

Designing Metal Roofs for Thermal Movement

SST Notation:

This article was published before the SST innovations of High-Capacity Starter/Rake Plates and extended tab Wind Clip that allow up to 7" of Thermal Cycle travel.

Utilizing both components will allow panel runs up to 500'-0" without mid-point fixity (floating panels in two directions) or require midpoint rafter step-downs.

Can we fool Mother Nature? Not really, all materials used in roof systems expand and contract with changes in temperature on daily and seasonal cycles. Even a cooling breeze, a cloud passing overhead, or sudden rain shower can cause roof systems to contract. If you don't take this into account, more often than not she will turn around and make a fool out of you. Thermal expansion/contraction is responsible for most roof leaks. Even small leaks can introduce enough moisture between the inside of the panel and the vapor retarder to cause a continuous condensation-evaporation cycle to form which in turn will oxidize the panels from the underside. Larger leaks cause damage to the roof insulation and reduce its effectiveness as an energy saver. Even larger leaks seep into the building envelope and damage the contents, interior finishes, interrupt workflow and generally disrupt the buildings' function. In the long run a properly designed weather tight roof will cost less than an improperly designed leaky low cost roof.

The Science

Thermal expansion occurs when heat is added to most materials causing the average amplitude of the atoms' vibration within the material to increase. This increase in energy in turn increases the separation between the atoms causing the material to expand. Consequently, removing the heat energy (cooling) decreases the separation causing the material to contract. Thermal expansion is equal for all planes of the material. Each different material type expands at a set rate peculiar to that material for one degree in material temperature change. This rate is known as the thermal expansion coefficient for that material (see table 1).

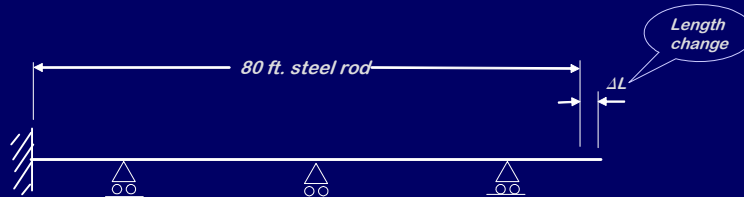
Table 1

e for 100 F°	
aluminum	= 0.00128
steel	= 0.00065
concrete	= 0.00099

The best example of this phenomenon can be illustrated by observing a mercury bulb thermometer – for each degree of temperature change; the mercury expands a set distance inside the tube thereby indicating the temperature. Knowing these physical properties, the linear expansion/contraction of an 80 feet long steel rod subjected to a 90-degree temperature change under ideal conditions can be calculated as shown in example 1.

Example 1 Metal Expansion / Contraction

$$\Delta L = (0.00065/100 \text{ F}^\circ) \times (T_2 - T_1) \text{ F}^\circ \times L$$



Example; 80 ft long steel rod, temperature change from 20 degree to 110 F°. Length change ?

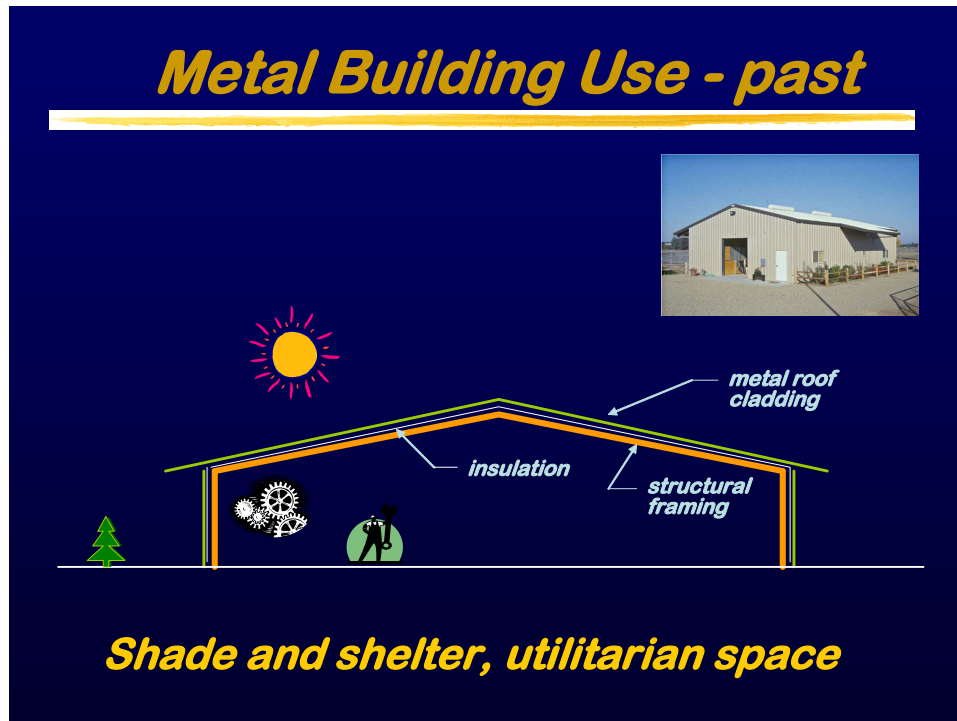
$$\Delta L = (0.00065/100) \times (110 - 20)^\circ \text{F} \times (80' \times 12'') = 0.5616''$$

