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Solar Panel Installations on Existing Structures

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***Abstract*—**The rising price of fossil fuels, government incentives and growing public aware-ness for the need to implement sustainable energy supplies has resulted in a large in-crease in solar panel installations across the country. For many sites the most eco-nomical solar panel installation uses existing, southerly facing rooftops. Adding solar panels to an existing roof typically means increased loads that must be borne by the building's structural elements. The structural design professional is responsible for ensuring a new solar panel installation is properly supported by an existing structure and configured to maximize energy generation.

***Keywords*—**Solar Panel, Structures, Structural Design.

I. Introduction

A successful solar panel installation on an existing rooftop includes documenting the as built condition of the structure and then calculating and applying loads from new solar panels. The structural engineer is called on to design economical structural reinforcement to bring existing buildings into compliance with current building code requirements for wind, snow and seismic loads. The most economical reinforcement design varies and depends on whether the existing roof is built from wood framing, wood trusses, steel framing or pre-engineered structural members.

II. Maximizing Solar Panel Efficiency on Existing Buildings

A. Environmental Factors

A variety of environmental factors influence the amount of solar energy available to convert into usable power. The closer the site lies to the equator means longer days and more direct sunlight. Sunlight intensity varies during the course of the day as well as during the course of a year. As everyone knows, the sun travels from east to west every day and is more directly overhead during the summer and lower in the sky during the winter. In order to maximize energy generation over the life of the solar panel installation, these factors must be implemented into the mounting design.

Solar insolation is a measure of the sun's radiant energy striking the earth's surface. Areas closer to the earth's equator receive more solar energy as compared to areas closer to the earth's Poles. For example, Miami receives an average of 5 kilowatt-hours per square meter of area every day whereas Philadelphia gets an average 4 kilowatt-hours per square meter of area every day. All other things being equal, solar panels in Miami have more solar energy available as compared to more northerly locations.

Another factor impacting solar panel efficiency is solar panel orientation. Solar energy generation is highest when panels face perpendicular to the sun. However, the angle of the sun constantly changes as it rises in the East and sets in the West. Orienting solar panels to obtain maximum efficiency is further complicated by the sun's declination angle. During the course of a typical year, the sun tends to sink towards the South Pole as winter and the winter solstice approaches and the sun rises towards the North Pole as summer and the summer solstice approaches. The loss of generating capacity as the sun moves away from perpendicular to the surface of the panel is represented in the chart below:

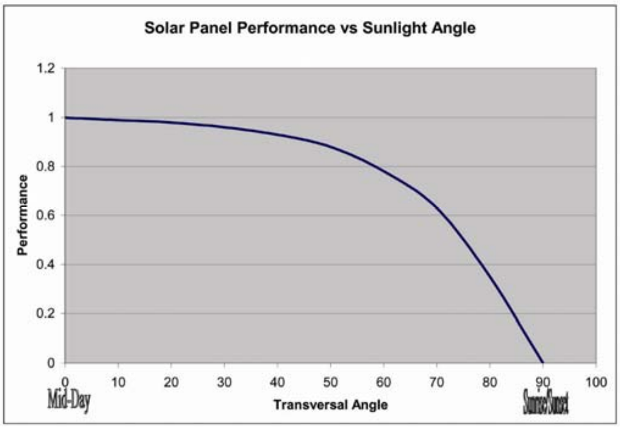

Fig. 1 Typical Solar Panel Generating Capacity vs. Sun Incidence Angle [1], [2]

A fixed mount solar panel is oriented facing a fixed direction and tilted at a fixed angle to the horizon. More efficient designs include installing hardware that vary the solar panel orientation and tilt over time. Variable orientation systems are more expensive given the additional hardware and maintenance requirements and are generally not used on existing structures.

B. Solar Panels and Existing Buildings – Optimizing Lifelong Energy Output

A good solar panel mounting system design takes advantage of environmental factors listed above in order to maximize energy output for the project owner's energy usage requirements. As an example, consider a proposed residential solar panel installation. The Miami residence has a flat, wood framed roof with the front of the house facing South. The roof

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measures 40 feet wide by 30 feet long.

