the entire area of the roof, the remaining area shall have the roof live load applied.

The exclusion of the roof live load in the area(s) covered by the panels does not preclude the design of building roofs from being designed for the roof live load requirements in CBC 1607A.11 for the loading condition where the solar panels system may be removed or not installed.

For solar panels that are mounted on carports and shade structures with open grid framing and no roof deck, the following two separate live loading conditions shall be applied in combination with other applicable loads.

1) 10 psf uniform roof live load per CBC 1607A.11.5 with no solar panel dead load
2) 300 lbs. concentrated roof live load per CBC Table 1607A.1 with solar panel dead load

As a condition for use of this reduced loading condition, the following note shall be shown on the construction plans: “No future roof decking or sheathing may be applied on the open grid framing.”

2.1.3 Requirements for Snow Load. When applicable, include snow loads and loads from snow drift.

2.1.4 Requirements for Wind Design: The wind design requirements are given in CBC Section 1609A (1609*). The CBC and ASCE 7-05 do not contain specific wind design provisions for solar panel systems. The following summarizes when the “Method 1 – Simplified Procedure” or “Method 2 - Analytical Procedure” in ASCE 7-05 Sections 6.4 and 6.5, respectively, may be used for the wind design of solar panel systems. “Method 3 – Wind Tunnel Procedure” in ASCE 7-05 Section 6.6 may be used for any solar panel system.

- **Flush-mounted systems on enclosed and partially enclosed building roofs:** Solar panel systems installed parallel to and less than 10 inches above
the roof surface shall be designed as roof components and cladding per ASCE 7-05 Section 6.5.12.4 (Method 2) with GC_{pi} (internal pressure coefficient) set equal to zero or per ASCE 7-05 Section 6.4.2.2 (Method 1). There shall be a minimum air gap around the perimeter of each solar module of 0.5 inches or between rows of panels of 1 inch to allow pressure equalization above and below panels. If the panels are installed less than 2 inches above the roof surface or the minimum air gap is not provided, or it is a BIPV system per Section 2.5 below, then GC_{pi} may not be set equal to zero as indicated above.

- **Low-profile tilted systems on enclosed and partially enclosed flat roof buildings:** Low-profile (<4 ft above roof surface) tilted solar panel systems installed on flat roof (\(\theta<7^\circ\)) buildings shall be designed using the analytical method outlined in SEAOC PV2-2012 “Wind Design for Low-Profile Solar Photovoltaic Arrays on Flat Roofs” Section 3, provided the geometric limitations contained therein are satisfied.

- **Freestanding ground supported systems:** Freestanding ground supported systems (e.g. solar carports, ground mounted arrays, etc.) shall be designed using the open building provisions in ASCE 7-05 Section 6.5.13.

- **Other systems:** Solar panel systems not meeting the limitations in the above methods shall use the Wind Tunnel Procedure in ASCE 7-05 Section 6.6.

**2.1.4.1 Wind Tunnel Procedure:** When utilizing Method 3 (wind tunnel procedure) in ASCE 7-05 Chapter 6 to develop wind loads for solar photovoltaic arrays, the wind tunnel model shall properly model the wind flow environment in accordance with ASCE 7-05 Section 6.6.2, and in accordance with the requirements in ASCE 49, “Wind Tunnel Testing for Buildings and Other Structures.”

- **Modeling:** When developing generalizable wind loads for rooftop solar photovoltaic arrays, the wind tunnel model shall include to scale the array configuration and layouts placed on the roof of a building that properly models the rooftop wind flow environment. The model shall include various building features that affect the wind flow environment on the roof. The testing and instrumentation shall be designed to determine the wind load effects in different roof zones (corner, edge, center, etc.). Modeling site-specific buildings is not necessary; rather, generic models with buildings large enough in plan area to capture the wind flow environment over different roof zones may be used.

- **Instrumentation:** Wind tunnel testing shall use an arrangement of pressure taps or other instrumentation methodology that is sufficient to establish design wind forces on solar panels and the variation of such forces as a function of effective wind area.

- **Results:** Wind tunnel results shall not be extrapolated to other panel geometry, panel inclination angle, panel row spacing, panel elevation above roof surface, or other roof shape types (e.g. gable, hip, barrel, flat, etc.) that were not part of the wind tunnel study. For moderate changes in panel angle, row spacing, or other parameters, reasonable interpolation between two or more tests is permitted. The limitations of any wind tunnel study, such as the range of array and building geometry parameters that were tested, shall be clearly reported along with the results. The wind tunnel results shall provide wind loads for the design of each structural element of the PV support system, such as by providing design wind pressures as a function of effective
wind area. The wind tunnel results shall be provided in a format that is compatible with ASCE 7 (e.g. GC factors) that can be adjusted for site and buildings characteristics (exposure, building height, wind speed, etc.).

a) Minimum Wind Pressure for Wind Tunnel Procedure: The minimum design wind loads based on a wind tunnel study for solar panel systems shall comply with this section.

- Flush-mounted systems on enclosed and partially enclosed building roofs and freestanding ground supported systems: These systems, as described in Section 2.1.4 above, shall comply with the following minimum design wind loads when based on a wind tunnel study, except for closely spaced ground mounted arrays that rely on shielding from adjacent rows where an independent peer review, as indicated in Section 2.1.4.1 (b) below, is performed to allow wind loads to be less than these minimums.
  - Minimum net pressure of 10 psf per ASCE 7-05 Section 6.1.4.
  - Loads for the main wind force resisting system shall be limited in accordance with CBC Section 1609A.1.1.2.1, except when the limiting value of 80 percent is being reduced further with specific testing indicated therein; then the limiting value of 80 percent may not be reduced to lower than 50 percent.
  - Pressures for components and cladding determined shall be limited in accordance with CBC Section 1609A.1.1.2.2, except when the limiting value of 80 percent is being reduced further with specific testing indicated therein, then the limiting value of 80 percent may not be reduced to lower than 65 percent.

- Low-profile tilted systems on enclosed and partially enclosed flat roof buildings: For low-profile tilted solar panel systems installed on flat roof buildings, as described in Section 2.1.4 above, shall comply with the following minimum design wind loads when based on a wind tunnel study, except values lower than these minimums are permitted where an independent peer review, as indicated in Section 2.1.4.1 (b) below, is performed.
  - Minimum design wind load: For systems that meet the limitations and geometry requirements in SEAOC PV2-2012 Section 3, the minimum design wind load based on a wind tunnel study shall be 50 percent of the values resulting from SEAOC PV2-2012 Section 3.

- Other systems: These systems, as described in Section 2.1.4 above, shall comply with the minimum design wind loads as indicated above for flush-mounted systems and free standing systems when based on a wind tunnel study. Limits lower than these minimums are subject to approval of DSA and an independent peer review.

b) Wind Tunnel Study Peer Review: The independent peer review is an objective, technical review by knowledgeable reviewer(s) experienced in performing wind tunnel studies on buildings and similar systems, in properly simulated atmospheric boundary layers.

DSA may require an independent peer review of a wind tunnel study in accordance with this section, depending on complexity and suitability of the study and qualifications of the wind tunnel laboratory. DSA will require an independent peer review of a wind tunnel study where wind load values lower than the minimums are being used, only where specifically allowed in Section 2.1.4.1(a),
or when utilizing an unattached system per Section 2.4 below. Once a particular wind tunnel study has been peer reviewed and found acceptable, it need not be peer reviewed for subsequent projects provided the applicability and findings are appropriate for such projects.

The peer review shall be completed before substantial portions of the design and/or analysis work will be reviewed by DSA.

- **Peer Reviewer Qualifications:** minimum qualifications and terms of employment for the peer reviewer shall be as follows:
  - The peer reviewer shall be independent from the wind tunnel laboratory that performed the study and prepared the report and shall bear no conflict of interest.
  - The peer reviewer shall be acceptable to DSA.
  - The peer reviewer shall have technical expertise in the application of wind tunnel studies on buildings similar to that being reviewed.
  - The peer reviewer shall have experience in performing or evaluating boundary layer wind tunnel studies and shall be familiar with the technical issues and regulations governing the wind tunnel procedure in ASCE 7 as it is applied to systems similar to solar photovoltaic arrays that use generalized wind tunnel data for design.

- **Peer Reviewer Responsibilities:** The peer reviewer shall review the wind tunnel report, including, but not limited to, data collection methods, data analysis, boundary layer modeling, array and building modeling, resulting wind loads and their relationship to effective wind area, conversion of data into GC values, and conditions of applicability of results to different buildings types, array geometry, etc. The peer reviewer shall prepare a written report to the client. Such a report should include, at a minimum, statements regarding the following:
  - Scope of peer review with limitations defined.
  - The status of the wind tunnel study at time of review.
  - Conformance of the wind tunnel study with the requirements of ASCE 7-05 Section 6.6.2 and ASCE 49.
  - Presentation of the conclusions of the reviewer identifying any areas that need further review, investigation and/or clarification.
  - Recommendations.
  - Whether, in the reviewer’s opinion, the wind loads derived from the wind tunnel study are in conformance with ASCE 7 for the intended use(s).

2.1.4.2 **Other Wind Design Considerations:**

a) **Shielding:** No reduction of wind load shall be taken for shielding or shadowing for interior rows of solar panel arrays provided by edge panels when utilizing using Method 1 (Simplified Procedure) or Method 2 (Analytical Procedure) in ASCE 7-05 Chapter 6. Shielding or shadowing effects shall be derived utilizing Method 3 (wind tunnel procedure) in ASCE 7-05 Chapter 6. Shielding or shadowing effects implicitly included within the analytical prescriptive procedure in SEAOC PV2-2012 Section 3 may be used.
b) **Computational Fluid Dynamics (CFD)** is not recognized by ASCE 7 as an acceptable method to develop wind loads, and therefore is not acceptable to DSA.

c) **Solar PV Wind Load Applied to Main Wind Force Resisting System (MWFRS):** For solar PV systems installed on buildings, the MWFRS shall be designed to include the wind load from the solar PV panels, except solar PV systems flush mounted to the roof. When calculating the contributing wind load from the solar PV panels, the effective wind area may be assumed to be the total area of solar arrays on the building. The increase of wind load on the MWFRS of existing buildings shall be evaluated per Title 24, Part 1, CAC Section 4-309.

### 2.1.5 Requirements for Seismic Design:

The seismic anchorage design of solar panels and racking systems attached to buildings shall be based on the requirements in CBC Section 1613A, and ASCE 7-05, Chapter 13.

**Friction** due to gravity cannot be used to resist seismic loads in combination with attachments as allowed in SEAOC PV1-2012 "Structural Seismic Requirements and Commentary for Rooftop Solar Photovoltaic Arrays" Section 4, unless shake table testing or nonlinear response history analysis is performed. Testing or analysis must be similar to that described in SEAOC PV1-2012 Section 9, demonstrating satisfactory load sharing between friction and attachments, subject to the peer review requirements in Section 2.4.2 below.

**Unattached solar panel systems** that resist seismic forces by friction alone shall be designed in accordance with Section 2.4 below.

**Solar carports, walkways, and other freestanding ground supported systems:** The seismic design of the seismic force resisting system of solar carports, walkways, and other freestanding ground supported systems sheltering any use or occupancy shall be based on ASCE 7-05, Chapter 12. The seismic design of freestanding ground supported systems not sheltering any use or occupancy, including fenced off systems, shall be based on ASCE 7-05, Chapter 15, except systems similar to buildings may be designed in accordance with Chapter 12 per ASCE 7-05 Section 15.4.

### 2.1.6 Requirements for Load Combinations:

The applicable load combinations in CBC 1605A shall be applied to all loading conditions, including evaluating the effects of dead load to counteract wind uplift for ballasted and anchored systems.

### 2.2 Solar Panels Supported on Framing Systems and Foundations:

DSA will review support frames or racking systems either supplied by manufacturers or designed by the architects or structural engineers in general responsible charge (see Section 4 below), foundations, primary structure, the connection details of panels to support frames and connection details of support frames to primary structures or foundations. The design of support frames and racking systems shall be based on calculations or testing in accordance with ICC AC 428 “Acceptance Criteria for Modular Framing Systems used to Support Photovoltaic (PV) Modules.”

### 2.3 Solar Panels supported on Standing Seam Metal Roofs (SSMR):

When solar panels are attached directly to SSMR, the attachment of SSMR panels to the roof structure shall be verified per Section 2.3.1 to demonstrate that the SSMR panel-to-structure attachment is capable of resisting the imposed loads from the solar panel system. The attachment of the solar panel to the SSMR shall be verified per Section 2.3.2. Testing on the final installed connections shall be performed per Section 2.3.3.
2.3.1 Standing Seam Metal Roof Panels:

a) **Attachment of New Metal Roof Panels:** The attachment of standing seam metal roof (SSMR) panels to the roof structure shall be detailed on the plans, including special detailing for areas of discontinuities (edges, ridge, corners, etc.).

b) **Structural Calculations for New Metal Roof Panels:** Provide structural calculations to demonstrate that the SSMR panel-to-structure attachment is capable of resisting the imposed loads from the solar panel system. Panel clip values shall be based on a valid evaluation report per IR A-5 or testing per ASTM E1592 as specified in CBC Section 1504.3.2.

c) **Existing Metal Roofs:** The sliding capacity of the existing SSMR panel attachments shall be determined by existing construction documents, roof panel removal, or by other acceptable means (removal of ridge cap, etc.). For verification by panel removal, one panel for every 3000 square feet of roof area and not less than a minimum of 3 locations per building shall be removed to verify the attachment method and shall be shown on the submitted plans. Except when the roof is subject to snow load, the sliding capacity need not be evaluated if the new sliding load (seismic, wind, etc.) is less than the displaced design live load sliding component. The uplift capacity of existing SSMR panels will be verified through the field testing indicated below in Section 2.3.3 b). This testing may be performed after plan approval if each solar PV racking beam is connected to every crossing seam; otherwise, the testing shall be conducted prior to plan approval.