under ideal conditions

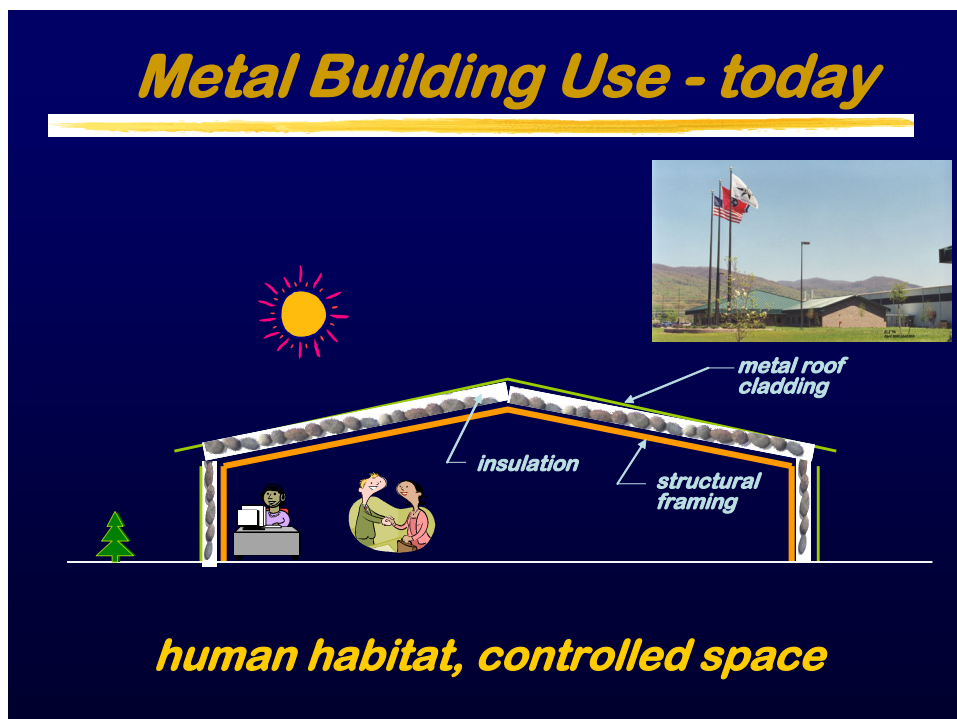
What were those ideal conditions? The steel rod was fixed at one end and free to expand without restriction on the other while being supported by frictionless roller supports, which are far from real world conditions.

A Brief History

Is the global warming/cooling of Mother Nature changing the way metal roofs expand and contract? The answer is no but the nature of the way we occupy the buildings under these roofs is. In the past, most buildings with metal roofs were used for shade and shelter or utilitarian space – meaning the temperature inside the building was nearly the same as the outside (Illustration 1).