The building owners want the maximum panel energy generation during the summer when the residence's air conditioning system is in use. The simplest roof mounting system would simply fasten panels flat down onto the roof. However, mounting pan-els flat reduces the amount of solar energy reaching the panel. Miami is located at 25.77° latitude. Normally, for fixed mount systems, the panel tilt angle is set to approximately the site's latitude. However, less tilt angle can be used to maximize energy generation during the summer months, when the sun is higher in the sky. As a rule of thumb, the tilt angle is reduced by 15° to maximize power generation during the summer which results in a 10° tilt angle.

Tilting solar panels on a flat roof presents additional design challenges and typically increases installation cost. The added power generation should be calculated to help determine whether mounting the solar panels at a tilt angle is worth the additional cost. For our example, annual and summer time power generated by the system is calculated using no tilt (0°) angle and the optimized summertime 10° tilt angle. The roof area in our example provides about 1000 square feet (93 square meters) of area available for solar panels. The added generating capacity of the 10° tilt is compared against the energy generation of a no tilt system to help determine whether the added structural complexity needed to tilt the system at an optimal angle makes economic sense. The difference in solar panel generating capacity for these two scenarios is depicted in Fig. 2.

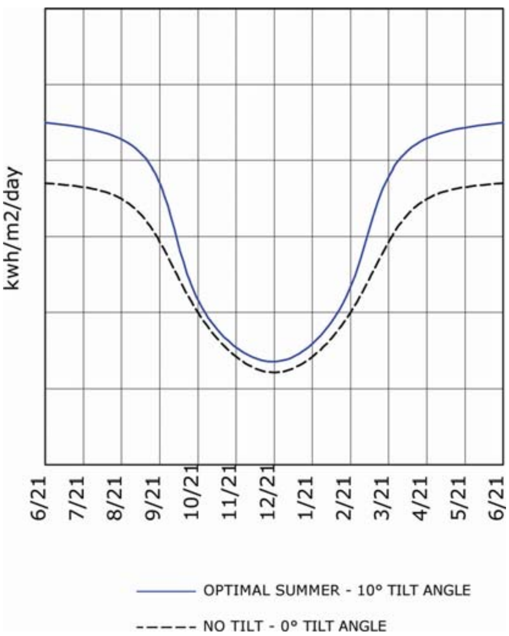

Fig. 2 Panel Power Generation at 0°and 10° Fixed Tilt Angle [1], [3]

Next the additional power generation for the summer months and the full year is determined and resulting savings calculated using current electric rates from the local utility. For our example, the optimal 10° summertime tilt can be expected to provide about 650kwh per year of additional electricity as compared to just fastening the panels directly to the flat roof:

TABLE I
ANNUAL POWER GENERATION COST

Tilt Angle	kwh	$ Annual Output at $0.112/kwh
0°	6728	$ 753.54
10°	7377	$ 826.22

TABLE II
SUMMER TIME POWER GENERATION (MAY – JULY)

Tilt Angle	kwh	$ Summer Output at $0.112/kwh
0°	2440	$ 273.28
10°	2735	$ 306.32

For rooftop installations, a mounting system that tilts the panels at an angle different from the roof angle imparts additional roof loads. Tilting the panels exposes additional area to wind as shown in Fig. 3. In Northerly climates tilting the panels can also result in additional snow loads by creating areas subjected to snow drifts and areas where the snow accumulates after sliding off panels.

For our example, panels installed with a 10° tilt will result in about a 5 foot high exposed face on the north side of the residence. Wind loads on this exposed face must be calculated and additional reinforcement likely needed along the northernmost roof mounts. At current electric rates, the optimized system generates about $70 worth of savings over a year or $1400 over a twenty year design life assuming electric rates remain the same. If the utility increases electric rates, the savings will be greater depending on the magnitude(s) of the increase(s). It would be up to the owner and engineer to decide whether the additional complexity and expense is worth the added generating capacity.