2.3.2 Solar Panel Attachment to Metal Roof Panels: The components of the solar panel array (rails, clips, fasteners, etc.) and its attachment to the SSMR panels shall be detailed on the plans and structural calculation shall be provided. Product information (model number, manufacturer, etc.) and installation procedure (torque, retightening of set screws, etc.) of the seam connecting devices (e.g. S-5 clips, AceClamp, etc.) shall be specified.

**Seam Connecting Device Testing:** The design values of the connecting devices (e.g. S-5 clips, AceClamp, etc.) between the panel array and the SSMR shall be based on testing on the same metal panel system (profile, manufacturer, and gauge) used for the project.

- The connecting device shall be tested for uplift and lateral load parallel to the seam; see Photograph #1 in Appendix D for uplift test.
- The failure criteria shall be the disengagement of the connecting device from the standing seam or the cracking of the standing seam, whichever occurs first.
- A minimum of five tests is required for each direction for each metal panel system, and the design value shall be the average of the five tests with a safety factor of 3 or higher.
- Manufacturer may submit results from previous tests performed by an accredited third party testing agency or may submit a valid evaluation report per IR A-5.
- The design values must be verified and submitted to DSA plan check prior to plan approval. Where previous test data is not available for installations on the existing metal panel system, the testing shall be fully detailed on the
approved plans and the test results shall be submitted and approved by DSA prior to commencement of the installation.

2.3.3 Field Testing: All testing shall be performed by personnel approved by the Architect or Structural Engineer of Record and DSA. The project inspector or designated special inspector shall observe the installation of all connecting devices to the seams. The approved plans shall clearly indicate the following testing requirements. The load rate shall be per Section 3.2.5 of ICC AC 428.

a) On New Roof: After all the connecting devices have been installed, test a minimum of 20 consecutive connections to twice the maximum ASD wind uplift load tributary to the connecting device based on the wind pressure at areas of discontinuity such as roof edges and ridges. If there is no failure in the 20 consecutive testing, test 10% of the remaining installed anchors. See Photograph #1 in Appendix D which illustrates this testing.

b) On Existing Roof: Field tests are required to verify the adequacy of the connection of the standing seam roof to the substrate and the seam connection device.

- 5 group tests of 3 (minimum) adjacent connecting devices on the same seam shall be performed. These devices shall be pull tested simultaneously to 1.67 times the maximum design wind load (ASD) on each device based on the pressure coefficients for the roof zones (1, 2 or 3) in which the connection is located.
- The reaction from the pull test shall bridge over at least one seam on each side of the tested seam. See Photograph #2 in Appendix D which illustrates this testing.
- After the initial 5 group tests, continue at a rate of 10% on the remaining connections.
- If failure occurs on any of the setups, additional tests shall be performed until 10 consecutive successful tests of the similar configuration are performed.
- The tests shall be distributed over the roof area to capture the various roof pressure zones (1, 2 and 3).

2.4 Unattached Solar PV Systems: Unattached solar PV arrays are ballast systems that are not attached to the roof. They rely on their weight and ballast to resist the wind uplift forces, while friction between the array supports and the roof surface resist seismic forces. The wind load design requirements are indicated in Section 2.1.4 above. Unattached arrays are only permitted when all of the following conditions are met:

- The maximum roof slope at the location of the array is less than or equal to 1:12 slope (4.8 degrees).
- The height above the roof surface to the center of mass of the solar array is less than the smaller of 36 inches and half the least plan dimension of the supporting base of the array.
- The array is designed to accommodate the seismic displacement determined by nonlinear response history analysis or shake table testing requirements in the SEAOC PV1-2012 “Structural Seismic Requirements and Commentary for Rooftop Solar Photovoltaic Arrays” Section 9. The seismic displacements may also be determined by the prescriptive design seismic displacements indicated in Section
7 of SEAOC PV1-2012 provided the additional limitations therein are complied with.

- The roof shall not be subject to significant ice, snow or frost considering the seismicity at the site. For the purposes of determining this, it will be acceptable to consider it as not significant if the lowest average monthly low temperature (LAMLT) for any month in the city the building is located and the seismicity at the site comply with any of the following limits.
  - Any roof where S_DS < 0.5.
  - Any roof where the LAMLT ≥ 32°F and S₁ < 0.75
  - Any roof where LAMLT ≥ 35°F

Appendix E lists major California cities and the LAMLT.

2.4.1 Requirements to Accommodate Seismic Displacements: The accommodation of seismic displacement shall be afforded by providing the minimum separations indicated in SEAOC PV1-2012 Section 6 to allow sliding.

- Qualifying parapet: Where SEAOC PV1-2012 Section 6 allows a smaller roof edge separation when there is a “qualifying” parapet, that parapet and its connection to the roof needs also to have the strength to resist the seismic impact load of the array striking the wall concurrently with the out-of-plane seismic inertial load of the wall and parapet. If the smaller roof edge separation is not used, then the parapet need not comply with this strength requirement.

- Minimum clearance around solar arrays shall be the larger of the seismic separation defined herein and minimum separation clearances required for firefighting access in Section 3.2.1 (f) below.

- Repositioning array: In the event that the array is displaced, due to seismic shaking, wind loads, or other reasons, the array shall be repositioned into its original design location so as to ensure that the proper seismic and firefighting access clearances and separations are maintained, in addition to electrical wiring seismic slack as required in Section 2.4.3 below.

- Interconnection: Each separate array shall be interconnected as an integral unit and have the strength as indicated in SEAOC PV1-2012 Section 6. Elements of the array that are not interconnected as specified shall be considered structurally separate and shall be provided with the required minimum separation.

- Friction testing per SEAOC PV1-2012 Section 8 shall be conducted where required in other sections of SEAOC PV1-2012 to be used to determine the seismic displacements.

2.4.2 Peer Review Requirements: DSA may require an independent peer review when the seismic displacements are determined by nonlinear response history analysis or shake table testing depending on complexity of the analysis and availability of staff qualified to perform such review. If seismic displacements are less than 50% of the values indicated in the prescriptive design seismic displacements indicated in Section 7 of SEAOC PV1-2012, then an independent peer review must be performed. The peer reviewer shall be approved by DSA and the peer review shall comply with CBC Section 3422.
2.4.3 **Other Considerations:** Unattached solar PV systems shall not cause excessive sagging of the roof resulting in water ponding. They shall also not block or impede drainage flows to any overflow drains and scuppers as a result of the movement of the array imposed by the seismic displacements.

The Electrical systems and other items attached to arrays shall be flexible and designed to accommodate the required minimum separation in a manner that meets code life-safety performance requirements. Details of providing slackness or movement capability to electrical wiring shall be included on the approved drawings for the solar installation.

2.5 **Building-Integrated Photovoltaic (BIPV) Roof Covering Systems:** BIPV roof cover systems include modules, shingles and panels that are attached to the roof by adhesive. Adhered photovoltaic panels may be accepted if test and analysis data, and quality control and assurance program are submitted to demonstrate compliance with ICC AC 365 “Acceptance Criteria for Building-Integrated Photovoltaic (BIPV) Roof Covering Systems.” Tests shall be performed by an accredited third party testing agency or a valid evaluation report per DSA IR A-5 may be submitted.

The local DSA Regional Office should be contacted early in the design phase if a BIPV system is anticipated.

3. **ACCESS COMPLIANCE, FIRE AND LIFE SAFETY AND ELECTRICAL REQUIREMENTS:** In addition to the above structural design requirements, the following requirements apply:

3.1 **Access Compliance:** Projects which consist only of solar alteration work installed on existing buildings and which are accessed only by ladders, catwalks or narrow passages and frequented only by maintenance personnel do not trigger accessibility code requirements or DSA accessibility review. See Section 1103 B.1, Exception 1, Part 2, Title 24, CCR, for detailed requirements. Also see DSA IR 11B-6: Mechanical Only Projects Exempt from Accessibility Review.

New shade structures, lunch shelters, canopies, and carports incorporating solar panels will require access compliance review. For example, a new shade structure over an existing parking lot will trigger access compliance review to determine if upgrades are required to the parking area and the path of travel to conform with current access compliance code requirements.

3.2 **Fire-Life Safety Requirements:** DSA Fire and Life Safety (FLS) has added the following for clarification and to address issues that have arisen during plan review. The State Fire Marshal has reviewed and concurred with the following provisions.

3.2.1 **General Requirements:** A PV System shall be typically considered equipment. There is typically not an occupancy group classification, building area limitation, or type of construction assignment to a PV system.

a) PV equipment supported by non-combustible framing installed in locations dedicated for building frontage used for area increases per California Building Code (CBC), Chapter 5, Section 506, shall be limited in size and may be allowed on a case by case basis. Maximum area that may be allowed for such systems shall not exceed 1/3 of the horizontal projected area of each frontage.

b) Open sided PV systems and framing that are non-combustible and without use underneath may be considered equipment and may be placed next to
property lines. Signs may be required on or near the system prohibiting any use or storage underneath the equipment.

c) Combustible PV systems and framing and those with use underneath such as for assembly or parking, may need to comply with 2010 CBC, Table 602. These structures may include those that do and that do not have a roof underneath the PV system.

d) PV systems (both the frame and the array) shall not be placed in fire department access roads. (Per Title 24 CCR, Division 1, Chapter 1, Section 3.05 and 2010 CFC Chapter 5, Section 503.)

e) Access to a public way or safe dispersal area shall not be obstructed by the system or system framing. (CBC 1027.6 and 442.3)

f) PV systems that cover a lunch area or similar (occupant load less than 50), that are not used for assembly purposes shall be considered equipment. Playgrounds would also fall into this category regardless of total occupant load.

g) Any PV system that is installed above an assembly use (i.e. Group A-3 or A-5 occupancy classification) shall be considered an open sided building structure and all or portions of CBC provisions apply on a case by case basis. Such areas might include an outdoor amphitheater, bleacher or grandstand seating with concentrated occupant loads and heavy use.

h) Fire Department concern for the installation of roof mounted PV systems will be addressed by DSA review to the State Fire Marshal Solar Photovoltaic Installation Guideline available at http://www.osfm.fire.ca.gov/pdf/reports/solarphotovoltaicguideline.pdf.

i) When a PV system, without riser framework, is installed directly on a rated roof assembly with a required classification greater than “Class C” found in CBC, Chapter 15, and for Chapter 7A applications, the system may be tested to UL 1703 Standards.

3.2.2 Specific Requirements for Open Sided, High Profile Ground Mounted PV Installations Above Parking Areas: For the purposes of this IR, “open sided, high profile ground mounted PV installation” means;

- The highest point of the panels is 10 feet or more from the ground
- Meets the minimum 6’ 8” clearance requirement below with a use underneath
- Structure has unobstructed openings throughout to allow heat and gases to escape and constitute a minimum of 70% of the area within perimeter of the solar array.

PV systems installed over parking spaces and limited in area to include only those areas where vehicle parking is permitted and 3,000 square feet or less are considered a Group “U” Occupancy.

The following code requirements are not applicable to PV installation considered as equipment or a Group “U” Occupancy:

- Fire Extinguishers per CFC Chapter 9, Section 906
• Exit Signs per CBC Chapter 10, Section 1011
• Emergency Lighting per CBC Chapter 10, Section 1006.3
• Automatic Fire Sprinkler System (not required by code)

PV systems installed over both parking spaces and drive aisles or PV system that exceeds 3,000 square feet without rated construction or five feet separation between systems, per CBC Chapter 4, Section 406.1.2, are considered an open parking garage (S-2 Occupancy Group), and all or portions of CBC code provisions apply on a case by case basis.

Group S-2 occupancy may be unlimited in area provided provisions found in CBC, Section 406.3.6 are met.

The following code requirements are not applicable to a Group “S-2” Occupancy PV system supported by non-combustible structure:
• Fire Extinguishers per CFC Chapter 9, Section 906
• Exit Signs per CBC Chapter 10, Section 1011
• Emergency Lighting per CBC Chapter 10, Section 1006.3
• Automatic Fire Sprinkler System (not required by code)

3.2.3 Specific Requirements for Entirely Fenced-Off, Ground Mounted PV Installations: A fire access gate with a lock that is capable of being cut away during emergency operations or a security lock such as “Knox Lock” shall be provided which meets the local fire authority having jurisdiction’s requirements when the proposed project is entirely fenced-off. Provide 10’ of clearance from all vegetation on all sides of the photovoltaic system.

3.3 Electrical Requirements: All provisions found in the California Electric Code (CEC) for photovoltaic systems shall apply. These CEC provisions include, but are not limited to, Articles 250, 310, and 690. Appendix A of this IR provides an example of a PV system grounding.

The interconnection, operating and metering requirements for generation facilities which are to be connected to a utility’s distribution system, over which the California Public Utilities Commission (CPUC) has jurisdiction shall comply with Rule 21. The School District must be the named customer on the utility account whether connection is through the school house meter or a separate meter dedicated to the proposed project.

3.4 Guard Requirements: The guard requirements for mechanical equipment near roof edges in CBC 1013.5 do not apply to solar panel arrays.

