METAL ROOFING FROM A TO Z

ALUMINUM ZINC

PART VI: Attachment of Metal Panels

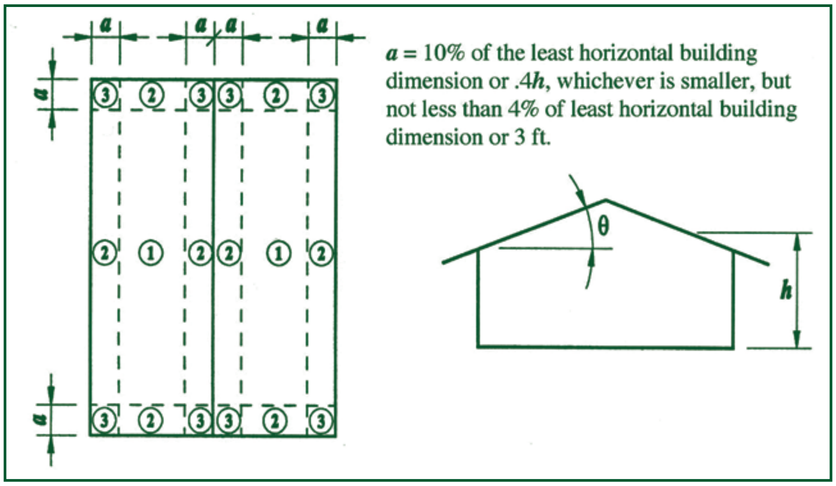
By Rob Haddock

***Editor's Note:** This is the sixth article in a multipart series about metal roofing in today's market. The series provides an in-depth look at materials and their uses, coatings, system designs, and installation techniques. It is reprinted with permission of* metalmag.

In previous A to Z articles, we have looked into history, materials, finishes, fabrication equipment, panel profiles, and standing seam types. In this article, we look at panel attachment and how it provides the necessary wind resistance while still allowing panels to respond to thermal loads. We also look at "panel pinning"—where and how it is done.

Wind Effects and Testing

Metal panels that comprise the finished surface of a roof constitute an airfoil of sorts. As wind buffets the walls of the building, it is redirected up and over the roof. As this happens, negative pressure (suction) is created over certain zones of the roof surface, producing "lift" or "uplift." This is the same dynamic that makes airplanes fly, and the effect can be quite exaggerated, threatening to tear the roof from its mounting. The frequency and strength of the metal panels' attachment, consequently, can be vital to roof survival during a windstorm.



a = 10% of the least horizontal building dimension or .4*h*, whichever is smaller, but not less than 4% of least horizontal building dimension or 3 ft.

Figure 1 – Zones 1, 2, and 3 each have pressure coefficients that vary with other aspects of the structure. Zone 3 experiences the greatest pressure; Zone 1, the least. Zones near the ridge are nonexistent when the slope is below 7 degrees.

Wind is measured by its speed in miles per hour, but those units of measurement are not useful to design structures and roofs. The forces that are exerted on the roof surface are determined by taking the highest historical wind speed and translating it into pounds of pressure per square foot of roof surface. This involves a number of tables, equations, and variables that include the height of the building and other size factors as well as the exposure factor from the effects of the surrounding terrain or nearby buildings.

The ASCE-7.05 design standard is the most widely accepted engineering standard to determine the relative effects of these variables. The standard divides the roof into "zones," each of which will experience different uplift forces resulting from the same wind speed (*Figure 1*). Corner zones are where the wind effects are the greatest. Perimeters are next, along with ridges on steeply sloped roofs. The "field" of the roof is where wind suction effects are the least.

The resistance of panels and attachments to the uplift forces to which they will be exposed is either calculated or tested. More design parameters and specifications require testing rather than structural engineering calculation. Recognized test methods include Underwriters Laboratories UL 580, Factory Mutual 4471, and ASTM E 1592.