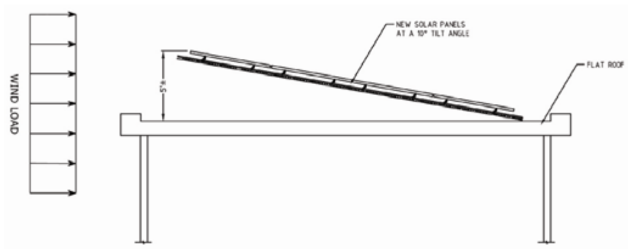

Fig. 3 Flat Roof Solar Panels at a 10° Tilt Angle

C. Existing Construction and Solar Panel Installation Considerations

Rooftop solar panel installations typically increase the building's wind, seismic and snow loads as well as adding dead load due to the weight of the panels and mounting system. Once the solar panel configuration is determined, the existing structure must be evaluated for added solar panel loads and reinforcement designed, if needed. Roof-top solar panel installations typically impart significant live loads not anticipated during the original building's design and construction. Wind, seismic and snow loads each present a unique set of challenges that must be accounted for in any new rooftop solar panel installation.

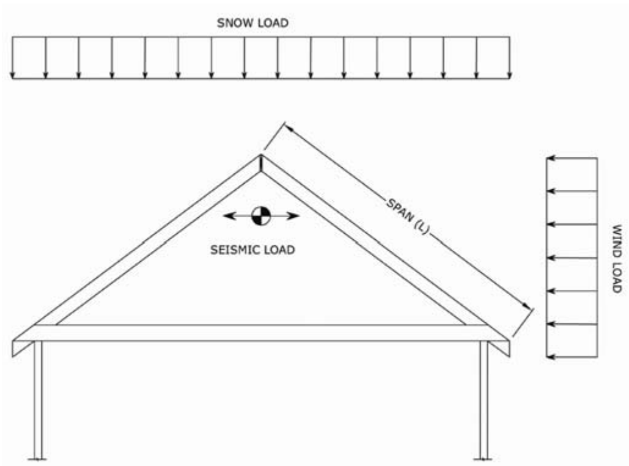

Fig. 4 Typical Roof Loads

Solar panel installations are typically most cost effective when placed on buildings with large, southerly facing roofs. As a result, most solar panel installations are on large factories, warehouses, storage facilities and include many residential structures. The structural support systems for these buildings vary widely. Wood framed and wood trusses as well as steel framed and pre-engineered steel buildings are the most common types buildings encountered.

Installing arrays of solar panels on an existing roof involves attaching solar panels and their mounting system to the existing building. The mounts for the solar panel support structure concentrate loads from the panels and associated wind, seismic and snow loads at discrete points on the existing roof structure. The impact of this arrangement results in converting distributed wind, seismic or snow loads into concentrated loads. Depending on the spacing of the solar panel mounts some roof framing members may no longer support live loads while other framing members end up with concentrated loads that can be several times the original design load.

