

# **Built-in Gutter Design and Detailing**

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## ABSTRACT

Built-in gutters are a frequently mis-constructed roof component. The basic principles of thermal movement, as well as their direct impact on material selection, appear to be misunderstood by both design professionals and contractors. Dubious details contained in some of the industry's standard reference manuals do not help the matter. Recommendations for proper built-in gutter design and detailing will be made, including a discussion of the stresses imposed upon built-in gutter liners under thermal load, seam selection, rivet selection and spacing, expansion joints, and layout. Common misconceptions concerning gutter design, having to do with metal temper and gauge, will also be examined.

## SPEAKER

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# Built-in Gutter Design and Detailing

## INTRODUCTION

Built-in gutters are a frequently mis-constructed roof component. The basic principles of thermal movement, as well as their direct impact on material selection, appear to be poorly understood by both design professionals and contractors. Worse yet, for years, some of the industry's standard reference manuals on metal flashings and gutters have been offering questionable information to those charged with the design and construction of roof drainage systems. As a result, built-in gutters are often plagued by open seams, fatigue cracks, and loose-locked seams located within the one of ice damming.

Incorrectly installed built-in gutters are not easily repaired. Open seams cannot simply be re-soldered due to the presence of dirt and moisture within the failed seams. Expansion joints cannot simply be installed after the fact if water flow to the outlets is to be maintained. Gutter replacement is often the only long-term remedy, but even this can be complex, especially when tie-in with an existing standing seam or batten seam roof is required.

After identifying common issues associated with the failure of built-in gutters, thermal movement and the stresses imposed upon built-in gutter liners under thermal load will be discussed. Basic principles associated with proper built-in gutter design and detailing will be outlined, including expansion joint design, seam selection, rivet selection and spacing, soldering, pan orientation, cleat type, and outlet tube materials. Common misconceptions

concerning gutter design, having to do with metal temper and gauge, will also be examined.

Throughout the paper, the issues discussed apply equally to pole gutters and box gutters, as some of the illustrations will show. Similarly, although copper built-in gutters are most frequently referenced in the paper, the principles are also applicable to other metals commonly used in the fabrication of built-in gutter liners, including lead-coated copper, tin/zinc alloy-coated copper, stainless steel, terne, and TCS II (stainless steel sheet coated with a tin/zinc alloy).

## COMMON CAUSES OF PREMATURE BUILT-IN GUTTER FAILURE

Reflecting back on a recent spate of projects, and then even further, to those completed over the past 20 years, a common thread appeared: problems with recently installed built-in gutters. One might expect 50- to 60-year-old gutters to have problems. Normal wear and abrasion at drip lines and outlet tubes will eventually create holes and result in leaks. It is when these "old timers" are replaced that the real problems seem to arise. More and more, building owners and property managers are reporting problems with built-in gutters installed within the past 10 years. Observation usually reveals that even the 10-year-old gutters have been leaking for some time, evidenced by layers of past, ineffective repairs and/or extensive deterioration of adjacent building systems, such as wood cornices, roof framing, and exterior masonry walls. Further, more often than not, the roof systems above these

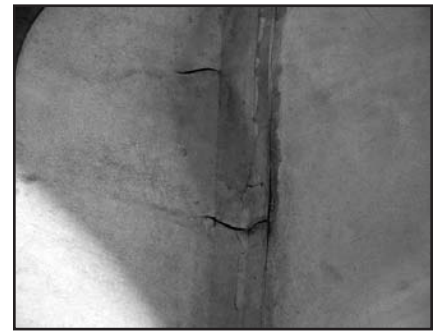
relatively new gutters – whether they be slate, tile, asphalt shingles, standing seam, or batten seam – are fine. Analysis of the problems associated with recently installed built-in gutters suggests that their design and installation are not well understood by today's design professionals and contractors. The building owner, frustrated by the leaks, just wants the problem to go away, holding to the hope that inexpensive repairs will save the day and adverse to even the possibility of having to start and pay for a major construction project yet again. Based upon over 20 years of observing what "works" and what does not "work," learning from past mistakes, and improving upon the designs of others, it is hoped that this paper will assist those responsible for specifying, detailing, and constructing built-in gutters with creating gutters that have a good chance of actually reaching the end of their expected serviceable lives and becoming "old timers."

## Open Seams and Fatigue Cracks

The most common problems associated with new built-in gutters are open seams and fatigue cracks (*Figure 1*). Unfortunately, these problems are also the most difficult to repair and most likely to condemn the gutter installation. Open seams and fatigue cracks are typically caused by improper accommodation of thermal movement in the gutter liner. Expansion joints are either not present, or placed too far apart to be effective. In addition, the top edge of the gutter apron is quite often nailed to the roof deck, rather than secured with cleats, thereby restricting thermal move-

ment, even if expansion joints are present. These conditions are difficult to repair for several reasons:

- 1) Open seams cannot simply be re-soldered to make them watertight. Dirt and moisture within the cracked seam turns into a black goop when heated and prevents new solder from being sweated into the seam.
- 2) Fatigue cracks can be patched with a copper "plate" riveted and soldered over the top of the affected area, but such a repair should only be considered temporary. The underlying cause of the fatigue crack – stresses associated with expansion and contraction of the gutter liner – remain, and will either cause the patch to fail, or simply transfer the stress to another point, resulting in another fatigue crack.
- 3) Installation of expansion joints to better accommodate thermal movement of the gutter liner is an obvious solution, but not readily achievable. Traditional expansion joints are formed by placing end walls at the ends of two adjacent lengths of gutter and leaving a small space between them. The end walls act as a dam and effectively prevent the flow of rainwater. So, adding expansion joints without re-sloping the gutters will prevent rainwater from reaching the downspouts. Re-sloping, of course, requires removal and replacement of the gutter liners.
- 4) Replacement of the troublesome gutter liner is often the only effective option, but again, can be



**Figure 1 – Open seam (left) and fatigue crack (right) in two different lead-coated copper gutter liners. Both are due to lack of expansion joints to accommodate thermal movement in the gutter liners.**

difficult to execute. The gutter liner, being at the roof eave, is always installed first, extending up under the roof system. When the roof system is comprised of slate shingles, for example, the bottom three or four courses of shingles can be removed, salvaged, and reinstalled to allow gutter replacement to occur. When the roof system consists of standing seam or batten seam metal roofing, the procedure becomes a bit trickier as the bottom several feet of roofing cannot easily be removed and reinstalled. As will be discussed below, the transition between a new gutter liner and existing metal roofing is not widely covered in standard industry publications and, even if well executed, it is rarely preferable to having the gutter liner installed first, followed by the metal roof system.

Open seams can also result from poorly soldered seams and seams that lack the proper strength to withstand the stresses imparted by thermal movement. The fact is, no matter how well designed a gutter might be, a poorly soldered seam will eventually fail. In the end, it all comes

down to good execution by the roofing mechanic. Conversely, a well-soldered seam will fail if the seam's design does not properly consider the geometry of the gutter, the gauge (thickness) of the gutter material, and the anticipated thermal loads.