These tests use various methods of inducing static pressure on the roof assemblies in an attempt to quantify their performance. Most of them are designed and intended for structural panels (panels installed over open support framing). In my opinion, they generally produce conservative results compared to the real-world effects of wind on a roof surface. This has to do with conservatism within the design standard and test methods as well as the inability of any test to replicate the unusual "microbursts" that wind produces on the surface as opposed to prolonged sustained pressures.

Some ongoing tests at Mississippi State University (*Figure 2*) using

Figure 2 – Research funded by the Metal Building Manufacturers Association (MBA) and the American Iron and Steel Institute (AISI) is ongoing at Mississippi State University. It utilizes electromagnetic fields to more accurately replicate the effects of wind on a roof surface.

electromagnetic fields rather than air pressure are getting closer to the real effects of wind on structural metal panels; however, testing of this type is too costly to be adopted as an industrywide procedure. The effects of wind on a roof surface that is installed over a deck are known to be mitigated to some degree, but the industry tests noted here cannot reflect this, and indeed some of them do not enable testing of these "nonstructural" panels over solid decks. (See *Figure 3*.)

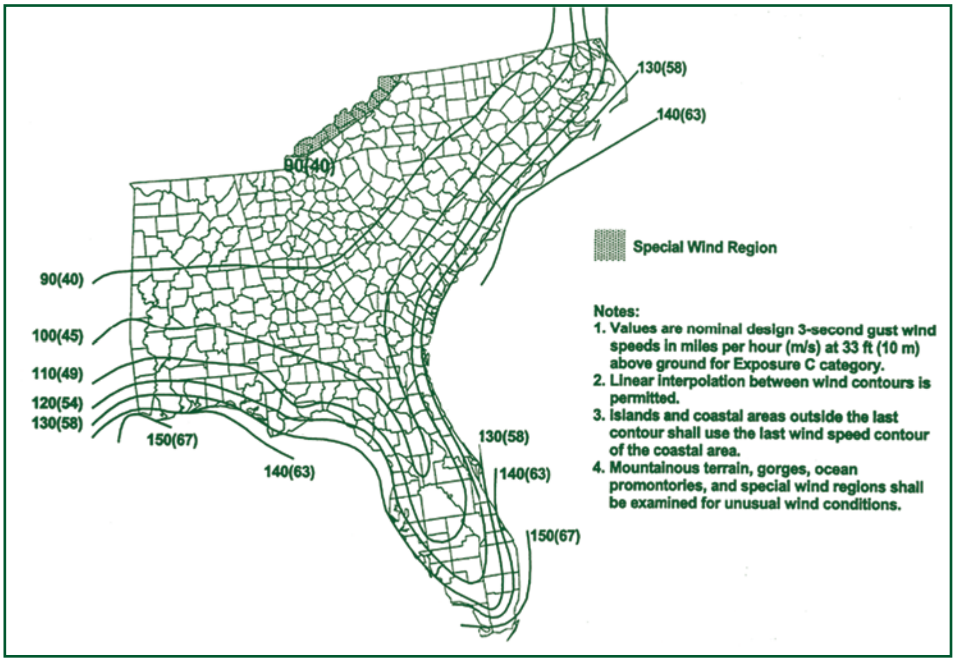
Because each test is very specific in terms of the material and assembly particulars, a manufacturer testing a new roof product may have to go through a battery of tests for each gauge, panel width, and material that he wishes to market. This can mean dozens of tests costing thousands of dollars each. Such repetition is necessary, however, as there are many variables in actual assemblies. Those variables include the gauge and mechanical properties of the material, geometric shape of the seam and profile, dimensions of the seam, strength of the clip or other attachment, and width of the panel. The metal roof assembly is a chain, in essence, with the weakest link representing the point of failure. Changing one of the variables means increasing or decreasing the strength of one of the links. But doubling the strength of one link does not necessarily double the strength of the chain—the failure point just moves to a different link.