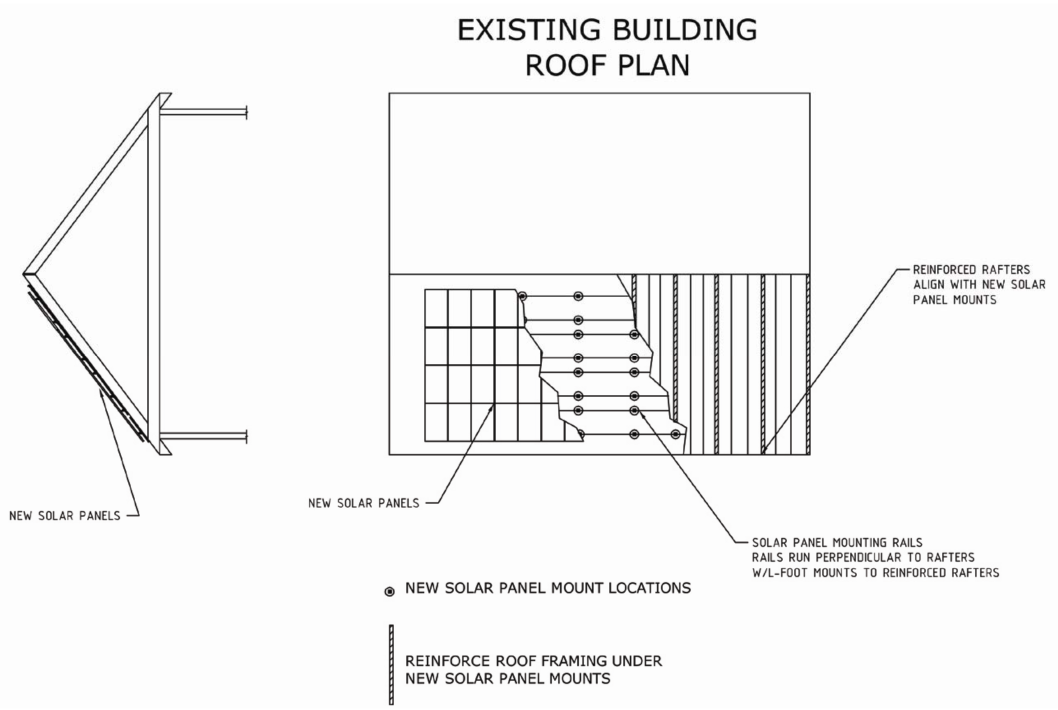

Fig. 5 Typical Existing Building, Solar Panel Roof Installation

When designing a new solar panel installation, wind, seismic and snow loads must be considered and efforts made to minimize their impact on the existing structure. Roof-top mounted solar panels are often located at the highest elevation and subjected to the building's most severe wind loads. The solar panel mounting system's lateral load carrying capacity is often the limiting factor in the mounting system design and wind loads are often responsible for generating the most severe lateral loads.

The added weight of a new rooftop solar panel system can result in significant seismic loads that also must be resisted. Many areas of the US are located in seismic zones and even relatively minor seismic events impart significant loads to a rooftop solar panel installation. Again, the added weight of a rooftop solar panel installation is located at the highest point of the structure where even gentle lateral seismic loads imparted to a heavy rooftop solar panel installation can cause damage to an inadequately reinforced building.

Finally, in northerly climates, snow loads present several challenges. The weight of the new solar panels increases loads on the structure and these loads are concentrated on the underlying structure where the solar panel system is mounted to the existing building. In addition to the added weight of solar panels, the solar panel mounting system typically presents obstructions where snow drifts can form. Solar panels are typically covered with glass and more slippery than most roofing surfaces. Accumulated snow can slide off panels and accumulate at gaps in the panel mounting system. Similarly, raised panels obstruct wind driven snow and can cause snow drifts.

III. Solar Panel Mounting Systems Impact on Existing Structures

Most rooftop solar panel installations require work to reinforce the existing building. Many existing buildings do not meet current building code requirements given building code changes since a building's original construction. During the original building design, most structural designers work to minimize structural member sizes to help keep construction costs down Also, the solar panel mounting system typically concentrates loads on fewer members. As a result, added forces generated by a new solar panel installation often overstress existing structural members which then need to be reinforced to carry the new loads.

The mounting configuration often depends on the solar panel selected by the Electrical Engineer. Each solar panel manufacturer seems to vary overall panel width and height by an inch or so from their competitors. Similarly, mounting holes and mounting hardware requirements vary from panel manufacturer to manufacturer. Manufacturer's installation specifications must be followed to avoid voiding the manufacturer's warranty. Of course, very few, if any, panels are manufactured to coincide with typical building dimensions where roof framing is typically laid out on a multiple of 16 inches on center.

Hardware needed to attach solar panels to the roof can be simplified by using framing components manufactured specifically for solar panels. These systems are typically rail like systems that allow flexibility where the solar panel is fastened down. Aluminum rails are fastened to the roof structure with stand-offs or brackets that are flashed to prevent water infiltration. These rails often double as a ground for the solar panels. The standoffs or brackets are located over the roof's structural members and the rails positioned to accommodate the solar panels' width and height. Once the mounting locations are determined, the associated mount loads can be calculated and reinforcement designed for the underlying structure see Fig. 5 & 6.