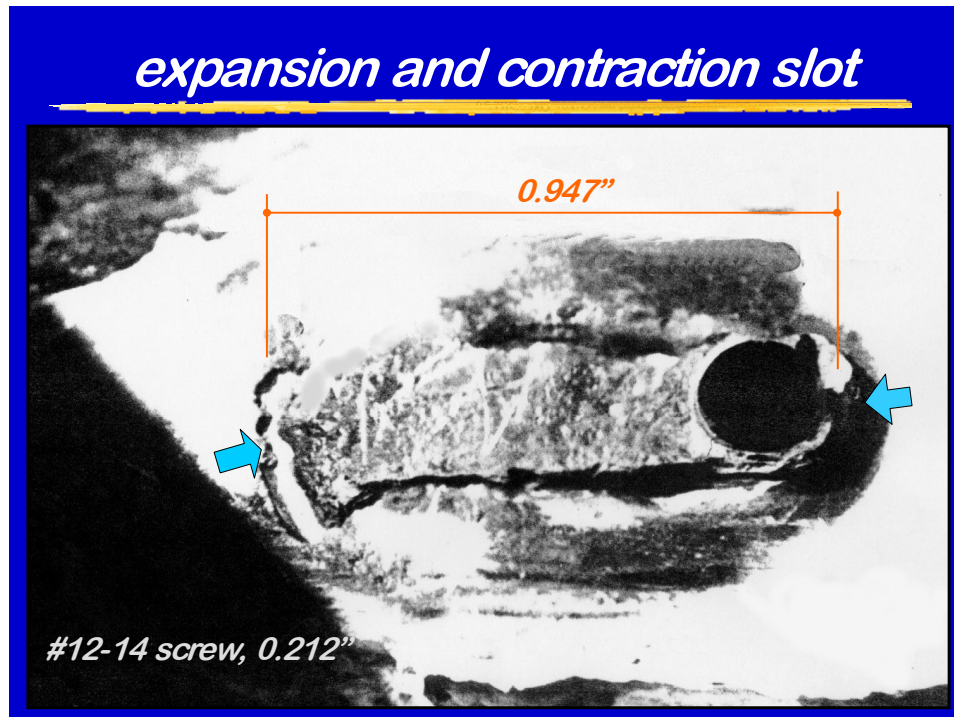
When a temperature change occurred, the roof expanded/contracted at nearly the same rate as the supporting framing therefore little stress was created on the panel connections. Through fastened roofs performed reasonably well. Today's structures are being designed for human habitat as a controlled space – meaning the temperature inside the building remains at a nearly constant temperature during the daily and seasonal temperature cycles (Illustration 2).



When a temperature change occurs, the roof expands/contracts while the supporting framing does at a much reduced rate since it resides inside the controlled envelope. If this differential movement is not accounted for then stress builds within the panel system and its connections. This stress will eventually compromise the integrity of the roof system.

Panel Systems

We can fight Mother Nature with a low cost through-fastened (screw down) system. This type of panel is attached to the supporting structure with lines of screws that penetrate the skin in the panel pan along each purlin line. As the panel expands/contracts from eave to ridge it pushes against its connection to the purlin. The effect is cumulative and engineering studies have shown that “Z” purlins will roll in the direction of the applied force until the panel to fastener interface can no longer sustain the bearing force. The panel will slot by tearing and piling up around the screw shank (photo 1) thereby relieving the expansion/contraction stress. Once the slot grows past the sealing washer a leak has been created. Through fastened systems can be used where the roof planes a relatively short without problems.



Or we can go along for the ride with a standing seam system as Mother Nature keeps it in constant motion from eave to ridge. There are many proprietary designs but all standing seam roofs float above the supporting structure as a steel membrane via clips. These clips are attached to the panels by hooks engaged into panel seams and fastened to the supporting structure with screws. This permits the system to be attached without fastener penetrations except at the line of fixity and at panel laps for wide roof planes. Less through fasteners means there is a lower probability for leaks. Fortunately, the panel acts as an accordion at each individual seam as expansion/contraction takes place from end wall to end wall.

There are two types of clips used with standing seam roof systems, one piece fixed clips and multi piece sliding clips. Fixed clips can be used on relatively short roof planes in much the same way as through-fastened roofs. The expansion/contraction is accommodated through purlin roll and cladding flexibility. Two piece sliding clips also come in many proprietary designs but function by attaching a base to the supporting structure and a tab that slides along the connection to the base while being dragged along by the hook engaged into the panel seam. Good clip design should determine clip tab fixity in the panel seam and then ensure that the force to slide the tab in the clip base is less than the clip fixity. The expansion/contraction is limited by the amount of slide designed into the clip and can be as long as 8” such as those designed by Building Research Systems. The clip should have a centering device to allow equal travel in both directions thus allowing a roof system installed in the summer at maximum expansion to fully contract and a roof system installed at maximum contraction in the winter to fully expand.