Panel Attachment

Panels are attached with either exposed or concealed fastenings. Exposed fasteners are used for certain panel types, including ribbed and corrugated profiles. This "direct" method of attachment can provide increased wind resistance but it does not provide for thermal movement of panels and has the obvious disadvantage of penetrating the weathering surface.

Such methods and systems must be utilized with some precaution for these reasons. When the structure to which they are attached consists of wood or steel purlins, thermal cycling is relieved to some extent by flexure or rotation of the purlins. When these systems are used over solid wood decks or bridged bar joists, however, fastening fatigue can result from repeated thermal cycling. It may, therefore, be a good idea to limit roof lengths for such applications, as thermal movement is directly related to length. Hundreds of years ago, brakeformed shapes were all fix-cleated to the structure, but their end-to-end joining was done with loose locks; and pan lengths were short, so thermal movement was never accumulated. Now, with roll-forming methods, panels have gotten considerably longer.

Most (not all) "concealed fastening" provides for differential thermal movement of panels to structure by the interface of the clip with the panel (*Figure 4*). A simple clip design would have this interface be a frictional engagement wherein the clip is rigidly attached to the building structure but slip-connected to the male seam component of the panel. This one-piece clip method is quite popular with most steep-slope roof



Notes:

1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10 m) above ground for Exposure C category.
2. Linear interpolation between wind contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

Figure 3 – Design begins with the fastest three-second gust as measured "on the ground" (33 ft above and lower). Because of ground friction, as building heights increase, wind speeds also increase; hence, a roof on a 100-ft-tall building will experience more severe wind effects than a one-story construction. For related reasons, surrounding construction and topography also play a role, resulting in different "exposures."

Figure 4 – Concealed fastened panels eliminate most fasteners from the weathering surface by using hold-down clips inside the side-seam joint. The clips permit thermal movement, but because the "flat" of the panel is unrestrained, wind resistance is diminished. Under load, the panel flat arcs upward, rotating the seam and disjointing.

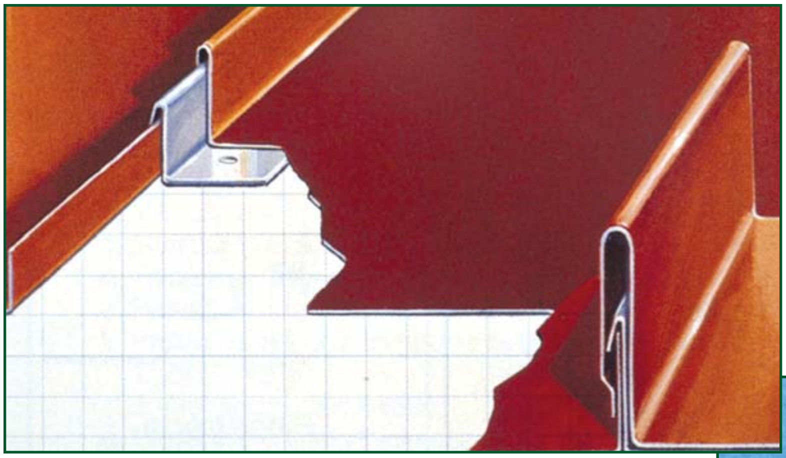
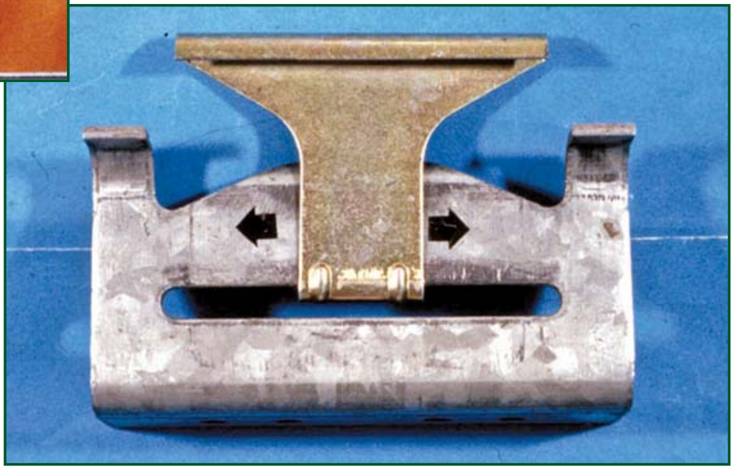


Figure 5 – One-piece clip designs provide for thermal cycling by a sliding engagement of the panel seam. The differential movement takes place between panel and clip.