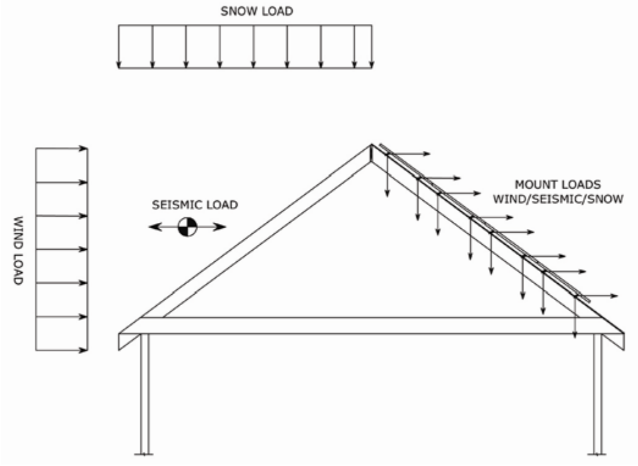

Fig. 6 Concentrated Solar Panel Loads on an Existing Roofs

IV. Reinforcement of Existing Structures

A. General

Once the solar panel mounting system is designed, the underlying building reinforcement can be determined. Typically, the new solar panel mounting system changes the load pattern on the building roof. Where the roof was previously uniformly loaded with wind, seismic or snow loads, these loads are now transferred to concentrated locations at the solar panel mounts. Some framing members may no longer carry any wind, seismic or snow loads, while other framing members have those loads increased by several times. Each type building presents unique design challenges.

B. Wood Framing

Many residential roofs are pitched roofs built from wood 2x framing members. As outlined previously, the new solar panel mounts must be designed to align with existing roof rafters. Concentrated loads from the solar panel system applied to a single rafter can be several times the original design load. These individual rafters must be reinforced to carry the new concentrated loads from the solar panel mounting system. Oftentimes, the most economical rafter reinforcement schemes involve sistering existing rafters with new framing members sized to carry the new loads. Another effective method of reinforcement involves the use of collar ties or other secondary members to reduce the rafter span. Appropriately sized and located collar ties installed on sets of rafters subjected to the new solar panel loads can improve a typical roof rafter's load carrying capacity by a factor of 4.