4. SOLAR PROJECT SUBMITTAL REQUIREMENTS: All projects involving installation of photovoltaic or solar thermal systems shall have a California licensed or registered architect or structural engineer in general responsible charge per Title 24, Part 1, Section 4-316. Applications for project review shall be submitted to the DSA Regional Offices, following the normal process for project submittal. An overview of the project submittal process and requirements may be found on the DSA web site. (See Appendix B of this IR for web links.)
In addition to the above requirements, the following items are also required for a complete submittal for DSA review:

4.1 General:

4.1.1 Construction plans and specifications shall be signed and stamped by the architect or structural engineer in general responsible charge per IR A-19. The architect or structural engineer in general responsible may use construction plans and specifications prepared by the manufacturer’s California registered engineer provided the requirements of IR A-18 are met.

4.1.2 The plans and specifications shall include anchorage or restraint details of the panels, BOS equipment, support structures, and foundations. Also submit any applicable anchorage calculations.

4.1.3 Shop drawings or fabrication and installation drawings of the system.

4.1.4 Calculations to verify that the primary structure will support the additional vertical and lateral loads from the panels and BOS equipment. Provide calculations verifying that roof deflection will not cause ponding and calculations for the racking system components, attachment to the structure, and other structural connections necessary to resist the applicable loads.

4.1.5 Submit wind tunnel test reports, non-linear time history analysis, shake table test, friction test, and other reports and calculations, as applicable.

5. SOLAR PROJECTS NOT SUBJECT TO DSA REVIEW AND APPROVAL:

5.1 Excluded Projects: Ground mounted solar energy systems projects which are a maximum height of eight feet (8’) or less, on public school sites, are not subject to DSA review, provided that all of the following conditions are met:
- the proposed project is not used for instructional purposes,
- students, teachers and the public will not be permitted to enter the project area, and
- there is no reasonable availability to or usage by persons with disabilities.

5.1.1 Fencing and Signage Requirements: Excluded Solar Projects, including the BOS, must be entirely fenced off to ensure that students, teachers and the public cannot gain access. The fence must be located at a distance from the equipment equal to or greater than the maximum height of the equipment. The maximum height of the equipment shall be measured from the finish grade or surface at the equipment to the equipment’s highest point. Signage stating “NOT OPEN TO THE PUBLIC – MAINTENANCE PERSONNEL ONLY” must be posted on the fence and on the equipment in an area which is visible by the public.

5.1.2 Areas Associated with Excluded Solar Projects:
- Equipment viewing areas associated with excluded solar projects that are used by students, teachers or the public are not excluded from DSA review and approval.
- Any alterations to existing electrical rooms or spaces, including those associated with but separated from ground mounted systems, for the
placement of electrical panels or electrical connections in conjunction with an excluded solar project must comply with Section 5.2, below.

5.1.3 Excluded Project Reporting to DSA: Per Title 24, Part I, Section 4-310, a resolution must be passed by the school board stating that the building or structure shall not be used for school purposes and that no pupils or teachers will be permitted to use or enter the building for said purposes or be subject to a hazard resulting from its collapse. A copy of the resolution shall be submitted to a DSA Regional Office upon award of the construction contract. Refer to Appendix “C” for “Sample Resolution.” See also Section 5.3 for inspection requirements that apply to all solar projects.

5.2 Projects Exempt from DSA Review: Alterations projects that consist only of installations of solar energy systems on existing school buildings may be exempt from DSA Structural Safety and Fire review when the total cost of the project (including any other construction, site work, etc.) is less than the cost limit indicated in IR A-10 for alteration projects. The cost limit is adjusted annually, from a baseline cost of $25,000 in 1999 dollars as required by Title 24, Part 1, Sections 4-308 and 4-309. Refer to IR A-10 for published cost limits, updated in January, and additional requirements.

Projects may be exempt from DSA Access Compliance review and approval per the provisions stated above, if there is no reasonable availability to, or usage by, persons with disabilities, or the project meets the requirements of CBC Section 1134B.2.1, Exception 4.

Free standing structures containing solar energy systems, shade structures, lunch shelters, canopies, large arrays of panels supported on a single pole, etc., are not exempt from DSA review.

5.3 Project Design and Inspection Requirements: All solar energy systems and their installation, including Excluded and Exempt projects not subject to DSA review, shall meet the design and construction requirements of Title 24 and applicable provisions of this IR, including inspection by a DSA certified project inspector.

Appendices:

Appendix A – Example of PV System Grounding
Appendix B – Hyperlinks to Web Pages
Appendix C – Sample Resolution
Appendix D – Standing Seam Metal Roof Testing
Appendix E – Lowest Average Monthly Low Temperature
Appendix A: Example of PV System Grounding

Appendix B: Hyperlinks to Web Pages

Documents referenced in this IR are available from the DSA Internet web site:
http://www.dgs.ca.gov/dsa/home.aspx


Overview of DSA Submittal Process:
http://www.dgs.ca.gov/dsa/Programs/progProject/overview.aspx

Fire Marshall’s Guideline:
http://www.osfm.fire.ca.gov/pdf/reports/solarphotovoltaicguideline.pdf
Appendix C: Sample Resolution

RESOLUTION

of the

(Governing entity i.e. School Board, Governing Board)

(Name of School District, Community College District, UC)

NEW GROUND MOUNTED PHOTOVOLTAIC PANEL PROJECT

WHEREAS, concerning the construction of ground mounted photovoltaic panel installation at (specify location, i.e. School site, address, campus) shall not be used for instructional purposes, and that no pupils or teachers or the public will be permitted to use or enter the said panel fenced enclosure for said purposes or be subject to a hazard resulting from its collapse.

NOW, THEREFORE, IT IS RESOLVED:

- The (Governing entity) of (Name of School District, Community College District, UC) directs the Administration as follows:
  1) Plans must be prepared by a California licensed Architect or Engineer
  2) The school board assumes responsibility for adequate inspection of the materials and work of construction to ensure compliance with the provisions of Parts 2, 3, 4, 5, 6, 7, 11, and 12, Title 24, C.C.R., as adopted by the California Building Standards Commission.
  3) The photovoltaic panels shall be ground mounted, less than or equal to 8 feet maximum in height, entirely fenced from student and public use, not associated with public viewing areas, not located in required side yards, do not encroach into fire access lanes, and provide signage stating “Not open to the Public – Maintenance personnel only.”
  4) To provide a fence such that the project is entirely fenced off from the rest of the campus and the fence is located at a distance from the equipment equal to or greater than the maximum height of the equipment. The maximum height shall be measured from the finish grade or surface at the equipment to the top of the equipment at its highest point. A fire access gate with a lock that is capable of being cut away during emergency operations or a security lock such as “Knox Lock” shall be provided which meets the requirements of the local fire authority having jurisdiction. 10 foot clearance from all vegetation on all sides of the photovoltaic system shall be provided.
  5) To provide a disconnect location which is identified and accessible for fire department fire-fighting operations. Architect/Engineer of record to coordinate with local utility provider for requirements regarding connection to service.

- That the (Governing entity) hereby adopts the resolution; and
- Directs the District staff to forward a copy of the adopted and signed resolution to DSA upon award of contract.

PASSED AND ADOPTED at (type of meeting; i.e. Regular board meeting, special session) of the (Legal governing entity) of the (Name of School District, Community College District, UC) on (Date)

ATTEST:

(Signature governing entity representative)
Appendix D: Standing Seam Metal Roof Testing

**Photograph #1**: Example of Test Apparatus to: (1) Determine the capacity of the Seam Connecting Device as required per Section 2.3.2, (2) Production testing of installed devices per Section 2.3.3 a).
Photograph #2: Example of Field Test as require per Section 2.3.3 b).

Test apparatus to bridge over adjacent seam on each side.

Stand outside of the area that is being tested so as not to alter the test results.

Test load shall be applied through the Seam Connecting Devices.

Seam Connecting Devices (S-5!, Ace clamps, etc.) are to be installed at the locations shown on the approved plans.
Appendix E: Lowest Average Monthly Low Temperature

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<thead>
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<th>City</th>
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<td>Big Bear</td>
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<td>Chico</td>
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<td>Fresno</td>
<td>38</td>
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<td>Hesperia</td>
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*Source: www.weather.com
## Prototype Cost, One Frame

### Mechanical Components and Inverter Cost

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### Cost of 7 Frames

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<td>20</td>
<td>$0.22</td>
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### Grand Total: $ 1,426.42
Appendix G: Single Line Diagram

Pg. 107-111
RECOMMENDED MIN. 8'-5\(\frac{1}{2}\)"

1) 3.855 KW DC SOLAR PHOTOVOLTAIC SYSTEM
2) SOLAR MODULES MOUNTED AT 31 DEGREE TILT. SYSTEM IS NOT BALLASTED.
3) SINGLE STORY, LOW PITCH, STANDING SEAM ROOF
4) CONNECT SYSTEM TO MAIN SERVICE PANEL VIA LOAD SIDE BREAKER

ELECTRICAL ENGINEER OF RECORD:

CHARLES JOY

BELLEVUE SANTA FE CHARTER SCHOOL
1401 SAN LUIS BAY DRIVE, SAN LUIS OBISPO, CA 93405
APN: 076-521-055

ENGINEER: CHARLES JOY  DRAFTER: CHARLES JOY

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<tr>
<td>PV-01</td>
<td>SITE PLAN AND MODULE LAYOUT</td>
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<td>PV-02</td>
<td>EQUIPMENT ELEVATION AND ELECTRICAL DETAILS</td>
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<td>PV-03</td>
<td>ONE LINE DIAGRAM</td>
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<td>PV-04</td>
<td>INVERTER SPECIFICATION SHEET</td>
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SYSTEM INFORMATION

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<tr>
<td>AR-02</td>
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LEGEND

(N) - NEW CONSTRUCTION
(E) - EXISTING CONSTRUCTION
(N) INVERTER WITH INTEGRATED DC DISCONNECT
(N) CONDUIT RUN
(N) JUNCTION BOX
(N) ARRAY AR-01
(N) ARRAY AR-02
(N) BUILDING "SCITECHATORIUM"
(E) SERVICE ENTRANCE & MAIN PANEL (EXTERIOR)
(E) PROPERTY LINE
(E) BATHROOMS
(E) SCIENCE BUILDING
(E) PROPERTY LINE
(E) PARKING
(E) PV ARRAY LOCATION
(E) SCIENCE BUILDING
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(ELECTRICAL ENGINEER OF RECORD:

CHARLES JOY

BELLEVUE SANTA FE CHARTER SCHOOL
1401 SAN LUIS BAY DRIVE, SAN LUIS OBISPO, CA 93405
APN: 076-521-055

SITE PLAN
SCALE: 1/16"=1'

PV-01  REV: A  5/9/2014
A1

MANUFACTURER SPECIFIED GROUNDING LOCATION

#10-24 18-8 SS LOCKNUT WITH EXTERNAL TOOTH LOCK WASHER

MODULE FRAME WALL
8 AWG BARE CU WIRE
SS SET SCREW INCLUDED

LAY-IN LUG TERMINAL AL/CU DUAL RATED (TIN PLATED CU) USE ILSCO GBL-4DBT OR APPROVED EQUIVALENT

NOTE:
1. REMOVAL OF PAINT IS NOT NEEDED PER UL 1703.11.3 AND 1703.11.4
2. LUG RATED FOR ONE WIRE ONLY

#10-24 x 3/4" SS HCS BOLT (TIGHTEN TO 5 FT-LBS TORQUE)

SS SET SCREW INCLUDED

8 AWG BARE CU WIRE

MODULE RACKING FRAME COMPONENT

A2

LAY-IN LUG TERMINAL AL/CU DUAL RATED (TIN PLATED CU) USE ILSCO GBL-4DBT OR APPROVED EQUIVALENT

#10-24 x 3/4" SS HCS BOLT (TIGHTEN TO 5 FT-LBS TORQUE)

#10-24 18-8 SS LOCKNUT WITH EXTERNAL TOOTH LOCK WASHER

ELECTRICAL ENGINEER OF RECORD:
CHARLES JOY

BELLEVUE SANTA FE CHARTER SCHOOL
1401 SAN LUIS BAY DRIVE, SAN LUIS OBISPO, CA 93405
APN: 076-521-055
CA C-10 ELECTRICAL #750184

EQUIPMENT ELEVATION
SCALE: NTS

PV-02
REV: A
5/9/2014
ELECTRICAL NOTES:
1. GROUNDING WIRE WILL BE BONDED DIRECTLY TO FACILITY GROUND. GROUND BETWEEN INVERTER AND POINT OF CONNECTION COMPLIES WITH 2011 NEC 690.47.
2. ELECTRICAL SYSTEM GROUNDING WILL COMPLY WITH 2011 NEC 250.
3. MODULE CONNECTIONS TO BE MADE WITH #10 PV WIRE PER 690.35(B).
4. ARRAY CONDUCTORS ARE SIZED FOR DERATED CURRENT PER STRING. 8.3 AMPS SHORT CIRCUIT CURRENT
125% DERATING FOR EXTREME IRRADIANCE CONDITIONS (NEC 690.8 (a))
125% DERATING, CONTINUOUS PHOTOVOLTAIC SOURCE CURRENT (NEC 690.8 (b))
156% TOTAL DERATING (COMBINATION OF ABOVE)
12.97 AMPS TOTAL CAPACITY

5. INVERTER PROVIDES NECESSARY GROUND FAULT PROTECTION AS REQUIRED BY 2011 NEC 690.5.
6. INVERTER PROVIDES NECESSARY ARC-FAULT CIRCUIT PROTECTION AS REQUIRED BY 2011 NEC 690.11.
7. PHOTOVOLTAIC SYSTEM HAS CONDUCTOR BONDED TO GROUND IN INVERTER AS REQUIRED BY 2011 NEC 690.41 SYSTEM GROUNDING, AND 690.42 POINT OF SYSTEM GROUNDING CONNECTION.
8. WHERE DC PHOTOVOLTAIC OUTPUT CIRCUITS ARE RUN INSIDE A BUILDING THEY SHALL BE CONTAINED IN A METALLIC RACEWAY, TYPE MC METAL-CLAD CABLE THAT COMPLIES WITH 2011 NEC 250.118(10) OR ENCLOSURE FROM THE POINT OF PENETRATION TO THE FIRST READILY ACCESSIBLE DISCONNECTING MEANS -2011 NEC 690.31 (E).
9. USE UL APPROVED BONDING FITTINGS AT ALL CONDUIT/BOX JUNCTIONS.
10. MODULES CONFORM TO UL 1703 REQUIREMENTS.
11. INVERTER CONFORMS TO AND IS LISTED UNDER UL 1741.
12. GROUND ALL RACKING COMPONENTS AND MODULES PER A1 & A2 ON PV-02.