Figure 6 – Most two-piece clip designs provide for differential movement within the clip itself. The base is fixed to the structure, and the top folds into the panel seam. The top does not move relative to the seam, preserving the integrity of seam sealants.



products, especially those that have "snap-together" seam types. The clip is stationary but allows for differential movement between panel and clip (*Figure 5*).

When sealants are used within a panel seam, often the clip design shown in *Figure 5* cannot work. This is because the differential movement between the panel and clip would abrade the sealant, jeopardizing weather integrity of the seam. In such cases, a different clip design must be employed. The most popular designs for such a seam involve dual component clips. The clip base is attached rigidly to the structure, and the clip top folds into the panel seam. Differential movement then takes place within the clip itself, between its two components—base and top. It bears mentioning that the clip is an integral part of the assembly and unique in most cases to the panel with which it is used. (See *Figure 6* for a dual-component clip.)

Figure 7 – If a panel is not "fixed" at some location, gravity or "drag loads" can pull it down the slope of the roof.

Panel Fixity

Clip fastenings that allow the panel to cycle freely in response to thermal loads also make it necessary to deliberately "pin" or "fix" the panel at some point along its length to prevent it from migrating out of position. Gravity or "drag loads," as they are sometimes called, will act in a direction parallel to the roof's surface, trying to pull the panel down the slope of the roof (*Figure 7*). These primarily comprise vertical loads (mostly snow) on the roof's surface. The only resistance to them (other than the panels' designed point of fixity) is the frictional resistance of the clip attachment and the friction between panel and structure. (*See sidebar on page 17 on calculating drag loads.*)

Panel fixity can be accomplished by using one or more "fixed clips" or by some method of direct panel fastening at that location. Use of fixed-clip methods depends upon the nature of the interface of clip to panel seam; with some designs, it is not possible.

The location of choice for fixity of steeply sloped architectural systems is at the ridge, where exposed fasteners can be hidden beneath a ridge cover. These systems will then accumulate movement at their eave end.

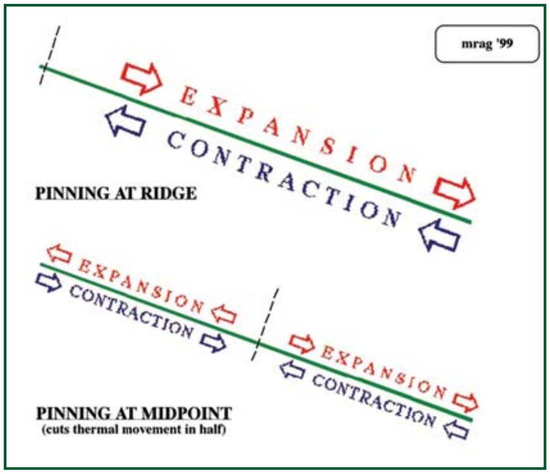


Figure 8 – The point of fixity may be at the ridge, the eave, or some midpoint. It is crucial that this point is singular, e.g. that "dual pinning" does not occur.

Conversely, the popular point of fixity for low-slope systems is at the eave. The primary reason for this preference is that such systems are often hydrostatic by design, and it is much easier to waterproof a joint that is stationary than one that moves. Such a system will then accumulate thermal movement to the ridge where a "bellows"-style ridge flashing can accommodate differential movement of the two opposing roof planes while maintaining a hydrostatic seal.