Real Life Field Conditions

In actual field conditions, the expansion/contraction of standing seam roofs is much less than the theoretical calculated value. As a metal standing seam panel expands/contracts it can develop a considerable amount of force along the seamed rib if it is restricted from moving. This value can be calculated through the known properties of the panel as shown in the Expansion Force example.

Expansion Force

Example; 24" wide SSMR panel 24 Ga, temperature change from 20 to 110 degree, the expansion force?

$P = 0.168 \times 29,000,000 \times (0.00065/100) \times 90 \quad F = 2,850 \text{ lbs.}$

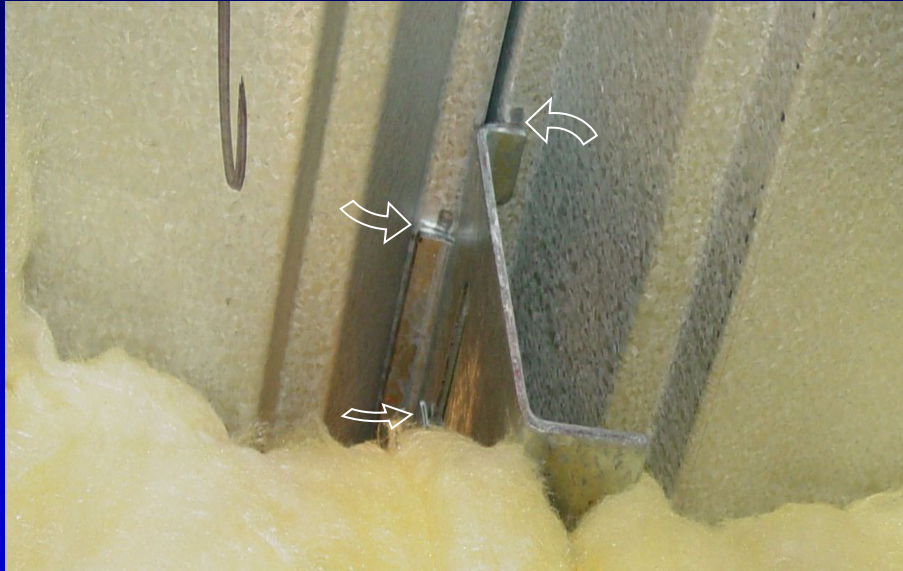
under ideal conditions

As the panel moves friction in the system and binding of the clips offset the expansion/contraction force along with cladding flexibility and purlin roll to limit the movement to less than theoretical. Field studies (photo3 & 4) have determined that for most systems this reduction can be as much as 20% below theoretical.

Field Condition Study

Thermal movements in a real-world condition is less than the theoretical calculated value.

Real Life Field Condition **Markings**



The adjusted formula for calculating expansion/contraction is shown in Example 3 SSMR Thermal Movement.

SSMR Thermal Movement

$$\Delta L = 0.000078 \times (T_2 - T_1) \times 0.80 \times L_r$$

- Expansion coefficient of steel = 0.00065 / 100 F°
- L_r = roof sheet run length in ft.
- T_1 and T_2 ; temperature differential ΔT in F°
- ΔL ; roof sheet length change, expansion or contraction in inches

Two sample cases on how to calculate expansion for real world conditions are illustrated in the following examples. The first, Example 4 is for an office building attached to an assembly plant located in the central part of the US. The second, Example 5, is for a typical convenience store located in central Florida.

Example 4 Thermal Movement

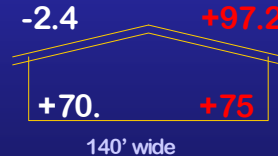
Springfield, MO.

140' wide building, low slope, office/ light décor assembly plant

Mean of annual extreme ; -2.4 to 97.2 F° per ASHRAE

$$\delta T = 97.2 - (-2.4) - (75-70) = 94.6$$

$$L = 140' / 2 = 70'$$



$$\Delta L = 0.000078 \times 94.6 \times 0.8 \times 70' = 0.413''$$

Example 5 Thermal Movement

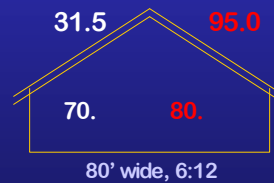
Tampa, FL.