Other frequently encountered problems not directly related to thermal movement pertain to detailing at the outside edge of the gutter and at outlet tubes. Where the built-in gutter sits behind a masonry parapet, the outside edge of the gutter is often terminated, or let, into a reglet cut into the face of the parapet's coping stone. This is an aesthetically pleasing detail in that the observer at grade cannot see any hint of the rainwater conduction system (*Figure 2*). Unfortunately, this detailing is prone to leakage as the reglet opens up. The problem is exacerbated if the gutter liner is let directly into the reglet, rather than being loose locked to a continuous cleat or apron, which in turn is let into the reglet. The former detail accelerates the rate of failure as it either: 1) inhibits thermal movement, resulting in open seams and fatigue cracks; or, more likely, 2) causes premature failure of the sealant or mortar filling the reglet as the diurnal juggernaut of thermal expansion and contraction continues unimpeded.



**Figure 2 – The outside edge of this built-in gutter liner is let into a reglet in the limestone coping stone. Compare this image to Revere's detail shown in Figure 7. Note, too, that the expansion joint is below the high water line of the gutter (compare to Figure 15).**

Another problem with the outside edge of built-in gutters occurs where the outside wall or leg is an integral part of the gutter framing or cornice, and is set too low.<sup>1</sup> During heavy rainfall, water rushing down the steep-slope roof above can simply “hop the curb” and run down the exterior wall. Both of the gutters shown in *Figure 3* were originally designed by top-tier, nineteenth-century, architectural legends in the Philadelphia region. The low outside edge of the gutter on the left was found to be contributing to efflorescence and scaling of the interior brownstone walls of the church. When informed of this, the client's first question was



“shouldn't we assume [the architect] knew how to design a gutter?” An intimidating question, to say the least, but the answer remains a resounding “no.”

Premature failure often occurs at outlet tubes. These areas are subject to the greatest wear as the greatest volume of water passes through the outlet tubes. The wear manifests itself as perforations or pinholes in the copper. The underlying problem is that the same weight copper was used to fabricate the outlet tube and the gutter. The goal should be to anticipate the accelerated wear, and use a heavier-weight copper for the outlet tube, so that the outlet and the gutter can achieve similar service lives.

### Improper Repairs

Not only is built-in gutter design and construction plagued by problems, the repairs implemented to address the faulty gutters are, more often than not, just as poorly conceived as the gutters themselves. Examples abound, but a few will suffice to make the point.

Fabric tape and mastic (a/k/a muck and fabric) is often placed atop open seams. If the soldered



**Figure 3 – The outside edge of these built-in gutters is set too low. In a heavy downpour, rainwater can overshoot the gutters and run down the exterior masonry walls.**

seam could not withstand the stresses of thermal movement, why should fabric tape and mastic do any better? Not only do they not hold up any better, fabric tape and mastic also suffer from ultraviolet (UV) degradation and cause accelerated wear of the underlying copper by both corroding the copper and preventing the formation of a protective patina. Fabric tape and mastic, along with sealants and flashing tapes, have their place. They are well suited for short-term repairs. Too often, however, they are relied upon as permanent fixes.

Trough-level expansion joints, although inferior to standard, raised, expansion joints, are sometimes required, and at least recognize that thermal movement of the gutter liner must be accommodated. With the installation of a trough-level expansion joint should come the recognition that it will have to be replaced periodically, at least several times over the life of the gutter itself. The key word here is “replaced.” When repair consists of placing a second trough level expansion joint over an existing one, a raised expansion joint is created, due to the thickness of the materials involved. This would be okay, save for the fact that the gutter was designed to slope in one direction (with water passing over the expansion joint), not two. The gutter shown in *Figure 4* contains three trough-level expansion joints piled one atop the other. All three leak, and the puddle pictured slowly drains through the wood cornice below, causing rot and deterioration along its way. The destruction does not stop there, however; water exiting the wood cornice soaks into the soil at grade and has caused a rising damp problem in the brick masonry foundation!

Relining failed built-in gutters with Ethylene Propylene Diene Monomer membrane (EPDM) is a

very popular solution in the Northeast. Done right, the EPDM can be expected to have service life of five to 10 years. Done wrong, as is typically the case, and the leaks persist. The leaks continue for several reasons: 1) termination bars and fasteners are placed within the zone of ice damming; 2) the membrane bucks water, either at its interface with the roofing material (i.e., the membrane is not run up, underneath the roofing above), or by stopping mid-way up large gusset areas and valleys (Figure 5); 3) seams open up as the underlying metal liner moves under thermal load; and, 4) the EPDM membrane is simply not capable of conforming to multiple, tightly spaced, inside and outside corners found in most built-in gutters (imagine a gutter-end wall, expansion joint, or outlet tube within a leader box).<sup>2</sup>



**Figure 4 – Trough-level, membrane expansion joint in a large, built-in gutter. Three expansion joints have been installed atop one another, creating a dam. The gutter outlet is located in the distance, near the gutter-end wall.**

Repair of a faulty or worn out gutter liner is never as good or long-lasting as a well detailed replacement. On the rare occasion that replacement does occur, however, detailing at the interface of the gutter and the standing or batten-seam roofing above often leaves much to be desired. Lapped and sealed seams are often employed as the gutter liner, or an apron joined to the gutter liner is simply slid up below the roofing as far as possible and the seam covered with sealant. Thermal movement quickly causes the sealant to fail, subjecting the lap to leakage via capillary movement of water and/or ice damming. To hold the overlying roof down, bolts are frequently set right down through the roofing and underlying gutter liner. A neoprene washer is typically expected to do the trick and keep water out of the hole thus created. The compression seal being relied upon quickly fails due to degradation of the neoprene and backing out of the fastener under thermal loads. In essence, there is now a hole in the roof/gutter liner every 12 to 24 inches on center.

#### **The Industry Does a Good Job, but...**

The roofing industry – trade associations, professional magazines, manufacturers – does a good job educating those in the field. Built-in gutter details in several highly regarded and generally excellent publications, are, however, of dubious integrity. Although it would be difficult for these publications to cover all conditions, their general guidance would seem to be leading design-



**Figure 5 – This lead-coated, copper built-in gutter has been re-lined with an EPDM membrane. The exposed edge of the membrane bucks water at the valley. Note, too, all of the tight inside and outside corners the membrane must accommodate.**

ers and contractors in the wrong direction, now and in the past.

Even a cursory look at the following five publications, design manuals all, reveals some significant problems:

*Copper And Common Sense*  
Revere Copper Products, Inc., Rome, NY, 7th Edition (1982) and 8th Edition (2005). Referred to herein as “Revere.”

*Architectural Sheet Metal Manual*, Sheet Metal and Air Conditioning Contractors' National Association (SMACNA), Chantilly, VA, 6th Edition (2003). Referred to herein as “SMACNA.”

*Designer Handbook, Standard Practices For: Stainless Steel Roofing, Flashing, Copings*, Specialty Steel Industry of North America, Washington, D.C., 1995. Referred to herein as “Specialty Steel Industry.”

*Technical Manual for the Design and Construction of Roofs of Stainless Steel Sheet*, No. 12 006, Nickel

Development Institute and Japanese Stainless Steel Association, Toronto, Ontario, Canada, 1989. Referred to herein as “NiDI.”