These statements are not meant to be exclusive, as there are exceptions in both cases. It is also possible to see a panel fixed at its midpoint, dividing thermal movement in half by sending it in both directions rather than one.

Having chosen a point of fixity for the metal panel system, it then becomes critical to ensure that such a point is singular (*Figure 8*). In other words, the panel should not be pinned inadvertently at any other point along its length. To do so would likely produce a failure of some sort. On occasion, the thermal movement integrity of a roof system is violated because some construction detail or roof accessory mounting did not preserve this characteristic (*Figures 9* and *10*). Design and as-built construction should be scrutinized in this regard. A fascia break detail, for example, fixes the panel at the point of the break; to fix it again at its opposite end would constitute dual pinning.

How Does Thermal Movement Occur?

As metal panels get hot, they expand, increasing their length. When they get cold, they contract, reducing that dimension.

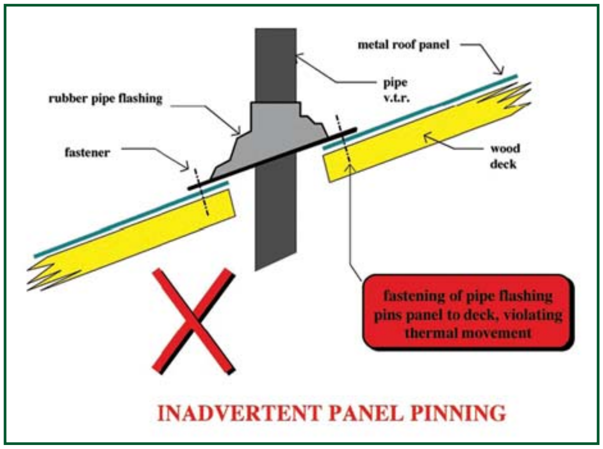


Figure 9 – Often, when a pipe is flashed through a steep roof product over a deck, it results in panel fixity. To avoid this, the deck should be overcut as shown.

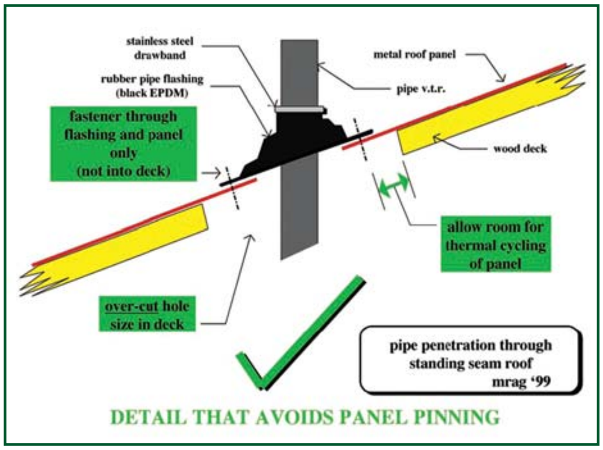
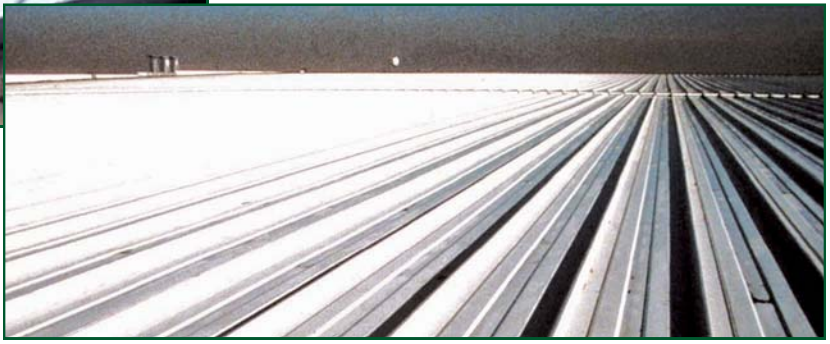


Figure 10 – Detail avoiding panel pinning.