80' wide, 6:12 (26.5°) slope roof for a quick stop, gas and go.

Mean of annual extreme ; 31.5 ~ 95.0 F° per ASHRAE

$$\delta T = (95.5-31.5) - (80-70) = 53.5 \text{ F}^\circ$$

$$L = (80'/2) / \text{Cos } 26.5^\circ = 44.69'$$

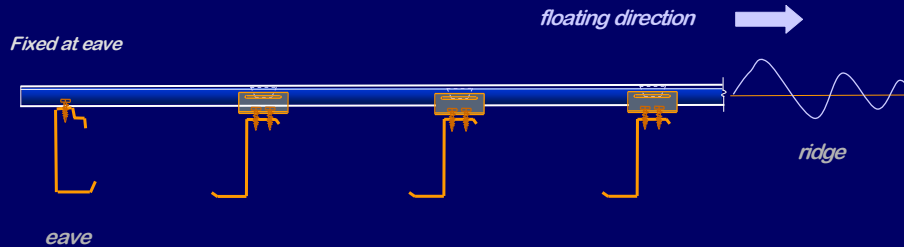


$$\Delta L = 0.000078 \times 53.5 \times 0.8 \times 44.69' = 0.149''$$

Design Recommendations on How to Control Thermal Movements

The roof system line of fixity should be at the low eave and the panels should be allowed to expand/contract to and from the ridge as shown in illustration titled SSMR Flow of Floating.

SSMR Flow of Floating

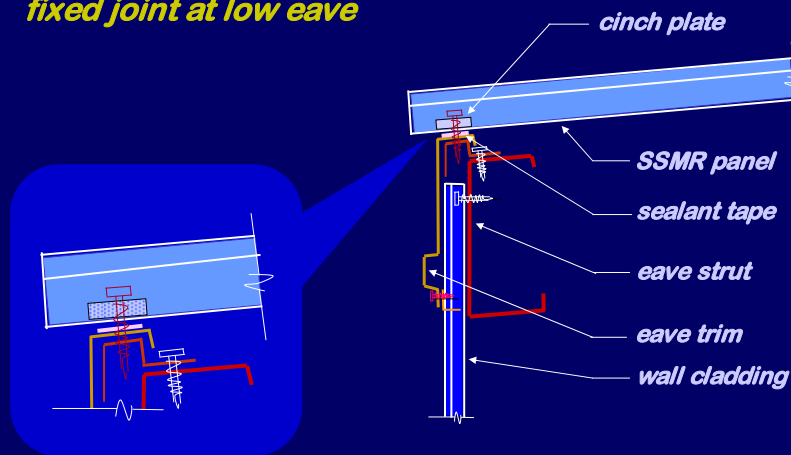


Anchored at low eave, floats to ridge

The fixed joint should provide enough fasteners with a cinch plate to resist the combined effects of gravity loads and expansion/contraction forces as shown in Anchorage at Eave. The cinch plate confines the panel material which helps to increase its bearing resistance against the fastener and compresses the sealant for a tight seal.

Anchorage at Eave

fixed joint at low eave

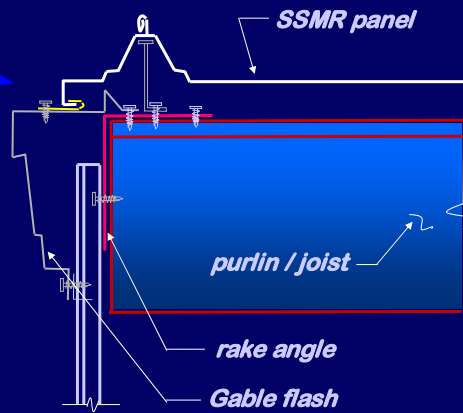


The roof system movement at the gable ends of the roof plane can be accomplished by one of two methods. The gable trim can be fixed to the supporting structure and the roof float over it via clip attachment as shown in Movement at Gable- A or the gable trim can be affixed to and float with the roof system and be attached to the wall via clips as shown in Movement at Gable- B.