SYSTEM CHARACTERISTICS STICKER

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<tr>
<th>Model Number</th>
<th>Q.Pro 215</th>
<th>Q.Pro 220</th>
<th>Q.Pro 225</th>
<th>Q.Pro 230</th>
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<td>alpha Voc [ºC]</td>
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NOTES TO INSTALLER:
- ADD (1) NEW 25 AMP 2-P PV BREAKER TO MAIN PANEL.
- INSTALL (4) 15 AMP KLKD FUSES INSIDE INTEGRATED FUSE DISCONNECT.
- GROUNDING WILL BE THROUGH-BOLTED, INSTEAD OF A THREAD CUTTING SCREW.

WARNING - Dual Power Sources
DO NOT USE IN PARALLEL SYSTEM.
WARNING - Electrical Shock Hazard
DO NOT TOUCH TERMINALS.

CAUTION: SOLAR ELECTRIC SYSTEM CONNECTED
TENSILE STRAP SHALL BE CONTAINED IN A METALLIC RACEWAY, TYPE MC METAL-CLAD CABLE OR ENCLOSURE FROM THE POINT OF PENETRATION TO THE FIRST READILY ACCESSIBLE DISCONNECTING MEANS - 2011 NEC 690.31 (E).

WARNING - Caution. Do not replace fuse with a larger one.
WARNING - MAY BE ENERGIZED IN THE OPEN POSITION.
WARNING - DC VOLTAGE IS ALWAYS PRESENT WHEN DISCONNECT, COMBINER BOX, OR EQUIVALENT IS OPEN:
- DC CONDUIT MAY BE ENERGIZED.
- INVERTER OUTPUT CONNECTION MAY BE ENERGIZED.
- SECOND SOURCE IS PHOTOVOLTAIC SYSTEM.

LABEL PLACEMENT:
- NEXT TO METER (ONLY IF DEFT REQUIRED)
- INSIDE OR FRONT OF PANEL
- ON SIDE OF PANEL

CAUTION: SOLAR CIRCUIT MAY BE ENERGIZED IN THE OPEN POSITION.
- INSIDE OR FRONT OF PANEL
- NEXT TO METER
- ON SIDE OF PANEL
- ON PANEL OR EQUIVALENT
- MAY BE ENERGIZED IN THE OPEN POSITION.

CAUTION: SOLAR MODULES ARE EXPOSED TO SUNLIGHT MAY BE ENERGIZED IN THE OPEN POSITION.

Insulation - Insulation - Electrical Shock Hazard
- MAY BE ENERGIZED IN THE OPEN POSITION.

CAUTION: SOLAR MODULES ARE EXPOSED TO SUNLIGHT MAY BE ENERGIZED IN THE OPEN POSITION.

WARNING - Electrical Shock Hazard
DO NOT TOUCH TERMINALS
- MAY BE ENERGIZED IN THE OPEN POSITION.

CALIBRATION - ELECTRICAL SYSTEM GROUNDING
- MAY BE ENERGIZED IN THE OPEN POSITION.

CAUTION: PHOTOVOLTAIC SYSTEM CONNECTED
- MAY BE ENERGIZED IN THE OPEN POSITION.

LABEL PLACEMENT:
- NEXT TO METER (ONLY IF DEFT REQUIRED)
- INSIDE OR FRONT OF PANEL
- ON SIDE OF PANEL
- ON PANEL OR EQUIVALENT
- MAY BE ENERGIZED IN THE OPEN POSITION.

CAUTION: PHOTOVOLTAIC SYSTEM CONNECTED
- MAY BE ENERGIZED IN THE OPEN POSITION.

WARNING - Dual Power Sources
DO NOT USE IN PARALLEL SYSTEM.
WARNING - Electrical Shock Hazard
DO NOT TOUCH TERMINALS.

CAUTION: PHOTOVOLTAIC SYSTEM CONNECTED
- MAY BE ENERGIZED IN THE OPEN POSITION.

LABEL PLACEMENT:
- NEXT TO METER (ONLY IF DEFT REQUIRED)
- INSIDE OR FRONT OF PANEL
- ON SIDE OF PANEL
- ON PANEL OR EQUIVALENT
- MAY BE ENERGIZED IN THE OPEN POSITION.

CAUTION: PHOTOVOLTAIC SYSTEM CONNECTED
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WARNING - Dual Power Sources
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WARNING - Electrical Shock Hazard
DO NOT TOUCH TERMINALS.

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DO NOT TOUCH TERMINALS.

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CAUTION: PHOTOVOLTAIC SYSTEM CONNECTED
- MAY BE ENERGIZED IN THE OPEN POSITION.

WARNING - Dual Power Sources
DO NOT USE IN PARALLEL SYSTEM.
WARNING - Electrical Shock Hazard
DO NOT TOUCH TERMINALS.

CAUTION: PHOTOVOLTAIC SYSTEM CONNECTED
- MAY BE ENERGIZED IN THE OPEN POSITION.
ENGINEER: CHARLES JOY  
DRAFTER: CHARLES JOY  

PHOTOVOLTAIC SYSTEM  

REC SOLAR, INC.  
810 Fiero Lane  
San Luis Obispo, California 93401  
Phone (805)540-7639

BELLEVUE SANTA FE CHARTER SCHOOL  
1401 San Luis Bay Drive, San Luis Obispo, CA 93405  

INVERTER SPECS  
SMA America, LLC

### Technical data

<table>
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<th>Sunny Bay 5000US</th>
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<td><strong>Input (DC)</strong></td>
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<td>Max. Module Power (Pm)</td>
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<td>6000 W</td>
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<td><strong>Output (AC)</strong></td>
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<tr>
<td>Max. AC Output Power</td>
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<tr>
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<td>120 V / 240 V</td>
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### General data

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* Partially data as of February 2016. NREL, US Inverter lab with grey bars

Type designation: SB 4000US/LG-22 SB 5000US/LG-22 SB 6000US/LG-22

**Standard feature** | **Optional feature** | **Not available**

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**Notation:** NTS = North American Time Standard; PV-04 = PV System; REV: A = Revision 4; 5/9/2014 = Date of last update.
Appendix H: G-Code

Pg. 112-137
Appendix G

HAAS VF2 Machine Codes [Brackets]

% O65412(REV_10_OP10_HORIZONTAL_B RAC_G110)
G90 G80 G40 G110
N0010T6M06 (1 IN END MILL)
S6000M03
M08
G01G43X-0.4599Y0.1928Z-0.4975F60.H06M08
G02X-0.1866Y0.2415I0.4604J-1.7938
G01X-0.0886Y0.2475
X1.1987Y.25
X1.9682
G02X0.4602Y1.9241L0.3271-1.7938
G01Z-1.15F90.
G00X1.15Y-0.6
G43Z2.5H07M08
G00X1.Y-6
G43Z5.5H07M08
G81X1.Y-.6Z-.6129R.5F30. (.1129 DEPTH)
G80
N0030T8M06 (U DRILL CHECK LENGTH)
S3260M03
G00G43Z2.5H08M08
G80
G28G91Z0.