Figures 11 and 12 – In the early days of metal roofing, pan lengths were short, so thermal movement never accumulated. As the "unbroken length" of panels increases, so does the dimensional gain or loss due to differences in surface temperature.

This cyclical changing of dimension is called thermal movement. This is a linear effect. In other words, it will accumulate in direct proportion to the panels' "unbroken" length. If panels are joined end to end with mechanical fasteners through the lap, then the unbroken length is the total length of two or more panels, not just one.

Thermal movement does not accumulate across the width of the panels because the unbroken length in that axis is so small. The geometry of panels and their joining method at side joints allow flexure at each joint so that the thermal effects never accumulate. Small, unitized metal covering products, such as shingles, minimize unbroken length dimensions; hence, thermal movement is rarely a consideration for such systems (*Figures 11* and *12*).

Total (or worst-case) thermal movement is calculated by extending the material's coefficient of expansion over its length and anticipated in-service temperature range throughout its service life. It is the surface temperature of the material and not ambient air that affects these extremes.

The maximum high-end temperature will be conditioned by the color of the panel and its solar absorption characteristics (lighter colors and high-gloss finishes will be cooler than dark colors and low-gloss finishes). A dark-colored panel with low gloss at right angles to the summer sun can approach temperatures of 200˚F.

In cold winter nighttime scenarios, the low extremes of surface temperature can actually dip 25˚ or 30˚ below ambient air. This is due to the principles of radiant ener-