Movement at Gable - A

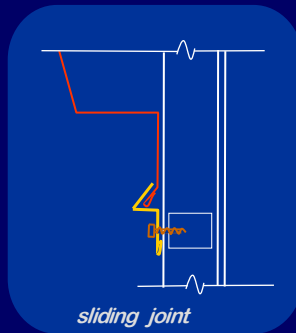


float at roof plane

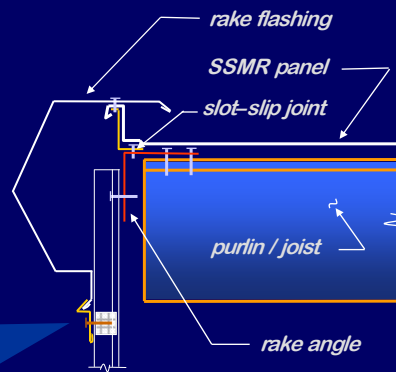


Movement at Gable - B

floating joint at wall plane



sliding joint



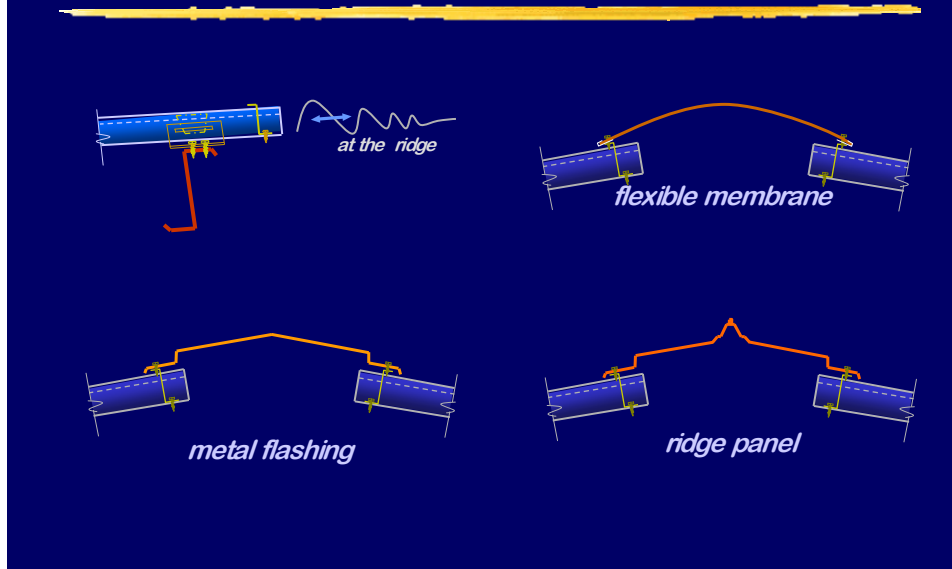
Eave trim and gutters or any other continuous longitudinal trim should be detailed for expansion/contraction even though the roof panels do not require it. The photo titled Longitudinal Trim Joint Failure shows what can happen when this minor detail is overlooked. If the structural system is long enough to require an expansion joint the panel should also include an expansion joint at that location due to the concentrated movement between the two supporting structural systems.

Longitudinal Trim Joint Failure



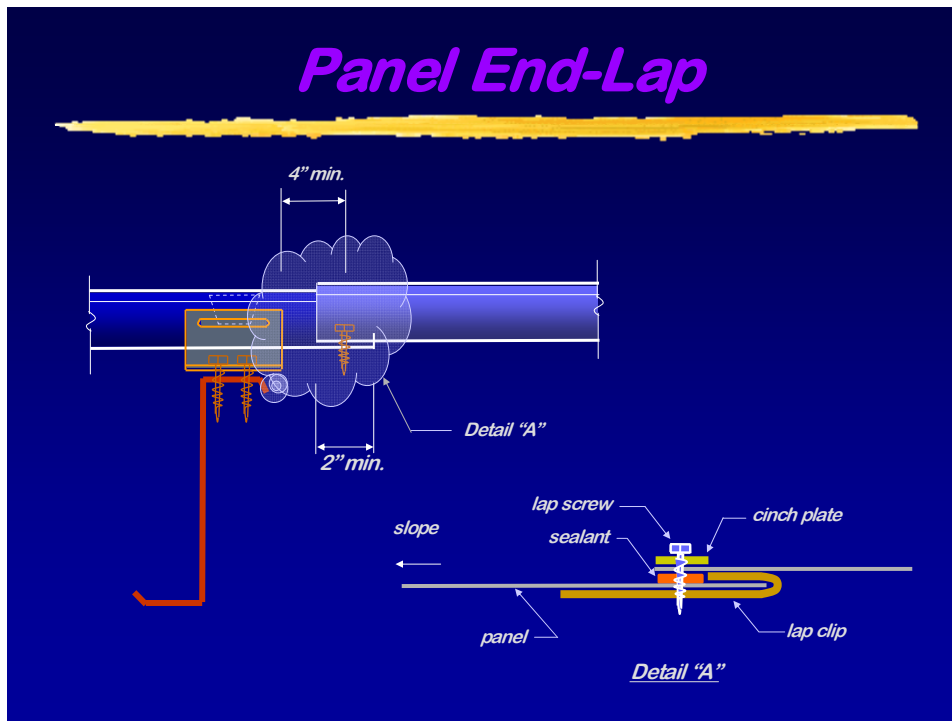
Ridge covers should be designed to flex as the roof planes move together and away with expansion and contraction as shown in Ridge details. The force to disengage the ridge connection to the end dams and the end dam fixity to the panel should be examined to be sure the system can accommodate the forces encountered with panel movement in both directions.