G28 Y0.
M30
%

% O32145(rev_10_horiz_brac_op20_g111)
G90 G80 G40 G111
N0010T6M06 (1 IN ROUGHER)
S6000M03
X3.3522Y.6194Z-1.4634 X3.6523Y-2.4912 X4.0526Y.0582
X3.4329Y.5607Z-1.4835 X3.6052Y-2.4988 X4.0599Y0.
X3.5236Y.5192Z-1.4946 X3.5088Y-2.5243Z-1.4934 X4.0553Y-0.107
X3.6055Y.4988Z-1.4975 X3.4194Y-2.5686Z-1.481 X4.055Y-.7945
X3.6525Y.4913 X3.3406Y-2.6297Z-1.4595 X4.0559Y-.8481
X3.6987Y.4799 X3.2755Y-2.7053Z-1.4277 X4.055Y-1.9839
X3.8055Y.4338 X3.1963Y-2.8872Z-1.3197 X4.0526Y-.20582
X3.8541Y.4018 X3.1854Y-2.9864Z-1.2234 X4.0424Y-.21155
X3.8988Y.3644 X3.1916Y-3.0706Z-.9975 X4.0257Y-.21713
X3.9387Y.322 Z.1F90. X4.0027Y-.2248
X3.9735Y.2753 G00X3.192Y1.0707 X3.9737Y-2.275
X4.0027Y.2248 Z-1.3975 X3.9413Y-.23185
X4.0257Y.1713 G01Z-1.4975F60. X3.9009Y-.23621
X4.0424Y.1155 X3.1861Y.9711Z-1.5464 X3.8541Y-.24018
X4.0526Y.0582 X3.2001Y.8724Z-1.5642 X3.8055Y-.24338
X4.0559Y0. X3.2335Y.7784Z-1.5761 X3.7534Y-.246
X4.0553Y-.0107 X3.2849Y.6929Z-1.5847 X3.6987Y-.24799
X4.055Y-.7945 X3.3522Y.6194Z-1.5907 X3.6523Y-.24912
X4.0559Y-.8481 X3.4329Y.5607Z-1.5947 X3.6052Y-.24988
X4.055Y-1.9839 X3.5236Y.5192Z-1.5969 X3.5088Y-.25243Z-1.5967
X4.0559Y-.2. X3.6055Y.4988Z-1.5975 X3.4194Y-.25686Z-1.5942
X4.0526Y-2.0582 X3.6525Y.4913 X3.3406Y-.26297Z-1.5899
X4.0257Y-2.1713 X3.7534Y.46 X3.2268Y-2.7923Z-1.5746
X4.0027Y-.2248 X3.8055Y.4338 X3.1963Y-.28872Z-1.5619
X3.9737Y-.2275 X3.1854Y-.29864Z-1.5427
X3.9413Y-.23185 X3.8988Y.3644 X3.1916Y-.30706Z-1.4975
X3.9009Y-.23621 X3.9387Y.322 Z.1F90.
X3.8541Y-.24018 X3.9735Y.2753 G00X.9895Y1.0414
X3.8055Y-.24338 X4.0027Y.2248 G01Z.0025F60.
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X.6512Y-.2.3644 X1.358Y1.0707Z-.9975 X.5243Y.1713
X.6113Y-.2.322 Z.1F90. X.5473Y.2.248
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X.5243Y-.2.1713 G01Z-.1.4975F60. X.6512Y.3.644
X.5076Y-.2.1155 X1.3687Y-.2.9683Z-.1.5464 X.6959Y.4.018
X.4974Y-.2.0582 X1.354Y-.2.8696Z-.1.5642 X.7445Y.4.338
X.4953Y-.2.0251 X1.32Y-.2.7759Z-.1.5761 X.7945Y.4.589
X.4945Y-.1.992 X1.268Y-.2.6907Z-.1.5847 X.8513Y.4.799
X.495Y-.1.1864 X1.2001Y-.2.6176Z-.1.5907 X.8975Y.4.913
X.4941Y-.1.1519 X1.1191Y-.2.5595Z-.1.5947 X.9445Y.4.988
X.495Y-.0.161 X1.0281Y-.2.5187Z-.1.5969 X.10409Y.5.2442-.1.5967
X.4941Y0. X.9461Y-.2.4988Z-.1.5975 X1.1303Y.5.6872-.1.5942
X.4974Y.0.582 X.8983Y-.2.4915 X1.2091Y.6.2982-.1.5899
X.5076Y.1155 X.8513Y-.2.4799 X1.2741Y.7.0542-.1.5835
X.5243Y.1713 X.7966Y-.2.46 X1.3229Y.7.9242-.1.5746
X.5473Y.2248 X.7445Y-.2.4338 X1.3533Y.8.8742-.1.5619
X.5765Y.2753 X.6059Y-.2.4018 X1.3643Y.9.8652-.1.5427
X.6113Y.322 X.6512Y-.2.3644 X1.3581Y.1.0707Z-.1.4975
X.6512Y.3644 X.6113Y-.2.322 Z0.9F90.
X.6959Y.4018 X.5767Y-.2.2756 N0020T8M06 (U DRILL)
X.7445Y.4338 X.5473Y-.2.2248 S3260M03
X.7945Y.4589 X.5243Y-.2.1713 G00X4.0Y-.1.
X.8513Y.4799 X.5076Y-.2.1155 G43Z.25H08M08
X.8975Y.4913 X.4974Y-.2.0582 G81X4.0Y-.1.2-.2.1106R.25F20.
X.9445Y.4988 X.4953Y-.2.0251 X.5
X.1.0409Y.5.2442Z-.1.4934 X.4945Y-.1.992 G80
X.1.1303Y.5.6872Z-.1.481 X.495Y-.1.1864 N0030T12M06 (90 DEG .500 CHAMFER TOOL)
X.1.2091Y.6.2982Z-.1.4505 X.4941Y-.1.1519 S3680M03
X.1.2741Y.7.0542Z-.1.4277 X.495Y-.0.161 G00X1.0Y-.13
X.1.3229Y.7.9242Z-.1.3828 X.4941Y0.
X.1.3533Y.8.8742Z-.1.3197 X.4974Y.0.582 G43Z.25H12M08
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G02X1.395Y-2.13I.-.13J0.
G01X.995
G02X.865Y-2.I0.13
G01Y0.
G02X.995Y.13I.13J0.
G01X1.015
Z.1
GO0X3.175
Z.-02
GO12.-12
X3.555
G02X3.685Y0.10J.-.13
G01Y-2.
G02X3.555Y-2.13I.-.13J0.
G01X3.155
G02X3.025Y-2.I0.13
G01Y0.
G02X3.155Y.13I.13J0.
G01X3.175
Z0.
G28G91Z0.
G28 Y0.
M30
%
%G01Z.0
G065456(REV_10_U_BRACKET_OP10_G113)
G90 G80 G40 G113
N0010T3 M06 (4 IN FACE MILL)
S1500M03
M08
G01G43X-2.2Y-.98Z-.3F30. H03 M08
X5.75
Z.1
G00X3.175
G28G91Z0.
G28 Y0.
M30
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G01X1.015
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GO0X3.175
Z.-02
GO12.-12
X3.555
G02X3.685Y0.10J.-.13
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G02X3.555Y-2.13I.-.13J0.
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Z0.
G28G91Z0.
G28 Y0.
M30
%
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G90 G80 G40 G113
N0010T7M06 (3 CENTER DRILL .250 Dia)
S8000 M03
M08
G81G43X.5Y-1.35Z-.1129R.1F20.H07M08
X3.25
G80
N0020T8M06 ( U Drill Over 2.81 Long )
S3260M03
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X3.25
G80
N0030T6M06 (1 in Hanita Rougher)
S6000M03
G00X.0061Y-3.2
G43Z.1H06M08
G01Z-.4175F60.
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G01X-.1298Y-2.6218
X-.125Y-2.4715
X-.129Y-2.3212
X-.1296Y-2.3097
G02X.1216Y-1.55761.1253.0422
X.3279Y-1.34881.9306J-.7131
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X5815Y-2.9353  X3.2207Y-2.0987  X3.0705Y.3467
X5523Y-2.8848  X3.2374Y-2.1545  X3.1337Y.282
X5293Y-2.8313  X3.2476Y-2.2118  X3.1685Y.2353
X5126Y-2.7755  X3.2509Y-2.27  X3.1977Y.1848
X5024Y-2.7182  X3.25Y-2.2852  X3.2207Y.1313
X4991Y-2.66  Y-2.6439  X3.2374Y.0755
X5Y-2.6439  X3.2509Y-2.66  X3.2476Y.0182
Y-2.2861  X3.2476Y-2.7182  X3.2509Y-.04
X4991Y-2.27  X3.2374Y-2.7755  X3.25Y-.0561
X5024Y-2.2118  X3.2207Y-2.8313  Y-.4139
X5126Y-2.1545  X3.1977Y-2.8848  X3.2509Y-.43
X5292Y-2.0988  X3.1685Y-2.9353  X3.2476Y-.4882
X5523Y-2.0452  X3.1337Y-2.982  X3.2374Y-.5455
X5815Y-1.9947  X3.0938Y-3.0244  X3.2207Y-.6013
X6151Y-1.9496  X3.0874Y-3.0297  X3.1977Y-.6548
X6962Y-1.8656  X3.0538Y-3.0644  X3.1685Y-.7053
X7409Y-1.8282  X3.0091Y-3.1018  X3.1337Y-.752
X7895Y-1.7962  X2.9605Y-3.1338  X3.0572Y-.8307
X8416Y-1.77  X2.9084Y-3.16  X3.0091Y-.8718
X8963Y-1.7501  X2.8537Y-3.1799  X2.9605Y-.9038
X953Y-1.7367  X2.797Y-3.1933  X2.9084Y-.93
X1.0109Y-1.7299  X2.7698Y-3.1978  X2.8537Y-.9499
X2.7391  Z.190.  X2.797Y-.9633
X2.797Y-1.7367  G00X2.6097Y.5013  X2.7391Y-.9701
X2.8537Y-1.7501  Z-.3175  X1.0109
X2.9084Y-1.77  G01Z-.8375F60.  X.953Y-.9633
X2.9605Y-1.7962  X2.7931Y5001  X.8963Y-.9499
X3.0091Y-1.8282  X2.797Y.4933  X.8416Y-.93
X3.0538Y-1.8656  X2.8537Y.4799  X.7925Y-.9053
X3.0709Y-1.8838  X2.9084Y.46  X.7409Y-.8718
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G01 X.283 Y-1.3103
G02 X-1.1309 Y-1.4368 I1.7409 J1.886
G01 X-1.1298 Y-1.3924
G02 X-1.1256 Y-1.5293 I2.8313
G02 X.033 Y.5125 I1.1343 J0.0824
G01 Z.1 F90.
G00 X3.7371 Z-1.1575
G01 Z-1.5975 F60.
G02 X3.8809 Y-2.2632 I-1.011 J-0.5582
G01 X3.8798 Y-2.0782
X3.875 Y-2.2285
X3.879 Y-2.3788
X3.87 Y-2.4191
X3.88 Y-2.6491
G02 X3.4206 Y-1.3502 I-1.1933 J0.0098
G01 X3.467 Y-1.3897
G02 X3.8809 Y-2.2632 I-1.7409 J-0.886
G01 X3.8798 Y-2.3081
X3.875 Y-2.4555
X3.878 Y-2.6029
G02 X3.8705 Y-2.8119 I-0.9476 J-0.0677
G01 X3.8693 Y-2.8198
G02 X3.7396 Y-3.2 I-1.1955 J1.955
G01 Z-1.1575
G01 Z1.1575
G02 X2.797 Y-1.7367
G01 Z-1.1575
G02 X2.8537 Y-1.7501
G01 Z2.797 Y4.933
X2.9605 Y-1.7962
X2.8537 Y-1.4799
N0040 T12 M06 (90 Degree .500 Dia Chamfer tool)

S3680 M03

G00 X1.02 Y-2.1

G43 Z.1 H12 M08

Z-.02

G01 Z-.12

X2.73

X.4991 Y-.04

Z.1

X.5024 Y.0182

X.5126 Y.0755

X.5293 Y.1313

X.5523 Y.1848

X.5815 Y.2353

G00 X1.02 Y.13

Z-.02

X2.73

G00 Y-.6

X.4991 Y-.04

Y-.4139

Z-.02

X1.02

X.5126 Y.0755

X.5293 Y.1313

X.5523 Y.1848

X.5815 Y.2353

X.6163 Y.282

X.6562 Y.3244

X.6626 Y.3297

X.6962 Y.3644

N0050 T23 M06 (.375 rounding cutter)

S3200 M03

G00 X2.73 Y-.28

X.7895 Y.4338

G00 X.792 Y-.35

G43 Z.1 H23 M08

Z-.249

X.8963 Y.4799

Z-.349 F10.

X.953 Y.4933

Y-3.29

X.1010 Y.5013

Z.1

X.1403 Y.5013

X.953 Y.9633

Z.1 F90.

G00 X.792 Y-.35

X.8963 Y.9499

N0040 T12 M06 (90 Degree .500 Dia Chamfer tool)

Z-.249

X.8416 Y.93

G01 Z-.349

X.8416 Y.93

S3680 M03

Y.65

X.7925 Y-.9053
Z.1  
G28G91Z0.  
G28 Y0.  
M30  
%

O64125(Rev_7_Solid_Base_OP10_G110)  
G90 G80 G40 G110  
N0010T7M06 (#3 Center Drill .250 Dia)  
S6000M03  
M08  
G81G43X1.Y- .6Z-.1129R.1F20.H07M08  
G80  
N0020T8M06  
S3260M03  
G00X1.Y-.6  
G43Z.25H08  
G80  
G28G91Z0.  
G28 Y0.  
M30  
%

O43625(Rev_10_Solid_Base_Op20_G111)  
G90G80G40G111  
N0010T6M06 (1 Inch Hanita Rougher .50 depth .750 over)  
S6000M03  
M08
Y-.0557  X1.0213Y-2.282  G01Z-1.5975F60.
X.9041Y-.04  X.9865Y-2.2353  X1.358Y-2.4933
X.9074Y.0182  X.9573Y-2.1848  X1.3013Y-2.4799
X.9176Y.0755  X.9343Y-2.1313  X1.2466Y-2.46
X.9343Y.1313  X.9176Y-2.0755  X1.1945Y-2.4338
X.9573Y.1848  X.9074Y-2.0182  X1.1459Y-2.4018
X.9865Y.2353  X.9041Y-1.96  X1.1012Y-2.3644
X1.0213Y.282  X.905Y-1.9443  X1.0841Y-2.3462
X1.1012Y.3644  Y-.0557  X1.0213Y-2.282
X1.1459Y.4018  X.9041Y-.04  X.9865Y-2.2353
X1.1945Y.4338  X.9074Y0.0182  X.9573Y-2.1848
X1.2466Y.46  X.9176Y.0755  X.9343Y-2.1313
X1.3013Y.4799  X.9343Y.1313  X.9176Y-2.0755
X1.358Y.4933  X.9573Y.1848  X.9074Y-2.0182
X1.3945Y.4988  X.9865Y.2353  X.9041Y-1.96
Z.1F90.  X.9021Y-282  X.905Y-1.9443
G00X.2759Y-2.4998  X.1012Y.3644  Y-.0557
Z-.6975  X.1459Y.4018  X.9041Y-.04
G01Z-1.1975F60.  X.1945Y.4338  X.9074Y.0182
G02X.155Y-1.9357I1.1445J5404  X.12466Y.46  X.9176Y.0755
G01Y-.0527  X.3013Y.4799  X.9343Y.1313
G02X.2807Y.4998I1.3155J-.0089  X.358Y.4933  X.9573Y.1848
G01Z.1F90.  X.3945Y.4988  X.9865Y.2353
G00X1.3942Y-2.4988  Z.1F90.  X.1021Y.282
Z-.6975  G00X.2759Y-2.4998  X.1012Y.3644
G01Z-1.1975F60.  Z-.10975  X.1459Y.4018
X.1358Y-2.4933  G01Z-1.5975F60.  X.1945Y.4338
X.3013Y-2.4799  G02X.155Y-1.9357I1.1445J5404  X.12466Y.46
X.12466Y-2.46  G01Y-.0527  X.3013Y.4799
X.1945Y-2.4338  G02X.2807Y.4998I1.3155J-.0089  X.358Y.4933
X.1459Y-2.4018  G01Z.1F90.  X.3945Y.4988
X.1012Y-2.3644  G00X1.3942Y-2.4988  Z.1F90.
X.10841Y-2.3462  Z-.10975  G00X.2741Y.4998
<table>
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<th>Command</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
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<td>G01Z-.3975F60.</td>
<td>X3.4041</td>
<td>Y-2.4018</td>
<td>Z.X3.6451-.0542</td>
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<tr>
<td>G02X4.395Y-.0643I-.1145J-.5404</td>
<td>X3.3555</td>
<td>Y-2.4338</td>
<td>Z.X3.645Y-1.9443</td>
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<td>G01Y-1.9331</td>
<td>X3.3034</td>
<td>Y-2.46</td>
<td>Z.X3.6459Y-1.96</td>
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<td>Z.X3.6324Y-2.0755</td>
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<td>G00X3.1555Y.4988</td>
<td>X3.1561Y-2.4988</td>
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<td>X3.4488Y.3644</td>
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<td>Z.X3.4072Y-2.3993</td>
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<tr>
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<td>Z.X3.3555Y-2.4338</td>
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<tr>
<td>X3.5287Y-2.282</td>
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X3.3034Y.46  G01Z-1.5975F60.  X3.4072Y-2.3993
X3.3555Y.4338  G02X4.395Y-.0643I-1.1445J-.5404  X3.3555Y-2.4338
X3.4041Y.4018  G01Y-1.9337  X3.3034Y-2.46
X3.4488Y.3644  G02X4.2735Y-2.4998I-1.2457J-.0288  X3.2487Y-2.4799
X3.4659Y.3462  G01Z.1F90.  X3.192Y-2.4933
X3.5287Y.282  G00X3.1555Y.4988  X3.1561Y-2.4988
X3.5635Y.2353  Z-1.0975  Z.1F90.
X3.5927Y.1848  G01Z-1.5975F60.  N002OT8M06 (U Drill No Peck 25 ipm)
X3.6157Y.1313  X3.192Y.4933  S3260M03
X3.6324Y.0755  X3.2487Y.4799  M08
X3.6426Y.0182  X3.3034Y.46  G00X4.05Y-1.
X3.6459Y-.04  X3.3555Y.4338  G43Z.25H08
Y-.1.9443  X3.4488Y.3644  G80
X3.6426Y-2.0182  X3.5287Y.282  G80
X3.6324Y-2.0755  X3.5635Y.2353  N003OT12M06 (90 deg .5 Dia Chamfer tool)
X3.6157Y-.2.1313  X3.5927Y.1848  S3680M03
X3.5927Y-.2.1848  X3.6157Y.1313  G00X4.125Y.13
X3.5635Y-.2.2353  X3.6322Y.0764  G43Z1H12M08
X3.5287Y-.2.282  X3.6426Y.0182  Z-.02
X3.4888Y-.3.244  X3.6459Y-.04  G01Z-.12F28.
X3.4824Y-.3.297  X3.645Y-.0557  X3.145
X3.4509Y-.3.3621  Y-.1.9443  G02X3.275Y.0J-.13
X3.4072Y-.3.3993  X3.6459Y-.96  G01Y-.2.
X3.3555Y-.2.4338  X3.6426Y-.2.0182  G02X3.145Y-.2.13J-.13J0.
X3.3034Y-.2.46  X3.6324Y-.2.0755  G01X1.405
X3.2487Y-.2.4799  X3.6157Y-.2.1313  G02X1.275Y-.2.10J.13
X3.192Y-.2.4933  X3.5927Y-.2.1848  G01Y0.
X3.1561Y-.2.4988  X3.5635Y-.2.2353  G02X1.405Y.13I.13J0.
Z.1F90.  X3.5287Y-.2.282  G01X1.425
G00X4.2741Y.4988  X3.4943Y-.2.3185  Z.1
Z-.1.0975  X3.4509Y-.2.3621
G28G91Z0.
G28 Y0.
M30
%
%
O6452(REV_2_MID_CLAMP_OP10_G117)
G90 G80 G40 G117
N0010T6 M06 (1 IN 3 FLUTE SHELL)
S6000M03
M08
G00X4.21Y-1.96
G01Z-.1F60.
X-.46
G01 Y-.04
G01X3.96
G01Z-.22F25.
G02X3.5Y-1.131.0791J.1031
G01X0.
G02X-.13Y-1.10J.13
G01Y0.
G02X0.Y1.13J1.130.
G01X3.5
G02X3.63Y0.10J-.13
G01Y1.
G02X3.5791Y-1.1031J-1.30.
G01Z1.
G00X1.804Y-.5
Z-.12
G01Z-.22
G03X1.804Y-.5J-1.0540.
G01Z1.
G28G91Z0.
G02X-.1702Y.4703J1.5857J-.0432
G01Z1.
G00X.3914Y-1.4993
G01Z-.0825
G02X.2359Y-.9669J1.9218J.5581
G01Y-.0305
G02X3.942Y.4996J1.0867J-.0358
G01Z1.
G00X1.1552Y-1.4978
G01Z-.0825
X1.086Y-1.473
X1.0324Y-1.4461
X.9824Y-1.4132
X.9365Y-1.3747
X.8554Y-1.2911
X.8196Y-1.2431
X.7896Y-1.1912
X.7659Y-1.1362
X.7487Y-1.0788
X.7383Y-.0198
X.7349Y-.96
Y-.04
X.7383Y.0198
X.7487Y.0788
X.7659Y.1362
X.7896Y.1912
X.8196Y.2431
X.8554Y.2911
X.9365Y.3747
X.9824Y.4132
X1.0324Y.4462
X1.0859Y.473
X1.1591Y.4988