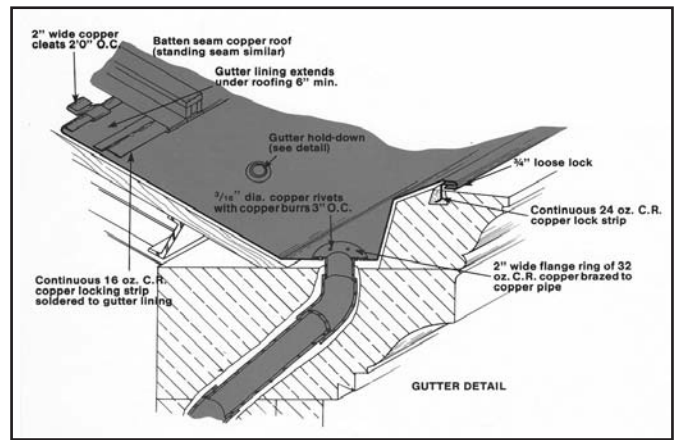
*Copper In Architecture*, Copper Development Association, Inc., New York, NY, 1992 Edition and 2007 online Edition. Referred to herein as “CDA.”

### Loose-Locked Seams in the Ice-Damming Region

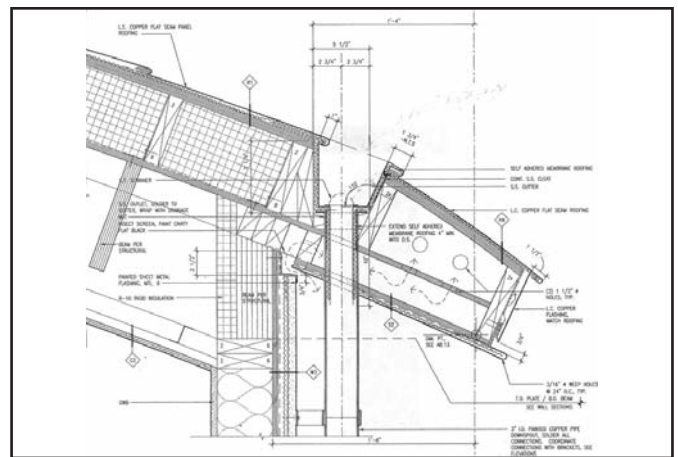
Placing a loose-locked seam at the top of the rear vertical leg of the gutter liner is shown in four of the five publications (Figure 6). This detail might be acceptable if the top of the rear leg is well above (say 12 or more inches, depending on climate) the outside edge of the gutter, or in regions of the country where ice damming is not likely to occur. Otherwise, the loose-lock seam will leak. To be fair, SMACNA states:

*“The metal roof system may need special features to lock to the gutter in a waterproof manner when ice dams are present with ponding behind them... Use only one-piece combination gutter-flashing in areas of ice and heavy snow.”*<sup>3</sup>

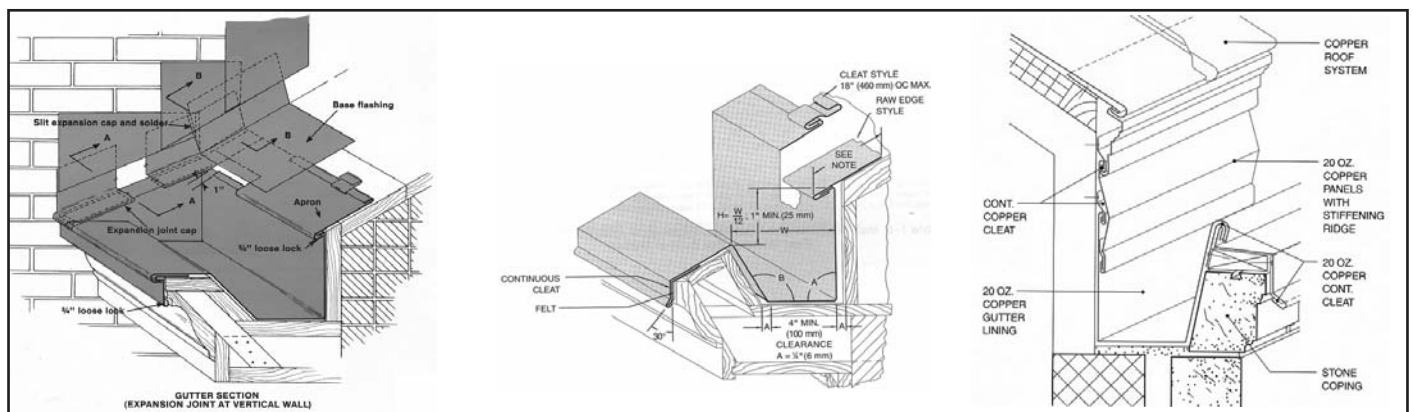
In its 1982 edition, *Revere* does show a gutter liner extending below a batten seam roof, but only to illustrate the “need” for a hold-down (Figure 7). In its 2005 edition, *Revere* offers that a second method is possible whereby the gutter liner is formed to “extend up on the roof deck to a point that will be at least six inches (6”) under the roofing.”<sup>4</sup> Although mention of this second method is helpful, *Revere* does not indicate when it should be employed. In the end, a picture is worth a thousand words, and what is pictured ends up on architects’ detail sheets as shown in Figure 8.



**Figure 7 – Gutter hold-down shown in *Copper and Common Sense*, 7th ed., p. 64 and 8th ed., p. 4.C.6.**

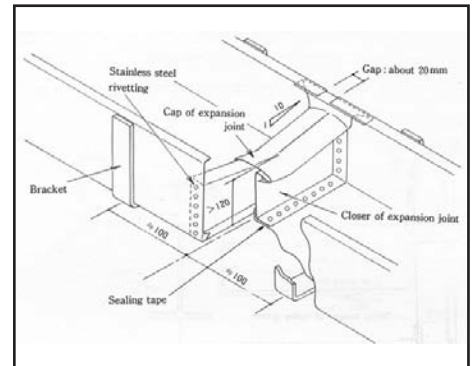
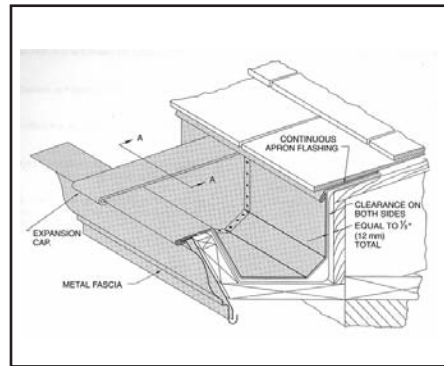
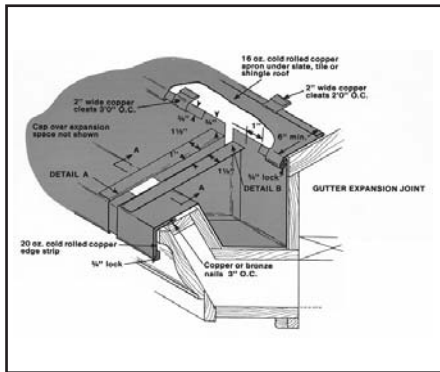


**Figure 8 – Detail for a residence in Maryland showing a loose lock seam between the lead-coated copper roofing and stainless-steel gutter liner within the zone of potential ice damming. Compare this Figure to the standard details shown in Figure 6.**



**Figure 6 – Four of the five design manuals consulted show loose-lock seams in the zone of possible ice damming. From left: *Copper and Common Sense*, 7th ed., p. 63 and 8th ed., p. 4.C.5; *Architectural Sheet Metal Manual*, 6th ed., p. 1.17; and, *Copper in Architecture*, 1992 ed., p. 4.4.5 and 2007 online edition. In the latter detail, the top inside leg of the gutter seems to be below the gutter’s outside edge.**





**Figure 11 – Vertically challenged expansion joints, from left: *Copper & Common Sense, 7th ed., p. 61 and 8th ed., p. 4.C.4*; *Architectural Sheet Metal Manual, 6th ed., p. 1.27*; and *Technical Manual for the Design and Construction of Roofs of Stainless Steel Sheet, p. 75*. Compare these details to Figure 15.**

recommended hold-downs where the sloping portion of gutter liners or other large flat areas are wider than 18 in.<sup>6</sup> Experience has shown that not only are hold-downs rarely, if ever, installed (at least in the Northeastern region of the country), lack of hold-downs has not resulted in widespread failure due to lifting of gutter liners. While there may be instances where hold-downs are beneficial, the temptation to penetrate the gutter trough with screws should be resisted in favor of an alternate design or the use of expansion cleats at transverse seams (*Figure 12*).