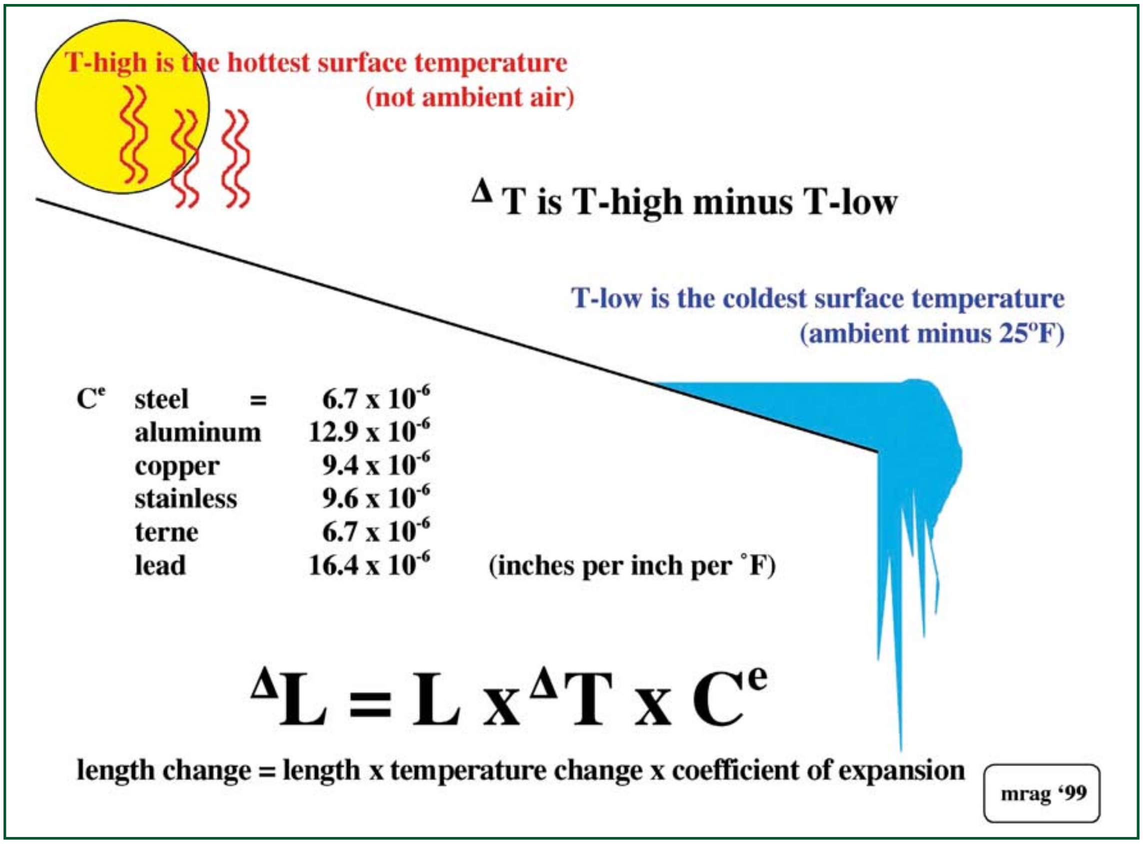


Figure 13 – Different metals have different expansion coefficients. Note that aluminum will gain or lose about double the dimension of steel when subjected to the same temperature differences.

gy. Skyward-facing objects radiate heat energy to the night sky. As this energy transfer occurs, the material loses BTUs, reducing its temperature. It is this same effect that results with dew or frost on the ground, roof, or windshield of your car. It is a combination of these factors that can result with delta figures of close to 250˚F in cold northern climates (*Figure 13*).

Because building structures are not directly exposed to direct solar gain or nighttime radiation, they do not expand and contract at the same rate as roof panels. Additionally, the structure is often a different material with a different coefficient of expansion. Hence, differential movement of the roof panels to the structure or deck to which they are mounted must be accommodated. If the roof moves an inch and a half but the structure only one-half inch, then differential movement of one inch must be provided by the clip attachment. Often, the structure is a conditioned element inside the insulated building envelope. When this is the case, it experiences no change in temperature and, therefore, no change in length. This means that the differential movement between roof and structure is equal to the total movement of the roof, with no offsetting or mitigating thermal cycling of the structure.

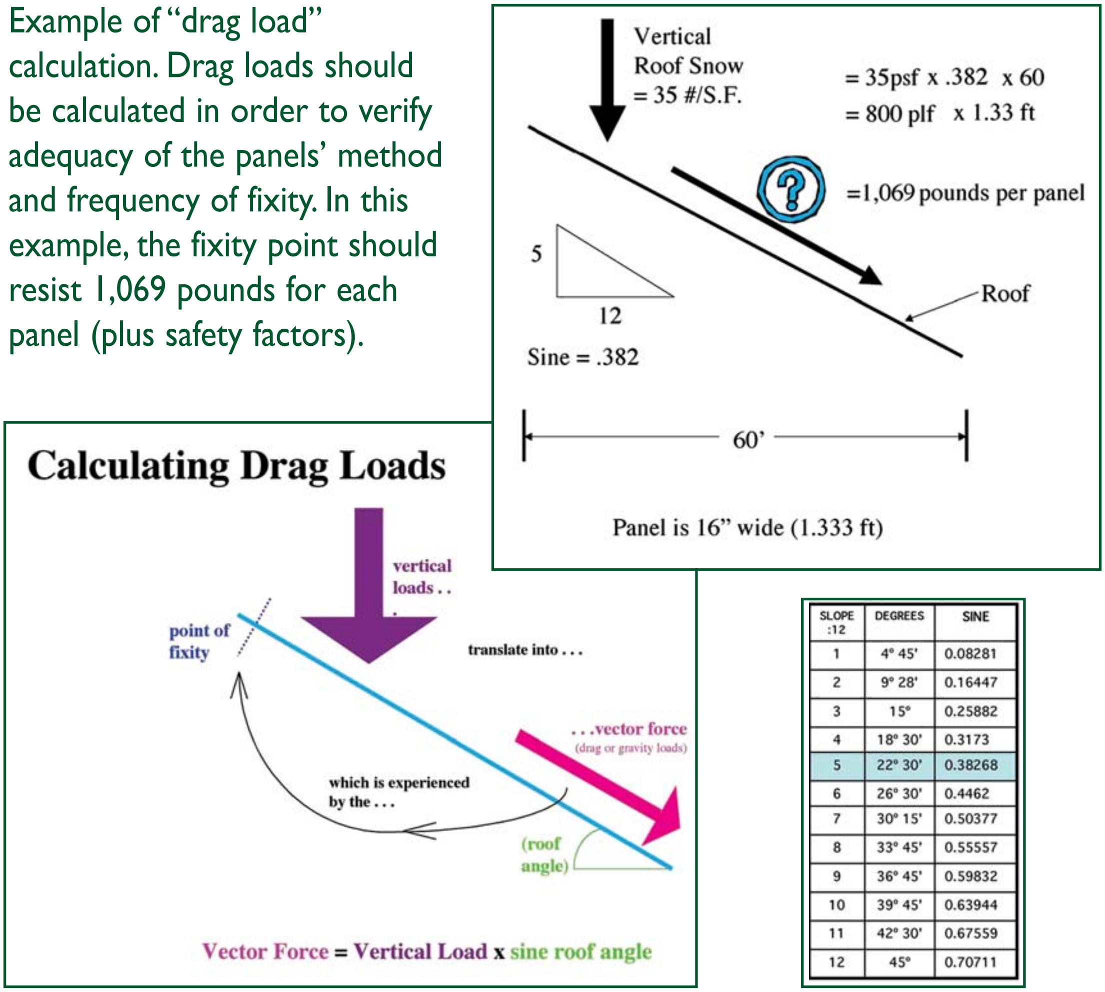
It bears mentioning that it is not unusual to see about 80% of this theoretical calculated thermal movement actually used in design. Panels distort a bit; structural mountings or members may be deflected and strained, but roofs don't seem to fail.