Ridge Details



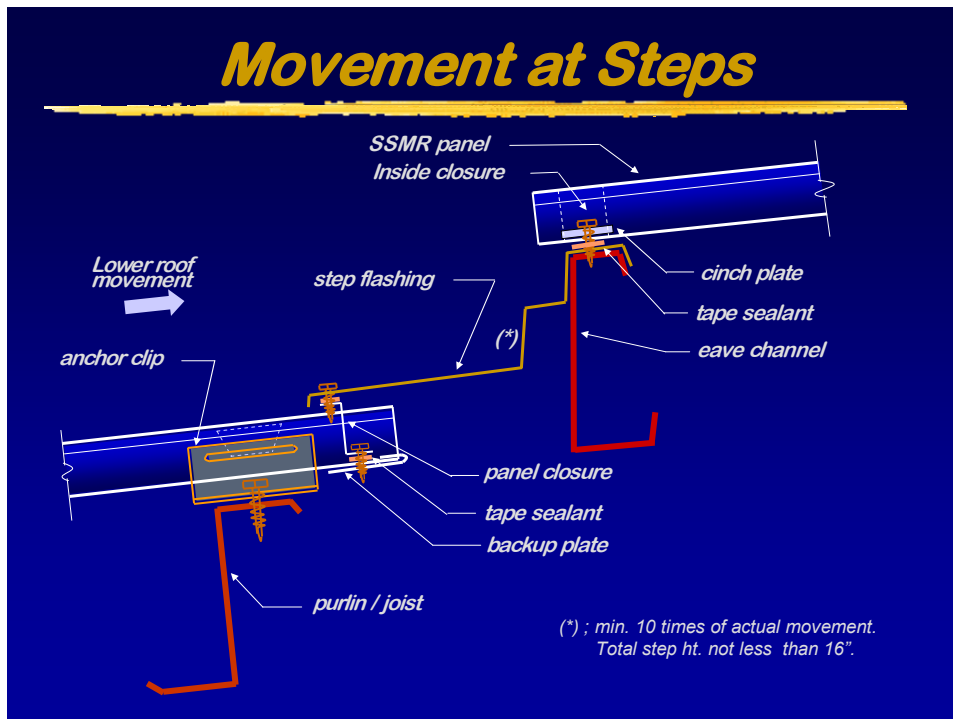
Proper panel end laps are critical in the success of wide floating roofs remaining weather tight. The end lap detail should be at least 2 inches long, provide enough room for the tape sealant to reside between the panels, have a heavy gauge back up plate and a quality cinch plate to tie it all together as illustrated. There needs to be enough screws in the end lap to pass the expansion forces from one panel to the other without the joint buckling or the fasteners failing.