### Repair Details

Repair details for built-in gutters are rarely found in design and installation manuals. *Revere* included nine paragraphs of text and a detail drawing showing the “Method of replacing faulty gutter lining” in its 1982 edition of *Copper and Common Sense*. The entire subject seems to have been eliminated from the 2005 edition. *SMACNA* dedicates seven paragraphs in an appendix to repairing and replacing metal roofs. None, however, is directly related to built-in gutters. None of the other publications provides information on gutter repair.

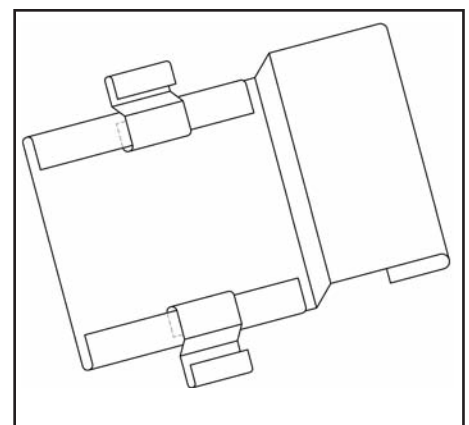
### Transverse Seam Design

Transverse seams occur in almost every built-in gutter. Their design and detailing are critical to the watertightness of the gutter. Of the five publications, *Revere* dedicates the most space to seam design. *Revere* recommends locked and soldered seams for gutter liners fabricated of 16- and 20-ounce copper sheet and lapped, riveted, and soldered seams for those fabricated of 24- and 32-ounce copper. On the subject of rivets, *Revere* has become very precise, but not very practical. In 1982, *Revere* recommended the use of 3/16-in-diameter solid copper rivets, with copper burrs or washers placed below the peened heads to prevent damage to the underlying copper. It allowed, however, that “several other types of rivets are satisfactory in making this type of seam.”<sup>7</sup> In its 2005 edition, *Revere* retracts the statement, saying: “Because of reduced joint strength, *Revere* does not suggest the use of smaller diameter blind rivets [i.e., pop rivets] for structural joints in 24 ounce or heavier copper.” As if to apologize for precluding the use of pop rivets in 24- and 32-ounce gutter liners, *Revere* states that it:

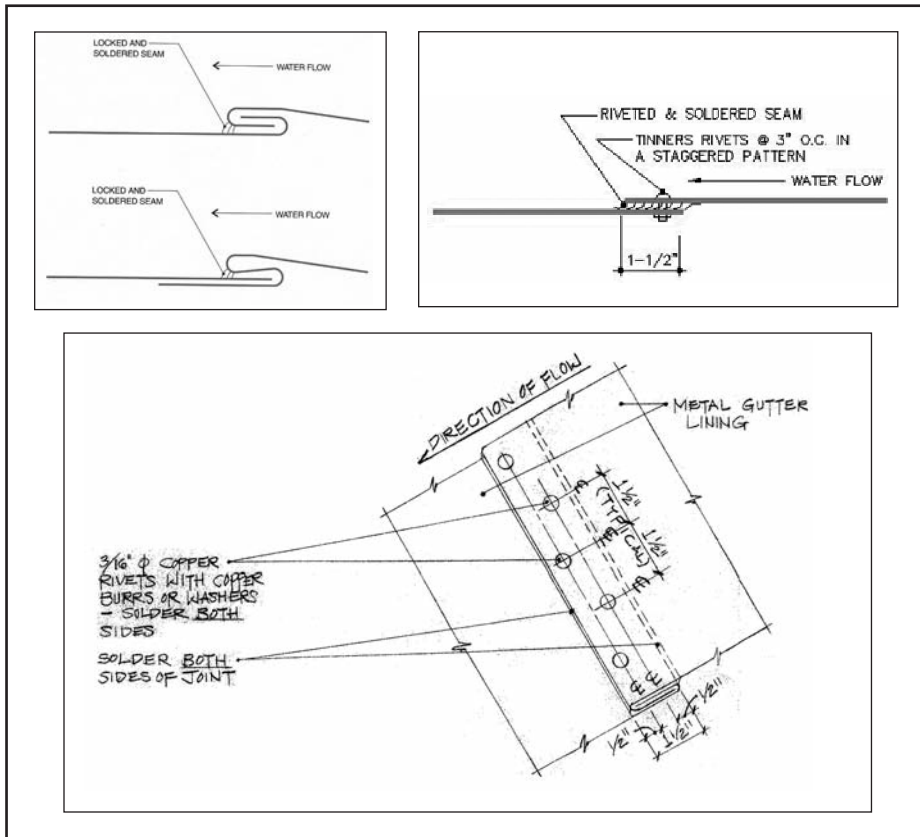
*...recognizes that peening solid rivets can be very difficult and labor-intensive. We also realized that it can be*

*exceedingly difficult to “buck” the concealed side/end of rivets if a gutter lining is installed before the rivets are peened.<sup>9</sup>*

*Revere* goes on to suggest that, to solve the problem, gutter sections be joined in the shop or on the roof and then set in position in the gutter trough. Can you imagine trying to set a 30- to 40-foot length of gutter in position without kinking it! Solid copper rivets may provide the strength *Revere* is looking for to hold transverse seams together, but there must be a better way! In fact, sev-



**Figure 12 – Although this detail can not be found in any design manual, such an expansion cleat may be a viable option for securing transverse seams in gutter liners where wind uplift is a concern.**



**Figure 13 – Two poorly depicted seams in the CDA's *Copper in Architecture*, 1992 ed., p. 4.4.5, top left. By 2007, the detail had changed to that shown at the top right, but the accompanying note left the reader confused as to whether the seam should be locked and soldered or lapped, riveted, and soldered (*Copper in Architecture*, 2007 online edition). One architect's interpretation is shown at bottom: a locked, riveted, and soldered seam.**

eral practical options are given below, in the Design Principles section of this paper.

The other publications are not nearly as detailed as *Revere* in their recommendations for transverse seams. *SMACNA* merely states that “all joints must be lapped, riveted, and soldered.”<sup>10</sup> The *Specialty Steel Industry* also recommends lapped, riveted, and soldered seams. Neither association mentions rivet type. The *Specialty Steel Industry* states that joint sealants may also be used. That is unfortunate, because built-in gutter seams made watertight with sealant have no chance of remaining so. Transverse seams in new gutters fabri-

cated of solderable metals, such as copper and stainless steel, should never be caulked or sealed.