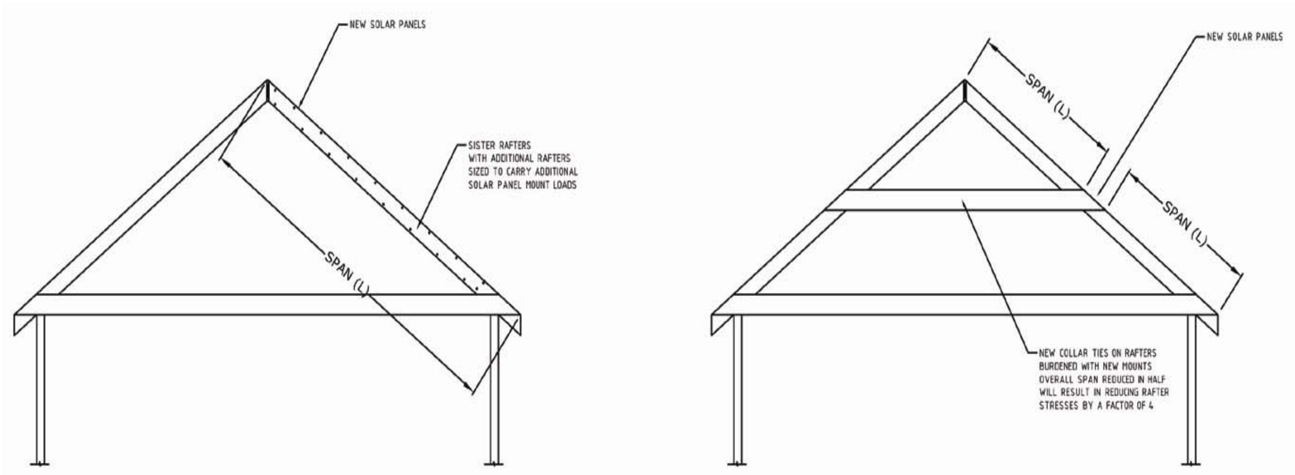

Fig. 7 Pitched, Wood Framed Roof Reinforcement

Larger buildings often use wood trusses to support the roof structure. Roof trusses are designed to meet code required wind, seismic and snow loads with very little added capacity factored in. Once uniform loads are converted to concentrated loads from the solar panel mounting system, the wood trusses must be analyzed for the new load pat-terns and reinforced if necessary. Typically, the most effective wood truss reinforcement method includes sistering the top and bottom chords of the truss. Most wood trusses use machine rated lumber with allowable bending stresses in excess of 2,000 psi. Any reinforcement should call for similar or better materials. In addition to sistered framing members, plywood sheathing is often used to ensure the structural integrity of the truss's secondary structural members.

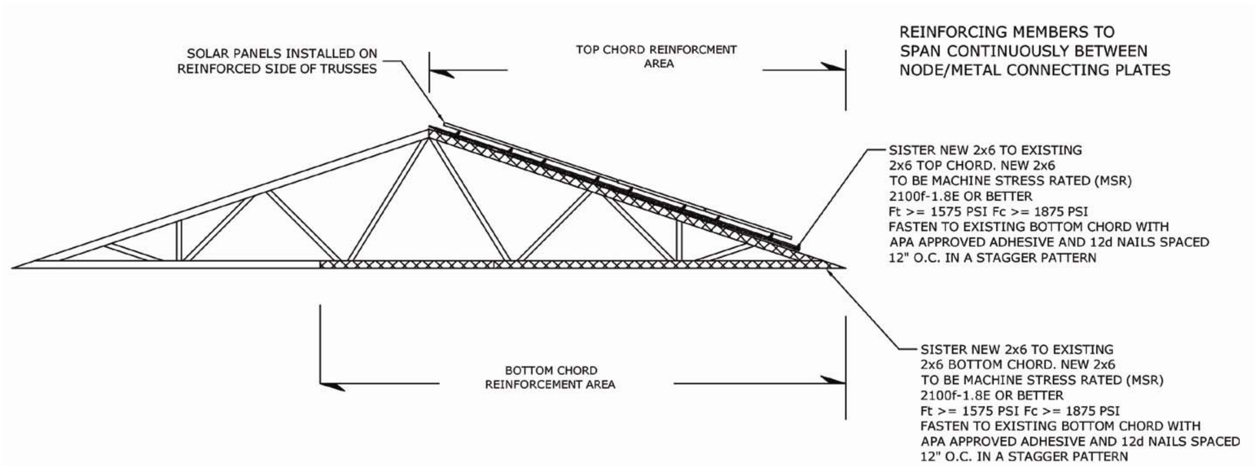

Fig. 8 Wood Truss Reinforcement Example

C. Pre-Engineered & Steel Framed Buildings:

Steel framed buildings typically have longer unsupported spans as compared to wood framed buildings. Concentrated forces from manufactured solar panel mounting sys-tem are often incapable of spanning the large distances between structural steel members. As a result, solar panel installations on steel framed buildings often include adding additional framing members. Bar joists can be reinforced with additional steel angles or bars welded in place to ensure concentrated loads are properly transferred as shown in Fig. 9 below.