On the other hand, if thermal movement calculations are based upon ambient air, they will often be only 50% of the correct extremes, and I have seen these fail—repeatedly. A single metal panel exerts forces measured in tons when it tries to move thermally; hence, a restriction of this anticipated movement could precipitate attachment fatigue and failure.

I have also seen engineers who try to prove that the panel will undergo a "buckling” failure before the attachment will fail. In other words, it will hump up, oil-can, or otherwise move out of plane to relieve the thermal forces. The trouble with this theory is that a member only buckles in compression (during an expansion cycle). Most attachment fatigue and failure occurs in tension (during cold-cycle contraction).

Manufactured clips usually include some mechanism to ensure that they are centered at the time of installation. In theory, the roof panels are installed somewhere in the mid-range of their in-service extremes. Although it may not be exactly at the halfway mark, common practice does not compensate for exact temperatures at installation. It is absurd to suppose that installers will move clips to some predetermined location contingent upon installation temperature. Even if they did, the temperature is likely to be different when the mechanical seaming is done. Most clips find their own “centering” within the range of thermal cycling of the roof within the first few months of service.

Example of “drag load” calculation. Drag loads should be calculated in order to verify adequacy of the panels’ method and frequency of fixity. In this example, the fixity point should resist 1,069 pounds for each panel (plus safety factors).



SLOPE :12	DEGREES	SINE
1	4° 45'	0.08281
2	9° 28'	0.16447
3	15°	0.25882
4	18° 30'	0.3173
5	22° 30'	0.38268
6	26° 30'	0.4462
7	30° 15'	0.50377
8	33° 45'	0.55557
9	36° 45'	0.59832
10	39° 45'	0.63944
11	42° 30'	0.67559
12	45°	0.70711

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Rob Haddock is president of the Metal Roof Advisory Group, Ltd., and a well-recognized authority on metal roofing. He is a consultant, technical writer, training curriculum author, inventor, and educator. Haddock is a member of NRCA, ASTM, ASCE, ASHRAE, MBCEA, and MCA. He has been a course author and instructor of RCI classes and a course instructor for the University of Wisconsin School of Engineering. He is also a recipient of RCI’s Horowitz Award.