In its 1992 publication, the CDA shows two variations for transverse seams: a locked and soldered seam poorly represented by showing the solder just along the leading edge (i.e., not sweated all the way through the seam), and a soldered slip seam, again with solder just on the leading edge (*Figure 13*). Neither of these seams possesses great strength and would surely crack after a few seasons of thermal movement in the gutter. In the CDA's 2007 edition, the detail has appropriately changed to a lapped, riveted, and

soldered seam (see *Figure 13*). The note that accompanies the new detail is, however, confusing. It reads:

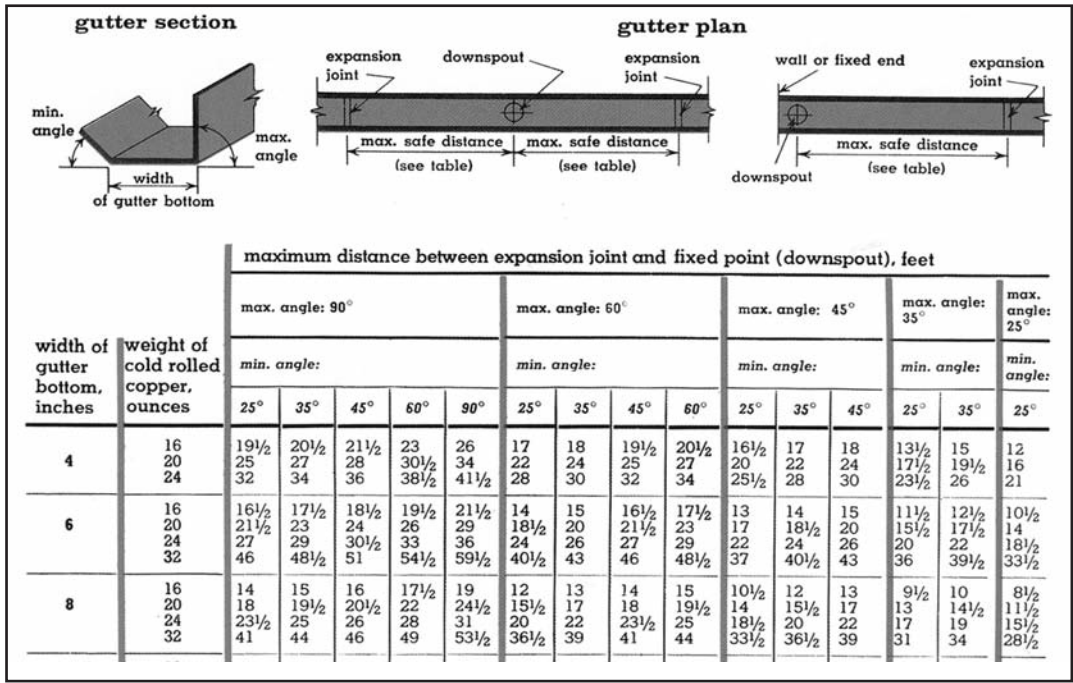
“Where seams occur in the copper gutter lining, a locked and soldered seam is required to maintain a water-tight gutter condition. The seam should be locked and soldered or riveted and soldered so as to allow the water to flow away from the joint.”<sup>11</sup>

It is not entirely clear which seam is recommended. An impractical seam like the one shown in *Figure 13* might result from such a note.

Given all of the above, it is not surprising that some questionable details are being put forth by design professionals. In other cases, the drawings simply sidestep the details. As one contractor recently stated: “We don't usually get detail drawings for our [built-in gutter] work (except from you!), as I think most architects shy away from that kind of stuff.” Anecdotal evidence, as well as direct observation, suggests that many contractors charged with the design of a built-in gutter are not aware of the laws of thermal expansion and contraction and simply use 16-ounce copper no matter the length or geometry of the gutter. Sixteen-ounce copper will certainly be less expensive than heavier weights and easier to fabricate. It also has a good chance of failing prematurely in long, wide gutters due to the stresses associated with thermal movement.

**UNDERSTANDING THERMAL MOVEMENT**

Built-in gutter problems are widespread, due largely to questionable workmanship and some questionable design standards. The primary key to rectifying the situation is understanding the



**Figure 14 – A portion of Revere's table for determining the spacing of expansion joints and weight of copper to be used in built-in gutters (Copper & Common Sense, 8th ed., p. 9.B.9).**

dynamics of thermal expansion and contraction. As Revere states, "When copper gutters are installed without proper consideration of the required columnar strength necessary to transfer movement, failure in the copper sheet occurs."<sup>12</sup>

Revere has been a leader in the scientific study of thermal movement since the late 1930s when it was found that an increasing number of copper gutters were failing. At the same time, the design recommendations of the copper and brass industry were called into question. And rightly so, as 16-ounce soft copper was recommended for virtually all copper flashings and gutters.<sup>13</sup> Revere's research led to a breakthrough in understanding the stresses imposed upon copper gutter liners undergoing changes in temperature.

All metals expand and contract with changes in temperature. The degree to which they move varies and has been quanti-

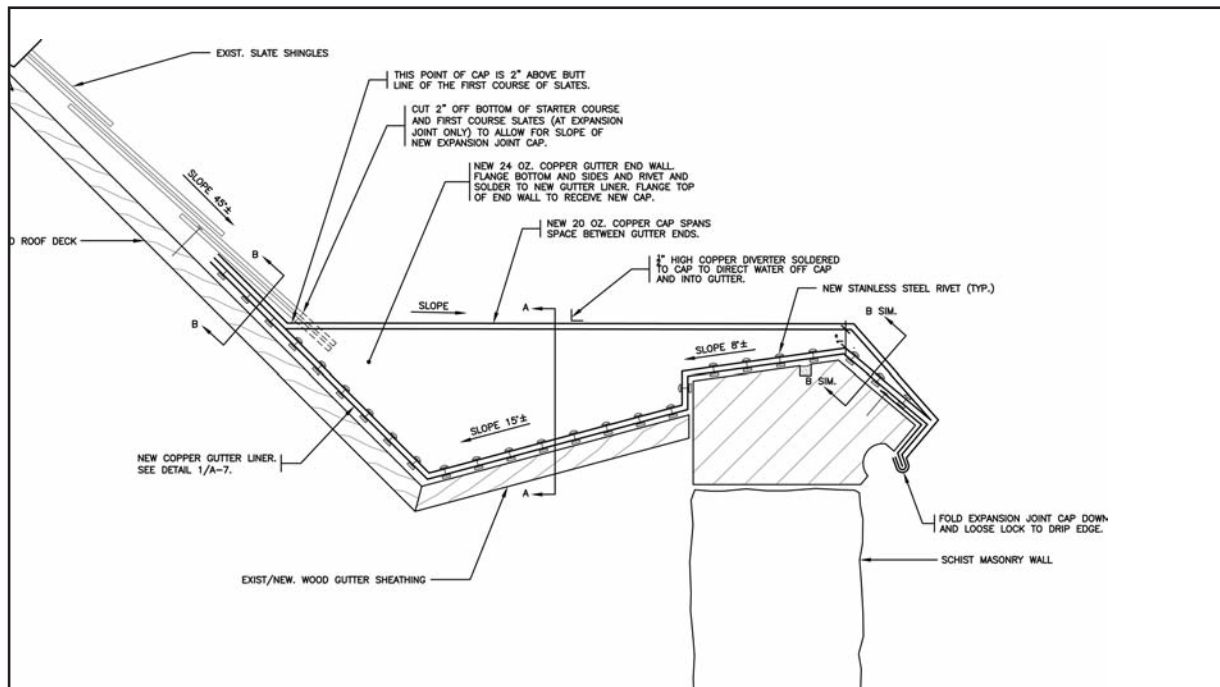
fied in a number called the Coefficient of Thermal Expansion. The Coefficient is expressed in inches per inch per degree Fahrenheit (in./in./F). Cold-rolled copper's Coefficient of Thermal Expansion is 0.0000098, while that of stainless steel (300 series) and aluminum (3003) are 0.0000096 and 0.0000129, respectively. A 10-ft-long piece of copper sheet will thus increase in length approximately 0.2352 in over a 200-degree temperature change.<sup>14</sup> A 30-foot-long piece of copper will increase in length approximately 0.7056 in. This movement cannot be stopped, only accommodated. If the movement is hindered, as by nailing the top edge of the gutter liner to the roof deck, or if too light a gauge is used given the length and shape of the gutter, the copper will flex at some point along its length. Repeated flexing will result in a fatigue or stress crack. Imagine taking a wire hanger and bending it back and forth repeatedly at its mid-point. After a rela-

tively short while, the hanger will snap in half due to metal fatigue.