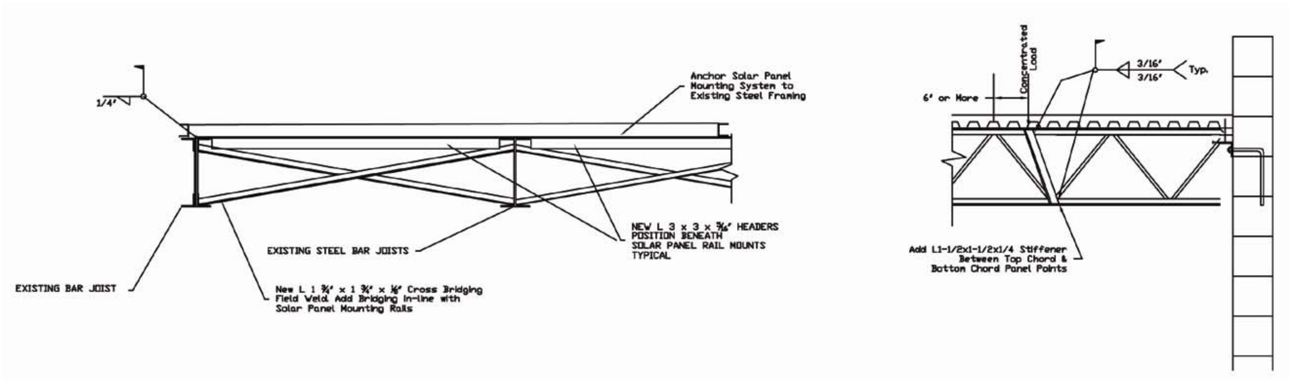

Fig. 9 Bar Joist Reinforcement Example

Z-purlins can similarly be reinforced by adding additional z-purlins or by cutting back the top flange of a similarly sized z-purlin and nesting the cutback z-purlin with the existing z-purlin. More extensive reinforcement methods include adding additional steel framing, columns and footers like that shown in Fig. 10.

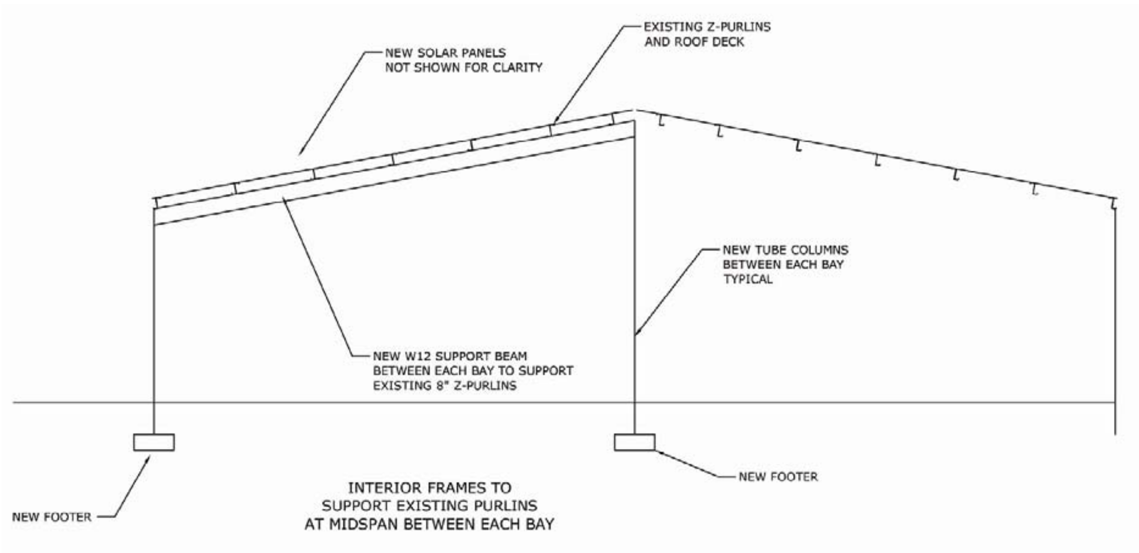

Fig. 10 Pre-Engineering Building Reinforcement Example

D.Conclusions

Engineering solar panels' structural framing to maximize panel efficiency and minimize construction costs help ensure the success of any solar panel installation. Solar panel installations on existing buildings often increase loads on structural members. When designing a solar panel support system the structural engineer must consider incorporating a tilt angle in the solar panel support framing to optimize solar panel output. Optimizing solar panel output can result in increased loads on the existing building. However, the structural engineer supplies maximum value to the building owner when the cost to reinforce the existing building is offset by gains in optimized solar panel output.

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