Panel End-Lap



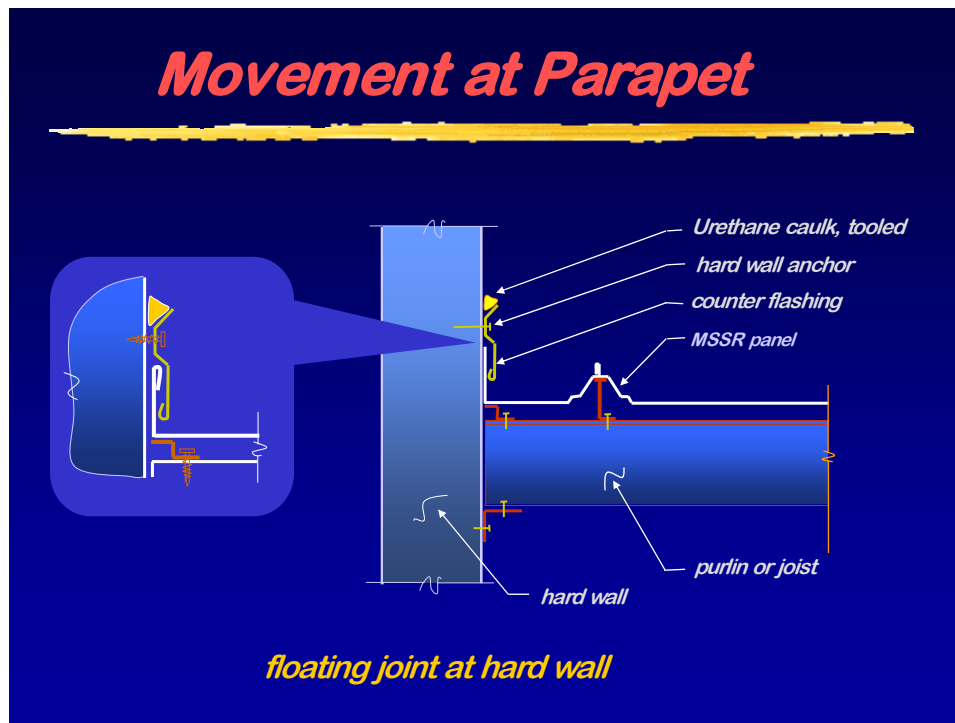
When roof planes are too wide for the available slide built into the panel clip itself then a roof step can be provided. The expansion/contraction movement is taken up in the flash and the upper roof starts the process anew.

Movement at Steps



Roof planes terminating against parapets or end wall steps are allowed to move by breaking the panel pan up into a weather tight leg and sealing with a counter flash. At hard wall parapets care should be taken to properly seal the counter flash to the wall material with a high grade urethane caulk.

Movement at Parapet



Reentrant corners at building width changes can cause major problems when the difference in width becomes too great. The panel on the wider roof plane is expanding/contracting while the panel at the narrower roof plane is fixed and not moving in relation to the wider roof plane. The panels can buckle, tear or break the point of fixity loose at this juncture if the forces are too great.

Large openings in the roof for service equipment should be accommodated with a floating roof curb. The curb should be able to slide on sub-framing as the roof system expands and contracts. When equipment loads or size requires a fixed curb for support a non-load bearing curb should surround the fixed curb and float with the roof system and be sealed to the fixed curb with flashing. Care should be taken to provide adequate room between the curbs at the uphill and downhill sides for the movement.

Pipe penetrations should have a large enough hole cut through the panel pan (never cut the rib) to allow for expansion/contraction. Rubber cone boots then should encompass the pipe and be able to fully cover the hole and flex with the panel movement.

Conclusion

- Thermal movement is a force of nature, it happens continuously everyday and is the major source of roof leaks.
- Designers must learn how to accommodate the thermal movement and the forces involved.
- As we do, a standing seam roof will last a long time with a trouble free service life.

Kwon S. Kim, P.E.

Kwon is president of Incheon Engineering, PLLC. He has been with major metal building systems manufacturers for 40 years. Throughout his tenure with the industry, Kwon has developed and successfully commercialized numerous roof systems and building components. Kwon is a registered professional engineer in 39 states and holds six U.S. patents. He is a member of ASTM, AWS, ASHRAE, SPE, and UL STP 580. He has served on many committees, including two terms as Chairperson of the Fire Protection and Insurance committee for MBMA.

Richard G. Starks, JR P.E.

Richard is the Vice President of Engineering and Product Development for Building Research Systems, which designs, develops, tests, deploys and licenses standing seam roof systems, clips, and accessories. He has been involved with metal building roof systems for over 30+ years and developed a mini-storage system for a major metal building system manufacturer while working in their product development department. He holds several related patents for roof system components and seamer technology innovations. He is a member of OSEA, ASCE and serves on the MBMA Technical and Energy committees.