Since the thermal movement cannot be prevented, it must be accommodated in the gutter design. Three primary factors come into play in accommodating thermal expansion and contraction: the weight or gauge of the copper; the geometry or shape of the gutter trough; and the distance between fixed points in the gutter (usually considered to be downspout locations and corners) or changes in direction. The three factors are interrelated. Change one, and the others must change as well in order to effectively accommodate

thermal movement. Stand a flat sheet of copper on end, and it will crumple and fall over. Bend that same piece of copper into a U shape, and it will stand upright and might even take some additional load pushing down on it. Spread the sides of the U out too far (i.e., increase the angle between the sides and the bottom of the U), and it will topple. Lengthen the U-shaped piece of copper several folds, and it might crumple and fall over. Increase the gauge of the copper sufficiently, however, and now it will stand upright. These same concepts apply to a gutter liner laying horizontally in a gutter trough and are why the ability of a gutter liner to accommodate thermal movement is sometimes referred to as its "columnar strength."

One of the results of Revere's pioneering research is a concise table that quantifies the above concepts, allowing one to determine the appropriate copper gauge for a gutter liner given its



**Figure 15 – Built-in gutter expansion joint with its outside edge raised 1 inch above the gutter's high water line. Detail by the author.**

shape and the distance between fixed points. A portion of *Revere's* table is reproduced in *Figure 14*. Using the built-in gutter shown in *Figure 8* as an example, if the distance between two downspouts is 60 ft, an expansion joint is to be placed at the mid-point between the two downspouts, the maximum angle is 90°, the minimum angle is 70° (not 110°), and the trough width is 5-1/2 in, then 24-ounce copper is required for the gutter liner. Note that the gutter width was rounded up to the nearest width given in the table (6 in) and that the minimum angle was rounded down to the nearest angle given (60°). These roundings are conservative in nature; in both cases, essentially supposing the gutter geometry to be “weaker” or less able to transfer thermal movement in the gutter liner to the expansion joint. That is, the actual gutter liner with a trough width of 5-1/2 in and minimum angle of 70° will possess greater columnar strength than calculated and should be able to transfer movement over even a greater distance than the 33 ft derived from

the table. Usually, the longest distance between an expansion joint and fixed point in a gutter system is selected as the “worst-case” scenario and the copper gauge thus calculated is used for all of a building's gutters. If one gutter section especially long, however, it is perfectly acceptable to calculate one copper gauge for it and another for the shorter gutters. In the example above, if the distance between the expansion joint and downspout in all of the building's other gutters is only 20 ft, 16-ounce copper could be employed in these gutters, thereby reducing the cost of material significantly.

Problems frequently arise right off the bat in gutter replacement projects when the calculations for determining the copper weight required reveal that the thermal loads will not be carried to the expansion joints. That is, the gutter geometry and distance between expansion joints and fixed points is such that even 32-ounce copper will not possess the columnar strength required to “make it” to the expansion joints.

In these situations, it is often necessary to alter the gutter layout, adding downspouts (fixed points) and expansion joints.<sup>15</sup> Some resloping of the gutter trough will also be required in order for rainwater to slope to the new downspout locations. When determining the new gutter layout, care must be taken to avoid placing new downspouts in line with existing window and door openings. The moral is: do not assume that the designer or contractor before you got it right. It is important to run through the steps necessary to determine gutter gauge and maximum safe distance between expansion joint and fixed point for each building and, sometimes, for each gutter in a given building.

Two common misconceptions related to thermal movement in gutters prevail among design professionals and contractors. The first surely dates back to the early 20th century. It posits that soft copper is best for use in built-in gutters because it can better flex to accommodate the inevitable

expansion and contraction of the copper that occurs with changes in temperature. While this is true, as explained earlier, all that flexing will eventually lead to metal fatigue and a gutter leak.<sup>16</sup> The second posits that the thicker the copper sheet used to fabricate a gutter liner, the more the gutter will expand and contract along its length. This is incorrect, as the coefficient of thermal expansion is a constant. It does not vary with a material's thickness.<sup>17</sup>

## BASIC PRINCIPLES OF BUILT-IN GUTTER DESIGN

Now that the weight of the copper sheet required has been determined based on the geometry of the gutter and distance between expansion joints and fixed points, the real detailing can begin. Guidelines are given below for the detailing of expansion joints, transverse seams, and a host of other important features critical to the long-term functioning of built-in gutters. Soldering is, perhaps, the most critical workmanship issue in the installation of built-in gutters. And while one cannot design good workmanship, several specification requirements can help to ensure high-quality soldering in the field.

### Expansion Joint Design

Expansion joints should be of raised design, formed by riveting and soldering end walls to the adjacent ends of gutter length and then loose-locking a copper cap over the space left between the two end walls. This is all fairly straightforward and as shown in most of the design manuals previously surveyed. The real key to a leak-free expansion joint is three-fold: 1) raise the outside end of the expansion joint above the outside edge of the gutter (i.e., get it above the gutter's high-water line); 2) run the expansion joint up under the roofing material as far as the gutter apron, again tak-

ing the top inside edge of the expansion joint well above the gutter's high-water line; and, 3) solder a small diverter on the expansion joint's cap to direct rainwater into the gutter trough rather than over the edge of the gutter (*Figure 15*).

### Seam Selection and Detailing

Locked and soldered transverse seams or lapped, riveted, and soldered transverse seams? That is the question. Lapped, riveted, and soldered seams are preferred. They are strong, watertight, and easier to install than locked and soldered seams. Rivets provide the strength. Solder provides the waterproofing. Forming is as easy as lapping one pan atop the other in the direction of water flow. Locked and soldered seams fall short in terms of ease of installation, which can result in a weaker and, sometimes, leaky seam. The problem arises at the inside corners formed by the intersection of the gutter trough and inside and outside legs of the gutter. In order to get two adjacent gutter pans to lock, some mechanics will snip a small "V" out of the under-folds and over-folds. This creates small points of weakness in the finished seam that can crack under thermal loads, snow loads, and the stresses associated with foot traffic.