Z1
N0020T8M06 (U DRILL)
S3260M03
G00X1.75Y-.5
G43Z.6H08M08
G83X1.75Y-.5Z-1.1106R.25Q1.1F30.
G80
G00Z
G02Z-.1
N0030T12M06 (90 DEGREE .500 DIA)
S3680M03
G00X3.5791Y-1.1031
G43Z.1H12M08
Z-.12
X.9823Y-1.4133  
G02X.3941Y.49961.0865J-.0355  
G02X.3.6701Y1.47031-1.5862J.0392
X.9364Y-1.3748  
G01Z.1  
G01Z.1
X.8553Y-1.2912  
G00X1.1547Y-1.4978  
G00X3.1086Y.4993
X.8195Y-1.2431  
Z-.2825  
G01Z-.0825
X.7896Y-1.1912  
G01Z-.4825  
G02X3.2641Y-.03311-.9218J-.5581
X.7658Y-1.1362  
X1.0859Y-1.4731  
G01Y-.9662
X.7487Y-1.0788  
X1.0324Y-1.4462  
G02X3.106Y-1.4993I-.0872J.0325
X.7382Y-1.0198  
X.9823Y-1.4133  
G01Z.1
X.7349Y-.96  
X.9364Y-1.3748  
G00X2.345Y.4978
Y-.04  
X.8553Y-1.2912  
G01Z-.0825
X.7382Y.0198  
X.8195Y-1.2431  
X2.414Y.473
X.7487Y.0788  
X.7896Y-1.1912  
X2.4676Y.4461
X.7658Y.1362  
X.7658Y-1.1362  
X2.5167Y.4132
X.7896Y.1912  
X.7486Y-1.0788  
X2.5635Y.3747
X.8195Y.2431  
X.7382Y-1.0198  
X2.6446Y.2911
X.8553Y.2912  
X.7349Y-.96  
X2.6804Y.2431
X.9364Y.3748  
Y-.04  
X2.7104Y.1912
X.9823Y.4133  
X.7382Y.0198  
X2.7341Y.1362
X1.0324Y.4462  
X.7486Y.0788  
X2.7513Y.0788
X1.0859Y.4731  
X.7658Y.1362  
X2.7617Y.0198
X1.1588Y.4988  
X.7896Y.1912  
X2.7651Y-.04
Z.1  
X.8195Y.2431  
Y-.9576
G00X-.1723Y-1.4695  
X.8553Y.2912  
X2.7617Y-1.0198
Z-.2825  
X.9364Y.3748  
X2.7513Y-1.0788
G01Z-.4825  
X.9823Y.4133  
X2.7341Y-1.1362
G02X-.2631Y-.97211.1.4854J.5281  
X1.0324Y.4462  
X2.7104Y-1.1912
G01Y-.0233  
X.10859Y.4731  
X2.6804Y-1.2431
G02X-.1702Y.47021.5855J-.0428  
X1.1588Y.4988  
X2.6446Y-1.2911
G01Z-.2825  
Z.1  
X2.5635Y-1.3747
G00X.3913Y-1.4993  
G00X3.6722Y.4695  
X2.5176Y-1.4132
G01Z-.4825  
G01Z-.0825  
X2.4676Y-1.4462
G02X.2359Y-.9668I.9218J.5579  
G02X3.7631Y-.02771.1.4854J-.5283  
X2.4141Y-1.473
G01Y-.0306  
G01Y-.9729  
X2.345Y-1.4978
X2.5177Y.4133 G02X3.1061Y-1.4993I-1.087J.0321 G01Z-.4975F30.
X2.5636Y.3748 G01Z.1 X.251
X2.6447Y.2912 G00X2.3454Y.4978 Y-.7486
X2.6805Y.2431 Z-.2825 X.401Y-.7483
X2.7104Y.1912 G01Z-.4825 Y-.2513
X2.7342Y.1362 X2.4141Y.4731 X.251Y-.2512
X2.7513Y.0788 X2.4676Y.4462 Y-.4965
X2.7618Y.0198 X2.5177Y.4133 X-.024
X2.7648Y-.0327 X2.5636Y.3748 Y-.9875
X2.7651Y-.9576 X2.6447Y.2912 X-.0243Y-.1.
X2.7618Y.1.0198 X2.6805Y.2431 G03X-.0068Y-.0241I.0238J-.0011
X2.7513Y.1.0788 X2.7104Y.1912 G01X.6793Y-.1.0228
X2.7342Y.1.1362 X2.7342Y.1.1362 X.676Y-.9431
X2.7104Y.1.1912 X2.7514Y.0788 Y-.0587
X2.681Y.1.2423 X2.7618Y.0198 X.6788Y.0234
X2.6447Y.1.2912 X2.7648Y-.0327 X-.0069Y.0241
X2.5636Y.1.3748 X2.7651Y-.9576 G03X-.0243Y.0001I.0061J-.0228
X2.5177Y.1.4133 X2.7618Y.1.0198 G01X-.024Y-.0125
X2.4676Y.1.4462 X2.7514Y.1.0788 Y-.4965
X2.4141Y.1.4731 X2.7342Y.1.1362 X-.299
X2.3452Y.1.4978 X2.7104Y.1.1912 Y-.9875
Z.1 X2.681Y.1.2423 G03X-.0224Y.1.2991I.2985J-.0136
G00X.6723Y.4695 X2.6447Y.1.2912 G01X.2.437Y.1.2967
Z-.2825 X2.5636Y.1.3748 G02X.1.0701J Y.1.204I.048J.2993
G01Z-.4825 X2.5177Y.1.4133 X.951Y-.9474I.1918J.245
G02X.3.7628Y-.0156I.1.4854J-.5281 X2.4676Y.1.4462 G01Y-.0526
G01X.3.7631Y-.9726 X2.4141Y.1.4731 G02X.1.0444Y.1.7721I.2911J.0156
G01Z-.2825 Z.1 G01X-.0224Y.2991
G00X.3.1087Y.4993 N0020T13M06 (.598 2 flute) G03X-.299Y-.0125I.0216J-.2978
G01Z-.4825 S2000M03 G01Y-.4965
G02X.3.2638Y-.0231I-.9218J-.5579 G00X-.299Y-.4965 Z.1
G01X.3.2641Y-.966 G43Z.1H13M08 N0030T13M06
Appendix I: Testing Procedure for SnapNrack Clamps

Pg. 138-143
Iron Web

4/15/2014

Test Plan: Allowable clamp load verification

**Background:** A solar panel frame, which will hold two solar panels, will be installed on the roof of the SciTechatorium. The frame will be secured onto the standing seam roof of SciTechatorium via SnapNrack wide base clamps. DSA, the governing body over school projects that involve solar installation, requires all clamps used in a solar project to be tested before they are used (see IR 16-8, section 2.3.2). Ideally, a replicate model of a section of the standing seam roof would be assembled and tested to failure. However, the building manufacturer declared bankruptcy and the team has been unable to obtain enough information to successfully replicate the roof. Therefore, testing of the clamps will take place on the project site roof. Furthermore, after analysis of the expected wind speeds, per IR 16-7, analysis of frame members, and an additional factor of safety of two, it has been estimated that at worst case scenario load of approximately 448 lbf can be experienced by a clamp.

**Purpose:** To validate clamps can hold a max load of at least 440 lbf.

**Instructions:**

1. Place clamp on a “T-intersection,” where a “T-intersection” is the point where a purlin beam and a standing seam crossover. Potential locations for testing are shown on the attached roof plan.
2. Place the test apparatus along the Z-Purlin beam.
3. Position the SnapNrack clamp over the standing seam.
4. Fully thread the 5/16 -18 bolt welded to the chain into the clamp and torque the nut to 16.7 lb-ft.
5. Adjust top adjusting nut so that the lever is level when chain is pulled taught.
6. Place a 15 lb weight on the opposite end (relative to the clamp) of apparatus.
7. Measure the absolute change vertical movement of the clamp (and seam of the roof, if applicable), *after each 15 lb increment is added.*
8. Add 15 lb, and repeat steps 6-7 until 448 lb of load is being applied to the clamp or if failure is observed.
9. Repeat steps 1-8 for two more trials at the current location and for three trials at another potential location to verify initial results.
Figure 1: Clamp testing fixture with cardboard stand.

Figure 2: Nut to be torqued to 16.7 ft-lbs.
Figure 3: Clamp testing fixture side view, top beam must be horizontal during testing.

Figure 4: Illustration of adjusting nut.
**Governing Static Equation:**

\[
\sum M_B = 0: A_y(32\text{in}) + 12.7 \text{ lbs} \times (19\text{in}) - 3.3 \text{ lbs} \times (5\text{in}) - F_w(8\text{in}) = 0
\]

\[
A_y(32\text{in}) + 241.3 - 16.5 - F_w(8\text{in}) = 0
\]

\[
A_y = -7.025 + F_w\cdot (0.25)
\]

or

\[
F_w = \frac{A_y + 7.025}{0.25}
\]

\[F_w = \text{Resulting upward force on clamp}\]

\[A_y = \text{Applied force}\]

<table>
<thead>
<tr>
<th>Lb force applied</th>
<th>Resultant upward force on clamp (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>88.1</td>
</tr>
<tr>
<td>30</td>
<td>148.1</td>
</tr>
<tr>
<td>45</td>
<td>208.1</td>
</tr>
<tr>
<td>60</td>
<td>268.1</td>
</tr>
<tr>
<td>75</td>
<td>328.1</td>
</tr>
<tr>
<td>90</td>
<td>388.1</td>
</tr>
<tr>
<td>105</td>
<td>448.1</td>
</tr>
</tbody>
</table>

*Table 1: Table tabulating applied force and resulting upward pull on clamp.*
\[ \Delta M_B = 0 : \ F_w(32\text{ in}) + 12.7\text{ lbs}(19\text{ in}) - 3.3\text{ lbs}(5\text{ in}) = A_y(8\text{ in}) \]

SOLVING FOR \( F_w \) GIVEN NEED FOR \( A_y = 500\text{ lbs} \)

\[ F_w(32\text{ in}) = (500\text{ lbs})(8\text{ in}) + 3.3\text{ lbs}(5\text{ in}) - 12.7\text{ lbs}(19\text{ in}) \]
Appendix J: Testing Procedure for Roof

Pg. 144-148
Test Plan: Uplift capacity

**Purpose:** To verify the uplift capacity of the existing standing seam roof panels and connection of the SnapNrack wide base clamps to the SSMR panels and then to the substrate is a minimum of 304 lbs.