When designing a lapped, riveted, and soldered seam, the following details should be considered: 1) Adjacent lengths of gutter should be lapped 1-1/2 inches. 2) Rivet pattern and spacing is critical. Generally, rivets are placed 1/2 inch in from each edge of the seam and laid out in two rows in a staggered pattern. The spacing between rivets within each row and the type of rivet employed depend largely on the weight of the copper being joined and the anticipated stress on the seams. So, for instance, copper pop rivets spaced at 2-1/2 inches to 3 inches on center are usually adequate

for 16- and 20-ounce copper gutter liners. Stainless steel pop rivets spaced closer together will provide added strength and should be considered for 24-ounce copper. Stainless steel pop rivets spaced closely together may also be adequate for small gutters constructed of 32-ounce copper. Solid copper rivets should be considered for large, 32-ounce copper gutter liners. 3) Stainless steel rivets tend to be a little more difficult to solder than copper rivets. Thorough fluxing of the rivet heads is critical. 4) The mandrel portion of pop rivets should be constructed of the same material as the rivet head, or one that is galvanically compatible with the head. Avoid the use of steel and copper-plated steel mandrels when using copper rivets, as these will leave unsightly rust stains at the seams. A magnet is a handy way to tell a copper-plated mandrel apart from a solid copper or brass mandrel.

### Soldering

No procedure in the fabrication and installation of built-in gutters is more critical to the gutter's watertightness than soldering. The topic of soldering demands an entire article in itself. In addition to selecting the correct flux and solder, removing any residues left over from the manufacturing process, cleaning the edges to be joined to bright metal, pre-tinning copper, and cleaning residual flux after soldering is complete, there are at least three additional critical steps that should be specified and followed.

First, the seam should be soldered the same day it is formed on the roof. This will help keep dust, dirt, rainwater, dew, and condensation out of the joint and make the task of soldering easier and more effective. If the seams cannot be soldered the same day, they should be protected until soldering can be take place. Similarly, if there are other construc-

tion activities generating a lot of dust in the vicinity of where seams are being formed, such as raking out of mortar joints or reglets, installation of the seams should be postponed until the other activity has ceased.

Second, the correct iron must be used. Gone are the days when the sheet metal mechanic used a fire pot and a pair of coppers (soldering irons) weighing 6 to 10 pounds per pair. Continuously heated irons are very common today, on account of the increased productivity they offer. That is okay, but the soldering tip on the continuously heated iron must still be in the 1- to 2-pound range in order to sufficiently heat all layers of metal within the seam and get the solder to flow or sweat through the entire seam. Smaller irons cannot do this, even if they are held in one place for a longer period of time. Seams soldered with irons that are too small have solder primarily along their leading edge and tend to crack and fail prematurely.

Third, mechanics should be tested and pre-qualified to perform soldering prior to the start of construction on site. Once in place in a gutter, it can be difficult to verify whether a seam is soldered well without destructive testing. Full-time field observation of soldering operations would be ideal, but too expensive for most projects to bear. The next best thing is to require each roofing mechanic anticipated to be involved in soldering to submit 12-in long samples of locked and soldered, and lapped, riveted, and soldered seams for approval. The back side of the sample seams can be easily observed and the samples can be cut in half across the seam to further verify that the solder has been sweated through all layers of metal the full width of the seam. Mechanics whose seams are rejected should not be permitted to undertake soldering

work on the project. Periodic, unannounced testing of pre-qualified mechanics throughout the course of the project may also be appropriate in some situations.

### **Gutter Pan Orientation and Cleat Location**

In most built-in gutters, gutter pans should be formed in 8- to 10-ft lengths and laid longitudinally. This will eliminate from 55% to 63% of the seams, the weakest points in the gutter. If the total girth of a gutter is much larger than 3 ft (the width of a typical copper sheet), then it may be necessary to consider other options. These include laying the pans transversely, using flat-seam copper pans (18 in x 24 in maximum size), and switching to another material, such as a fluid-applied membrane waterproofing system (which has no seams).

Regardless of whether the gutter pans are laid longitudinally or transversely, standard-type cleats should not be installed at the transverse seams, as they would inhibit thermal movement of the gutter liner. If wind uplift is a concern or if cleats are necessary to help the new gutter liner to lay flat, expansion cleats may be used (*Figure 12*).

Cleats should be installed along the top (inside) and bottom (outside) edges of the gutter liner to allow the gutter to expand and contract longitudinally. The cleats should be spaced at about 12 inches on center and secured with two nails each to prevent the cleats from rotating and pinching the gutter liner. Laid out in this way, the cleats not only help to hold the gutter liner in place, but also act as guides as the copper liner moves under thermal load.

In most U.S. climates (except, perhaps, the desert southwest), the temptation to loose-lock a separate gutter apron to the gutter trough (at the top of the gutter

liner's inside vertical leg) should be avoided. To take it a step further, not only should the gutter apron be continuous with the gutter trough, it should also extend up the roof slope to a point at least 1 to 3 inches above the outside edge of the gutter. Where the build-up of snow and ice in the gutter can be expected and where ice damming might be anticipated, it is sometimes prudent to construct a continuous watertight system between the gutter apron and roof system above. One way to achieve this is to strip-in the top edge of the gutter apron with a self-adhering ice dam protection membrane. In order to be effective, the top edge of the stripping must be adhered directly to the roof deck, with the roofing material's underlayment lapped atop it.

Tight tolerances can be tough to achieve in building construction. One that should be observed pertains to the gutter trough. The bottom of the gutter trough must be kept in direct contact with the substrate material, (usually wood sheathing, felt, and rosin paper). If the substrate is not a perfect plane, the gutter liner will span between the high and low points in the substrate and be subject to kinking under load, whether that load stems from foot traffic, water-soaked leaves and debris, ponded water, or snow and ice. Minor unevenness in the substrate usually can be leveled by installing additional layers of roofing felt and/or resin paper in the low areas of the substrate. If major troughs and crests are present in the substrate, strong consideration should be given to repairing or replacing the trough to achieve a planar surface.

### **Outlet Tubes and Overflow Scuppers**

Outlet tubes suffer from more wear than any other portion of the gutter liner, due to the greater quantity of water flowing through

the outlet. Knowing this, it is prudent to use a heavier gauge metal for the outlet tube than the gutter liner itself. For example, if the gutter liner is fabricated of 20-ounce copper, 24-ounce copper might be used for the outlet tube. In all cases, the longitudinal seam in the outlet tube must be well soldered along its entire length. Alternatively, outlet tubes can be fabricated of Drain Waste and Vent (DWV) solid copper drainage tube for even greater wear resistance. Four-inch-diameter DWV tubing has a wall thickness of approximately 0.058 inches, nearly 80% thicker than 24-ounce copper sheet. Another advantage of DWV copper tubing is that it has no longitudinal seams to leak or burst apart. Joints between adjacent lengths of DWV copper tubing should be sweated with solder like copper plumbing. Use emery cloth to clean the joint area, flux-core solder, and a torch to sufficiently heat the copper.<sup>19</sup> Whether sheet copper or DWV copper tubing is used, the 1/2-in flange at the top end of the outlet tube must be continuous and free of splits and snips which create points of weakness in the riveted and soldered seam between the outlet tube and gutter liner.<sup>20</sup> Lastly, the outlet tube and downspout should have approximately the same cross-sectional area.

If the gutter trough is very deep, allowing large pools of rainwater to collect should the outlet tube(s) become clogged, overflow scuppers should be installed. Overflow scuppers should be placed several inches above the outlet tube (in a parapet wall, for example), be the same size as the outlet tube, and sloped at a downward angle to the outside. Since they hopefully will be put to use with much less frequency than the outlet tube itself, overflow scupper tubes can be fabricated of the same weight metal as the gutter liner.