**Test to be conducted in accordance to:** IR 16-8 Section 2.3.3 (b)

**Instructions:**

1. Place the test apparatus along the Z-Purlin beam
2. Position the SnapNrack clamp over the standing seam.
3. Fully thread the 5/16 -18 bolt welded to the chain into the clamp and torque the nut to 16.7 lb-ft (Refer to figure 1).
4. Adjust top adjusting nut so that the lever is level when chain is pulled taut.
5. Repeat steps 1-4 to position two additional testing apparatuses along the same seam spaced 4ft apart.
6. Place a 5 lb, weight on the opposite end (relative to the clamp) of apparatus (see table 1 for resulting upward pull on clamp).
7. Observe and note any changes to the clamp or seam of the roof.
8. If failure is not observed, add a 5 lb, weight to the next apparatus and observe reaction.
9. Continue loading test apparatuses sequentially until 305 lb, of load is being applied to the clamps or failure is observed.
10. Repeat steps 1-9 for four other roof zones.
Figure 1: Nut to be torqued to 16.7 ft-lbs.
**Governing Static Equation:**

\[ \sum M_B = 0: A_y \cdot (12 \text{ in}) + 3.11 \text{ lbs} \cdot (7 \text{ in}) - 10.1 \text{ lbs} \cdot (26 \text{ in}) - C_y (48 \text{ in}) = 0 \]

\[ A_y = \frac{10.1 \text{ lbs} \cdot (26 \text{ in}) + C_y (48 \text{ in}) - 3.11 \text{ lbs} \cdot (7 \text{ in})}{12 \text{ in}} \]

or

\[ F_w = \frac{A_y \cdot (12 \text{ in}) + 3.11 \text{ lbs} \cdot (7 \text{ in}) - 10.1 \text{ lbs} \cdot (26 \text{ in})}{48 \text{ in}} \]

\( A_y = \text{Resulting upward force on clamp/roof connection point} \)

\( C_y = \text{Applied force} \)

<table>
<thead>
<tr>
<th>Lb force applied</th>
<th>Resultant upward force on clamp (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>40.0</td>
</tr>
<tr>
<td>10</td>
<td>60.1</td>
</tr>
<tr>
<td>15</td>
<td>80.1</td>
</tr>
<tr>
<td>20</td>
<td>100.1</td>
</tr>
<tr>
<td>25</td>
<td>120.1</td>
</tr>
<tr>
<td>30</td>
<td>140.1</td>
</tr>
<tr>
<td>35</td>
<td>160.1</td>
</tr>
<tr>
<td>40</td>
<td>180.1</td>
</tr>
<tr>
<td>45</td>
<td>200.1</td>
</tr>
<tr>
<td>50</td>
<td>220.1</td>
</tr>
<tr>
<td>55</td>
<td>240.1</td>
</tr>
<tr>
<td>60</td>
<td>260.1</td>
</tr>
<tr>
<td>65</td>
<td>280.1</td>
</tr>
<tr>
<td>70</td>
<td>300.1</td>
</tr>
<tr>
<td>75</td>
<td>320.1</td>
</tr>
</tbody>
</table>

*Table 1: Table tabulating applied force and resulting upward pull on clamp.*
Figure 2: FBD of loading beam, where counter clockwise moments are positive
Appendix K: Structural Engineer's Structural Calculations
Pg. 149-158
Structural Calculations for Roof Mounted PV Panels

Bellevue-Santa Fe Charter School
SciTechatorium Roof
1401 San Luis Bay Dr
San Luis Obispo, CA 93405

Expires 6-30-15

Check for the following Load Combinations:
Load Combination #1: Wind Uplift - 0.6DL Standoff connections
Load Combination #2: DL Rf + DL Solar on Purlins
Load Combination #3: DL Rf + DL Solar + Wind Down on Purlins
Load Combination #4: DL Rf + LL Roof + DL Solar on Purlins
Load Combination #6: DL Rf + DL Solar - Wind Up on Purlins

References: CBC 2010, IBC 2012, ASCE 7-10, NDS 2005
Check Wind Uplift Loads per ASCE 7-10 - Components and Cladding:

<table>
<thead>
<tr>
<th>Roof Type:</th>
<th>Z-Purlin Rafters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof Slope:</td>
<td>$\theta := 3$ degrees</td>
</tr>
<tr>
<td>Sloped Ceiling:</td>
<td>No</td>
</tr>
<tr>
<td>Ceiling Type:</td>
<td>None</td>
</tr>
<tr>
<td>Mean Roof Height:</td>
<td>$h_a := 12$</td>
</tr>
<tr>
<td>Span of Purlin:</td>
<td>$L_a := 11.5$ ft</td>
</tr>
<tr>
<td>Purlin Size and spacing:</td>
<td>$Z_a = 6\times2.5\times14$Ga@48&quot; o.c.</td>
</tr>
</tbody>
</table>

**Rafter spacing:**

- $s_a := 4.0$ ft
- $C := C_a := .15$
- $DL_{Solar} := 3.0$ psf

SnapNrack wide base clamps.

| Wind Speed: | $V := 110$ mph |
| Ground Snow: | $S := 0$ psf |
| Roofing Corr: | $Corr := 2.0$ psf |
| Standoff Mount tributary (along rails): | $s_{sp} := 4.0$ ft |
| Standoff spacing (perpendicular to rails): | $w := 2.75$ ft |

(Kzt := 1.0) Assumes Roof is not on top of a hill, bluff, or mountain ridge. Use 1.0

- $I := 1.0$
- $6 \times 2.5 \times 14$ Gage
- $S_a := 1.522$ in$^3$
Gross Section Properties
Z-Sections

<table>
<thead>
<tr>
<th>Section</th>
<th>Dimensions</th>
<th>Properties of Full Section</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>in.</td>
<td>in.</td>
</tr>
<tr>
<td>8 X 3.2&quot; 12 D</td>
<td>8</td>
<td>2.12</td>
</tr>
<tr>
<td>8 X 3.2&quot; 13 D</td>
<td>8</td>
<td>2.12</td>
</tr>
<tr>
<td>8 X 3.2&quot; 14 D</td>
<td>8</td>
<td>2.12</td>
</tr>
<tr>
<td>8 X 3.2&quot; 15 D</td>
<td>8</td>
<td>2.12</td>
</tr>
<tr>
<td>8 X 3.2&quot; 16 D</td>
<td>8</td>
<td>2.12</td>
</tr>
<tr>
<td>8 X 3.2&quot; 17 D</td>
<td>8</td>
<td>2.12</td>
</tr>
<tr>
<td>8 X 3.2&quot; 18 D</td>
<td>8</td>
<td>2.12</td>
</tr>
<tr>
<td>8 X 3.2&quot; 19 D</td>
<td>8</td>
<td>2.12</td>
</tr>
<tr>
<td>8 X 3.2&quot; 20 D</td>
<td>8</td>
<td>2.12</td>
</tr>
<tr>
<td>8 X 3.2&quot; 21 D</td>
<td>8</td>
<td>2.12</td>
</tr>
<tr>
<td>8 X 3.2&quot; 22 D</td>
<td>8</td>
<td>2.12</td>
</tr>
<tr>
<td>8 X 3.2&quot; 23 D</td>
<td>8</td>
<td>2.12</td>
</tr>
</tbody>
</table>

Array System - Layout

TA := s_sp × w = 11 sf
K_zt := 1.0 Use = 1.0 Constant
K_d := 0.85 Constant
I = 1 Constant
Given: h_a = 12 ft θ = 3 degrees Exposure C

<table>
<thead>
<tr>
<th>Table 1</th>
<th>GC.pnet</th>
</tr>
</thead>
<tbody>
<tr>
<td>External (minus) Internal Pressure Coefficient</td>
<td></td>
</tr>
<tr>
<td>Roof Angle</td>
<td>Worst Case 2E, 3E Uplift</td>
</tr>
<tr>
<td>0 to 20</td>
<td>-1.07 -0.3 = -1.37</td>
</tr>
<tr>
<td>21 to 25</td>
<td>-0.80 -0.3 = -1.10</td>
</tr>
<tr>
<td>27 to 30</td>
<td>-0.55 -0.3 = -0.83</td>
</tr>
<tr>
<td>31 to 45</td>
<td>-0.35 -0.3 = -0.63</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2 (for Kz)</th>
<th>Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height to Roof</td>
<td>C</td>
</tr>
<tr>
<td>0 to 15 ft.</td>
<td>.85</td>
</tr>
<tr>
<td>15 to 20 ft.</td>
<td>.90</td>
</tr>
<tr>
<td>21 to 25 ft.</td>
<td>.94</td>
</tr>
<tr>
<td>26 to 30 ft.</td>
<td>.98</td>
</tr>
</tbody>
</table>
Design of rooftop mounting structures.

\[ q_h := 0.00256 \times K_z \times K_{zt} \times K_d \times V^2 \times 1 = 22.38 \text{ psf} \]
\[ p := q_h \times \left( G_{C_p} - G_{C_{pi}} \right) \text{ psf} \]
\[ G_{C_{pnet}} := G_{C_p} - G_{C_{pi}} \]

\[ G_{C_{pnet}} := 1.37 \quad \text{(From Table 1 above)} \]

\[ p_{up} := q_h \times G_{C_{pnet}} = 30.7 \text{ psf maximum Uplift} \]

\[ p_{dn} := 16.0 \text{ psf Constant} \]

Roof Dead Loads

Carried by the Purlins:

Roofing:

\[ \text{Roofing} := \text{Corr} = 2 \text{ psf} \]

Rafter size and spacing

\[ Z \text{ purlins} = 0.9 \quad s_a = 4 \text{ ft} \]
\[ \text{Misc.} = 0.5 \]

\[ DL := \text{Roofing} + 0.9 + 0.5 = 3.4 \text{ psf} \]
\[ wDL := DL \times s_a = 13.6 \text{ plf} \]
Check Loading Combination #1: Wind Uplift Connection to Existing Roof:

Use: SnapNrack wide base clamps at Z-Purlin:
Net Uplift at each Standoff @ Zone 1:

Trib. Area: \( TA = 11 \text{ sf} \) \( p_{up} = 30.7 \text{ psf} \)

\[ \text{NetUplift1} := TA \times \left( 0.6 \times p_{up} - 0.6 \times DL_{Solar} \times \cos(\theta \times \text{deg}) \right) = 182.6 \text{ lb uplift per standoff} \]

\[ W_{allowable} := 250 \text{ lbs} < \text{NetUplift1} \]

\[ \% := \frac{W_{allowable} \times 100}{\text{NetUplift1}} = 137 \]

\( \ll \) If equal to or more than 100\% Code Compliant, OK!

**Loading Combination #1 PASS!**

Use: SnapNrack wide base clamps at Z-Purlin:

Loading Combination #2: (DL Rf + DL Solar) to Purlin:

**Solar Panels:**

\( P_{sp} := TA \times DL_{Solar} = 33 \) \( \text{lb} \)

\( s_{sp} = 4 \) \( \text{Fb} := 24000 \)

\( w_{sp} := s_{sp} \times DL_{Solar} = 12 \) \( \text{plf} \)

**Rafter spacing:**

\( s_{a} = 4 \) \( \text{ft o.c.} \)

\( L_{a} = 11.5 \) \( \text{ft} \)

\( a := 3 \)

\[ M1 := \left( \frac{wDL \times L_{a}^{2}}{8} + \frac{P_{sp} \times L_{a}}{4} \right) \times \cos(\theta \times \text{deg}) = 319.26 \text{ lb-ft} \]

\[ S_{r} := M1 \times \frac{12}{Fb} = 0.16 \]

\[ \% := \frac{S_{a} \times 100}{S_{r}} = 953 \]

\( \ll \) If equal to or more than 100\% Code Compliant, OK!

**Loading Combination #2 PASS!**
Loading Combination #3: (DL Rf + DL Solar + .6Wind Down) to Purlin:

\[ P := TA \times (0.6 \times p_{dn} + DLSolar \times \cos(\theta \times \text{deg})) = 138.6 \text{ lb down per standoff} \]

\[ w_{dn} := s_{sp} \times (0.6 \times p_{dn} + DLSolar \times \cos(\theta \times \text{deg})) = 50.38 \text{ plf} \]

\[ M1 := \left( \frac{wDL \times L_a^2}{8} \right) \times \cos(\theta \times \text{deg}) + P \times \frac{L_a}{4} = 623 \text{ lb-ft} \]

\[ F_b = 2.4 \times 10^4 \]

\[ S_r := \frac{M1}{12} \times \frac{12}{F_b} = 0.311 \]

\[ \% := \frac{S_a \times 100}{S_r} = 489 \text{ \%} \text{ \%} \text{ << If equal to or more than 100\% Code Compliant, OK!} \]

**Loading Combination #3 PASS!**

Load Combination #4: DL Rf + LL Roof + DL Solar on Purlins.

\[ RfLL := 20 \text{ psf} \quad wLL := RfLL \times s_{sp} = 80 \text{ plf} \quad wDL = 13.6 \text{ plf} \]

\[ P := TA \times DLSolar \times \cos(\theta \times \text{deg}) = 33 \text{ lb down per standoff} \]

\[ w_{dn} := (wLL + wDL) \times \cos(\theta \times \text{deg}) = 93.47 \text{ plf} \]

\[ M1 := \left( \frac{w_{dn} \times L_a^2}{8} \right) \times \cos(\theta \times \text{deg}) + P \times \frac{L_a}{4} = 1638 \text{ lb-ft} \]

\[ F_b = 2.4 \times 10^4 \]

\[ S_r := M1 \times \frac{12}{F_b} = 0.819 \]

\[ \% := \frac{S_a \times 100}{S_r} = 186 \text{ \%} \text{ \%} \text{ << If equal to or more than 100\% Code Compliant, OK!} \]