## Gutter Replacement

When a relatively new gutter is in such poor condition that it must be replaced, the design principles outlined above all apply. The tricky part, however, can be in integrating the new built-in gutter with the existing roof system. If the existing roof system consists of individual units such as slate or tile, it is relatively easy to remove, salvage, and reinstall the shingles to permit gutter replacement. Similarly, asphalt shingles can be removed and simply replaced to allow the new gutter to be set in place first, followed by the overlying roofing. If the existing roof system consists of standing or batten-seam copper roofing, the task becomes more difficult. The question becomes, how does one get the new gutter up, underneath the existing roofing, without having to remove the entire roof?

With a batten seam roof, it is often possible to cut the nails securing the wood batten to the roof deck using a reciprocating saw or slate ripper, and then slide the new gutter apron up, below the batten seam roof pans. Since the upper portion of the transverse seams in the gutter apron cannot be soldered once installed (they are now below the roof pans), they must be soldered beforehand. This, in turn, requires that the apron be slid into place in long lengths equal to the distance between expansion joints. Once in place, the apron can be locked and soldered, or lapped, riveted, and soldered to the gutter liner and the battens re-secured to the roof deck using screws set through the top of the battens (i.e., out of the major flow areas), an inch or two above the top edge of the gutter apron. The screws must be covered with copper caps soldered to the battens to make them watertight.

With a standing seam copper roof, there is no good place to

locate screws for re-securing the pans to the roof deck. And since the top edge of the new gutter apron cannot be cleated to the deck (it is below the roof pans), securing the bottom edge of the roof pans with clips soldered to the gutter apron will not work - one unsecured element is being fastened to another. One solution is to cut the existing gutter liner, removing that portion which is in the trough and leaving the gutter apron in place. The new gutter liner can then be locked and soldered, or lapped, riveted, and soldered to the gutter apron. Of course, this solution will not work in all circumstances. For example, the existing gutter apron may not extend far enough up below the standing seam pans, may be nailed rather than cleated to the roof deck, or be in poor condition itself. In such cases, the unique aspects of the particular project, such as the overall condition of the roof, gutter configuration, budget, climate, etc., will play a large part in determining an appropriate course of action.

## Other Design Considerations

Other important considerations in the design and installation of built-in gutters include their size in relation to the roof area they will serve and rainfall intensity for the region, their depth-to-width ratio, sacrificial flashings, redundant waterproofing systems, heat-trace systems, and the number, location, and capacity of the downspouts serving the gutters. Some of these topics are well covered in other publications.<sup>21</sup>

When detailing a gutter, it is best to think about it under the worst of conditions - not under the sporadic, gentle rain, but rather in the middle of a drenching downpour, with the outlet tubes completely clogged, or in the days after a major blizzard, with the trough packed full of snow and ice. Try to imagine how

the gutter will drain, where the water will travel to, and, if there is ice damming, where might that alternating layer of water and ice penetrate? If the gutter liner is designed and installed with the worst of possible conditions in mind, it should be able to handle these situations, and anything else Mother Nature throws at it.

#### FOOTNOTES

1. Although it is possible to set the outside edge of the gutter too high, resulting in an inefficient depth-to-width ratio, or inadequate strength to resist snow and ice loads, the condition does not appear to be a common one.
2. Fluid-applied membrane waterproofing systems with conformable reinforcing mats might be a more lasting re-lining option, but seem to be infrequently employed, perhaps due to cost or unfamiliarity with the systems available.
3. *Architectural Sheet Metal Manual*, 6th ed., (Chantilly, VA: Sheet Metal and Air Conditioning Contractors' National Association, 2003), p. 1.16. The text goes on to reference Figure 6-16, but the figure is of little help.
4. *Copper and Common Sense*, 8th ed., (Rome, NY: Revere Copper Products, Inc., 2005), p. 4.C.6.
5. *Copper and Common Sense*, 7th ed., (Rome, NY: Revere Copper Products, Inc., 1982), p. 62.
6. *Copper and Common Sense*, 8th ed., p. 4.C.3.
7. *Copper and Common Sense*, 7th ed., p. 14.
8. *Copper and Common Sense*, 8th ed., p. 2.7

9. *Ibid.*, p. 5.B.7.
10. *Architectural Sheet Metal Manual*, p. 1.16.
11. "Copper In Architecture," online ed., (New York, NY: Copper Development Association, Inc., 2007).
12. *Copper and Common Sense*, 7th ed., p. 62.
13. Dave Hunt, "Using Common Sense," *Metalmag*, Vol. 8, No. 3 (March/April 2007): p. 96. As late as 1942, one popular publication stated "It is the consensus opinion that the best material for gutter lining is in the order named: soft copper, lead, tin and galvani ed iron," (Anderson, Edwin P., *Sheet Metal Pattern Layouts*, (New York, NY: Theo. Audel & Co., Publishers, 1942), p. 620).
14.  $\Delta L = L_o \times C \times \Delta T$ , where  $\Delta L$  is the change in length,  $L_o$  is the initial length of the gutter,  $C$  is the coefficient of thermal expansion (a constant), and  $\Delta T$  is the change in temperature. Thus,  $120 \text{ in} \times 0.0000098 \times 200 \text{ degrees} = 0.2352 \text{ in}$ , or approximately  $15/64 \text{ in}$ . It should be noted that many design manuals assume a 100-degree change in temperature. In the northeastern United States, a 200-degree seasonal temperature change is a more prudent assumption, given nighttime winter lows at or below zero and summertime highs at around 100 degrees F. It is important to keep in mind that the temperature of copper in direct sunlight in the summertime will be much greater than the ambient air temperature. Note, as well, that expansion

across a gutter's width is usually ignored, except for very wide gutters. A 16-in-wide gutter trough, for example, will increase in width approximately  $1/32$  inch over a 200-degree temperature change, well below the tolerance possible in the fabrication of a built-in gutter liner.

15. Changing the gutter geometry is another option, but either not possible or not alterable enough to make much of a difference. For example, changing the minimum angle of the gutter in Figure 8 from  $70^\circ$  to  $90^\circ$  by adding blocking will result in an increase of just 3 ft in the maximum safe distance between expansion joint and fixed point (see *Figure 14*).
16. It is important to recognize that built-in gutter liners do not behave like flat-seam copper roofing pans. The latter are essentially flat sheets, able to billow or "oil-can" as they heat up and expand. Built-in gutter liners, for all practical purposes, cannot oil can longitudinally due to their brake-formed shape. Try it with a piece of  $8\text{-}1/2 \times 11$  paper: Lay it flat on a flat surface and push the two ends together – it will billow in the center. Fold 90-degree bends along opposite sides and try to push the two ends together (using all of your fingers in the "trough" of the paper gutter) – the paper will kink, not billow.
17. The thicker copper will undergo a proportionally greater increase in thickness over a given temperature change. Thus, 32-

ounce copper will increase in thickness approximately 4/10,000 in more than 16-ounce copper over a 200-degree temperature change.

18. See *Copper and Common Sense*, 8th ed., p. 5.B.2, for a good introduction to soldering.
19. Other methods of joining copper tubing may be possible, such as using patented couplers under compression.

20. Various methods of forming the 1/2-in flange are possible. One method is to heat the copper and slowly draw the flange out with a ball-peen hammer and anvil. Another is to run the tube through a turning machine and then stretch and draw out the flange with stretching hammers and square stakes.

21. One such publication is: Stephen Patterson, Madan Mehta, and Richard J. Wagner, "Roof Drainage," *RCIF Publication No. 02.03*, (Raleigh, N.C.: RCI, Inc., 2003).