**Loading Combination #4 PASS!**
Loading Combination #6: \(0.6(DL \text{ Rf} + DL \text{ Solar}) - (.6\text{Wind Up})\) to Purlin:

\[
p_{up} = 30.661 \quad p_{dn} = 16
\]

\[
P_5 := TA \times \left(0.6 \times p_{up} - 0.6 \times DL_{\text{Solar}} \times \cos(\theta \times \text{deg})\right) = 182.6 \quad \text{lb uplift per standoff}
\]

\[
w_{up} := s_{sp} \times \left(0.6 \times p_{up} - 0.6 \times DL_{\text{Solar}} \times \cos(\theta \times \text{deg})\right) = 66.4 \quad \text{pf}
\]

\[
M_6 := \left(P_5 \times \frac{L_a}{4}\right) - 0.6 \times \text{wDL} \times \frac{L_a^2}{8} \times \cos(\theta \times \text{deg}) = 390 \quad \text{lb-ft}
\]

\[
F_b = 2.4 \times 10^4
\]

\[
S_r := M_6 \times \frac{12}{F_b} = 0.195
\]

\[
\% := \frac{S_a \times 100}{S_r} = 780 \quad \% \ll If \ equal \ to \ or \ more \ than \ 100\% \ Code \ Compliant, \ OK!
\]

\textbf{Loading Combination #6 PASS!}

\textbf{Limits of Scope of Work and Liability}
Appendix L: Signed permits from county

Pg. 159-164
Construction Permit
San Luis Obispo County Department of Planning and Building
County Government Center San Luis Obispo, California 93408 Telephone: (805) 781-5600

Applicant: SAN LUIS COASTAL UNIFIED SCHOOL DIS
Permit: Wind/Solar Energy System

PROJECT DESCRIPTION
GRID TIED, ROOF MOUNTED 3.82KW PV SYSTEM.
Photovoltaic 4.00

PROJECT DETAILS
Lot Size: 7.33 Acres Insp. Area: 04
Setbacks:

Parcel(s) for this project: 076-521-055 Occupancy Class U
Types of Construction: VB - All materials-no fire resistance

APPLICABLE CODES
2008 California Energy Code
2013 California Building Code, Vols 1 & 2
2013 California Electrical Code
2013 California Fire Code
2013 California Green Building Code
2013 California Mechanical Code
2013 California Plumbing Code
2013 California Reference Standards Code
2013 California Residential Code
County Building and Construction Ordinance - Title 19
County Coastal Zone Land Use Ordinance - Title 23
County Fire Code Ordinance - Title 16
County Land Use Ordinance - Title 22

CONTACTS
Owner: SAN LUIS COASTAL UNIFIED SCHOOL DIS
Phone: 805-596-4105 x4210

Engineer: ADAMS JAMES ADRIAN
146 SAN JOSE CT. SAN LUIS OBISPO CA 93401
Email: jadams@solar-roof-check.com
Phone: 805-215-8665

Contractor: PROCESS DIAGNOSTICS
Construction Permit

San Luis Obispo County Department of Planning and Building
County Government Center San Luis Obispo, California 93408 Telephone: (805) 761-5600

1400 FILAREE WAY ARROYO GRANDE CA 93420
Phone: 805-540-0978
775 FIERO LANE SAN LUIS OBISPO CA 93401
Lic #:C750184
Email: cjoy@recsolar.com
Phone: 805-528-9705

SPECIAL REQUIREMENTS

Prior to Foundation
None

Prior to Frame
None

Prior to Final
ELECTRICAL ABOVE BFE - F UnMet Building Inspector to verify inverter and elec panel above base flood elevation (above highest adjacent grade will work).
Construction Permit
San Luis Obispo County Department of Planning and Building
County Government Center San Luis Obispo, California 93408 Telephone: (805) 781-5600

LEGAL DECLARATIONS

APPLICANT IS (check one) ⮕ OWNER ⮕ CONTRACTOR

OWNER-BUILDER DECLARATION (if applicant is owner of the property or owner’s authorized agent, he/she must certify one of the following statements to be true):

☒ I, as owner of the property, or my employees with wages as their sole compensation, will do the work and the structure is not offered nor intended for sale.

☐ I, as owner of the property, am exclusively contracting with licensed contractors to construct this project.

WORKER COMPENSATION DECLARATION (every applicant owner must certify one of the following statements to be true):

☐ I hereby affirm that I have a current certificate of consent to insure or a certificate of workers compensation insurance and that I will maintain this certificate until completion of this project.

☒ I certify that in the performance of the work for which this permit is issued, I shall not employ any person in any manner so as to become subject to the Worker’s Compensation Laws of California.

☒ OWNER/AGENT ACKNOWLEDGES SPECIAL REQUIREMENTS.

NOTICE TO APPLICANT: If, after making any of the foregoing declarations, you become subject to any Labor Code or License Law provision, you must comply with such provisions or this permit shall be deemed revoked.

APPLICANT AGREEMENT: I certify that I have read this permit form and state that the information on it and on the permit application is correct. I agree to comply with all County ordinances and state laws relating to building construction and with all special requirements identified on the permit, and I hereby authorize representatives of the County to enter upon the above-mentioned property for inspection purposes. Every permit issued shall become invalid as follows:

1) Permits for buildings with a floor area of 1000 square feet or greater shall remain valid for a time period of three years from the date of issuance.

2) Permits for buildings with a floor area of less than 1000 square feet or for other miscellaneous work shall remain valid for a time period of one year from date of issuance.

3) Permits for work that was started and/or completed prior to issuance of the permit (also known as “as-built”) shall be valid for a time period of 180 days from the date of issuance.

In order to received this permit you may have paid Public Utility Fees, Road Fees, and/or Air Quality Mitigation Fees in the amounts shown on your Statement of Fees and Project Hold Conditions. Pursuant to the Mitigation Fee Act (California Government Code Section 6600 et seq.), the issuance of this permit begins a 90-day period for protesting such fees.

Signed: Wesley H. Weizenburger
Date: 5/24/14

Print Name: Wesley H. Weizenburger

Person signing here is (check one): ⮕ Actual Applicant

☒ Authorized Employee/Partner Applicant

☒ Authorized Agent per Consent of Landowner Form

*** PLEASE CALL USA 1-800-227-2600 UNDERGROUND SERVICE ALERT BEFORE DIGGING ***

Initials: [Signature]

5/21/2014 4:28:51PM

Construction_Permit.rpt
Construction Permit
San Luis Obispo County Department of Planning and Building
County Government Center San Luis Obispo, California 93408 Telephone: (805) 781-5600

Dear Property Owner(s):

A Stormwater Pollution Prevention Plan (SWPPP) is required for all construction activities in California that include clearing, grading, disturbances to the ground such as stockpiling, or excavation that results in soil disturbances of one acre or more of total land area, or which is part of a common plan of development or sale (i.e. part of a parcel or tract map with more than an acre of total site disturbance including subdivision improvements).

The SWPPP requires lot owners, such as you, to be responsible for protecting stormwater runoff during and after construction of homes. In order to help ensure that home construction does not result in stormwater pollution, the homeowner and their representative in charge of construction are required to use Best Management Practices to eliminate or minimize pollutants in stormwater runoff. Construction Best Management Practices are structural controls and construction measures that primarily emphasize erosion and sediment control and pollution prevention.

This is brought to your attention to ensure that you are aware of the need to include Best Management Practices during and after construction (see your approved sedimentation and erosion control plans). Failure to do so may result in enforcement action by the Regional Water Quality Control Board or County Code Enforcement.

If you have any questions, please contact the following Water Board staff or County staff:

   David Innis at (805) 549-3150 or dbinnis@waterboards.ca.gov
   Elizabeth Szwabowski at (805) 781-5725 or eszwabowski@co.slo.ca.us
   Murry Wilson at (805) 788-2352 or mwilson@co.slo.ca.us
## Inspection Record Card - MISC.

**COUNTY OF SAN LUIS OBISPO**  
PLANNING & BUILDING DEPT.  
976 OSOS ST. ROOM 200  
SAN LUIS OBISPO, CA 93408  
805-781-5600  
www.sloplanning.org

Please call 788-2076 one working day before you want an inspection. Have the permit number and 3 digit inspection code ready when you call. The approved plans and this inspection card MUST be in an obvious place on site the day of inspection. SITE ID OR ADDRESS MUST BE POSTED IN CONSPICUOUS PLACE.  
You may call your inspector between 7:00 and 8:00 a.m. any workday with questions about inspections or about your job.

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### Case: PMT2013-02844

**SAN LUIS COASTAL UNIFIED SCHOOL DIS**  
**APN:** 076-521-055  
Wind/Solar Energy System  
GRID TIED, ROOF MOUNTED 3.82KW PV SYSTEM  
01401 SAN LUIS BAY DR AVLB

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### EROSION CONTROL MEASURES MUST BE IN PLACE FOR THE DURATION OF PROJECT

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Changes of Scope

The original project scope (October 1, 2014) included the design and manufacturing of PV solar panel frame(s) to support 11 panels by June, 2014. However, as time moved forward, the design scope was changed multiple times.

- December 6, 2013 we received a note from our project sponsor with the following message:

  “Wes of the SciTech of BSFCS just offered to sponsor 6 or 7 solar panels to our project. They are 270 Watt panels with size of 78-1/4” x 39-1/8" and Voc of 44.5V at std. conditions. I am wondering whether your team is able to handle that. After you finish all of your finals, please think about it and let me know the feasibility.”

- January 7, 2014 the team agrees to comply with sponsor’s request with the understanding that if funding is compromised then the original nine panels are the first priority

- April 30, 2014 (10:36 AM) the team receives the following message:

  “NEC 690.4 requires all equipment to be identified and listed for the application. Although the Q-Cells modules are approved for use in Europe, from what I can tell, the modules are not listed by a US Nationally Recognized Testing Laboratory (NRTL) such as UL or TUV (ie UL1703).”

- April 30, 2014 (noon) the team is approached by sponsor and asked to redesign the frame for 16 panels, which mean NEC 690.4 requirements, donated to IME department in December 2014

- April 30, 2014 (3:00 to 4:30 PM) the team meets with project advisor, IME department chair, and project sponsor and agree to redesign frame for the new 16 donated panels

- May 01, 2014 the team receives the following message from sponsor:

  “Today is a good day. I have good news. I contacted Hanwha Q Cells USA this morning and I am told that the QPro panels we have meet UL requirements. Thanks to Charlie Joy. He received a quote for a very simple external AFCI unit that is $356. This would allow us to use the donated SunnyBoy 3000US-10 inverter without issue. Thus, we can move forward with our original plan.”
Project Liability

Although one of the original goals of the project was to be able to install the solar panel frames at the project site, it was not the team understands that we would personally be part of the installation process. However, through the course of the project the team did agree to personally be part of the installation team provided we were released from all liability associated with the project (both now and in the future). We received the following note from project sponsor:

“Dear Iron Web team,

I talked to Mr. David Carroll, Risk Manager of Cal Poly this morning. He said that Cal Poly side will be fine if students agree to follow the safety rules during climbing the ladder and working on the roof and sign the attached release of liability form. He wants to make sure the SLCUSD and BSFCS understand that this is a student project, there is no warranty, the project is provided as-is.

I also discussed with your advisor, Prof. McFarland this morning. He would like all of you get protected from any future accidents related to this project and want BSFCS or SLCUSD sign some paperwork to release your liability from any future accident related to this project. I will work with BSFCS and SLUCSD to get some signed documents to release your liability from any future accidents related to this project.

Could you please sign attached Cal Poly's release of liability form and turn them in to the IME office?

I am very impressed with the work have done so far. Keep up the good work.

Thanks and best regards,

John Pan”

Having received this note our team worked under the assumption we would not be held liable for anything associated with work required by this project. Furthermore, the Department of State Architecture (DSA) requires that the clamps that the frame design would use, as well as the roof, be tested. The team created a two test plans (one for the clamps and another for the roof). The clamp test plan was reviewed and stamped by a California Certified Structural Engineer (See Appendix I). We then proceeded to execute the clamp test plan. During test run 3 of clamp testing there was a sudden jump of the clamp (see page 35 in main report for link to YouTube video). Our team was concerned that the clip which holds the standing seam onto the roof had come off so we immediately took the
load of the clamp and stopped testing. We then requested the roof be inspected by a qualified individual. Our team sent out the following message to project sponsor:

“The team has discussed the possibility of a clip coming off in the roof structure after our second run of testing. This can be seen a few (about 5) minutes after the following link of the second test run: https://www.youtube.com/watch?v=IFPm1-G2748#t=313.

We believe it would be best if someone, either from the school or the district, could investigate the area that was tested to confirm or deny that damage has been done to the roof structure. Could you please contact either of these two entities about this issue?”

The sponsor responded with the following message:

“One good news is that this afternoon Mr. Chick Fedel asked one retired roof contractor checked the roof where we tested last Wednesday. They found NOTHING was damaged. Mr. Fedel took a few pictures and informed Mr. Brian Getz about the good news”

The team then requested the inspector make a report of his findings, but that was never provided.

Finally, our team was informed (on May 12, 2014) that we would not be receiving a written document with release of liability since it all work is being conducted under licensed individuals. See the following message from one of our team members regarding a conversation with project sponsor:

“Talked to Pan about liability. He said that we don’t exist on the records and that we are simply volunteers helping the contractor (Dr. Wes) install these panels. In the event that something does go wrong, the backlash will fall on the professionals that helped us with this project (contractor, SE, EE). He said he cannot email the group about this because emails must be worded extremely carefully as they can be used as legal documentation.”