CASE STUDY

Good Architecture, Poor Roof

By Thomas L. Smith, AIA, RRC

ABSTRACT

A terne metal roof was specified and installed on a new church during the winter of 1996-1997. The building is located in the eastern part of the U.S., in an area subject to snowfall. Shortly after construction, leakage periodically occurred at clerestory windows and some roof areas. The architect, general contractor (GC), and roofing contractor attempted to address the problems, but their attempts were unsuccessful. In 2001, the author was retained by the building owner to investigate the leakage problems. Because they could not be effectively repaired, in the latter part of 2001 and early 2002, all of the roof coverings were removed and replaced. The clerestory windows were also removed, new sill flashings installed, and the windows reinstalled.

As part of the investigation, the National Research Council of Canada performed extensive analysis pertaining to corrosion of the metal panels.

Figure 1: General view of the roof.

INTRODUCTION

The church is a very unique and aesthetically pleasing building *(Figure 1)*. Five shed roofs cover the sanctuary (roof areas 1-5 on *Figure 2*). These roofs have different slopes, from 2-3/4:12 to 5:12. The eave-to-ridge distance also varies, with the greatest distance being 112'. These roofs drained into a stainless steel, built-in gutter. Clerestory windows occur at the walls between the different roof areas *(Figure 3)*.

Five shed roofs cover other areas of the church (roof areas 6-10). These roofs also have different slopes, from 1:12 to 3-3/4:12. The entry canopy is also a shed roof that slopes toward the build-

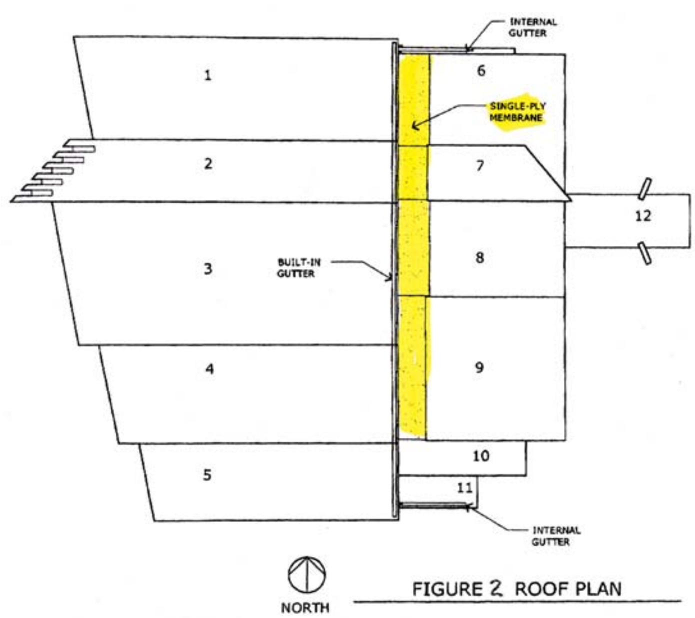


Figure 2: Roof plan.

Figure 3: View of some of the clerestory windows. Although the roof overhangs provide some protection from rainfall, they do not protect the windows from wind-driven rain.

ing at a 3/4:12 slope (roof area 12). Roof areas 1-10 and 12 had standing seam terne panels with 1"-high ribs. Roof 11 has a slope of 1/2:12; it had a soldered, flat-locked, terne roof. A TPO membrane occurred at the valley between the toe of roof areas 6-10 and the wall below the eave of the sanctuary sheds *(Figure 4)*. The water from roof areas 6-11 drained to two stainless steel internal gutters. The water from roof area 12 drained into a stainless steel internal gutter at the wall juncture.

The roof assembly over the sanctuary (1-5) consisted of the following components:

Figure 4: View of the TPO membrane in the valley area. Water falling from the TPO membrane eroded the paint on the terne below.

- Terne metal panel, field painted on the topside with a mill-applied shop coat on the underside. (Terne is a sheet steel that is factory-coated on each side with an alloy of 80% lead and 20% tin.)[1]
- Rosin paper.
- #30 asphalt-saturated felt.
- OSB.
- Rigid insulation.
- Tongue-and-groove wood decking.

The roof assembly over areas 6-12 was similar to the above, except for the deck, which was metal. The TPO was fully adhered to OSB.

INITIAL LEAKAGE AND RESPONSE

Initial leakage occurred in the sanctuary. Water dripped from the vicinity of several clerestory windows. The architect made a site visit, but did not perform any destructive observations. His report incorrectly attributed the leakage to the soffit installation. However, no corrective action related to the soffit was taken.

The clerestory windows contained a high-quality, commercial-grade storefront glazing. The system was designed with an internal gutter to intercept water that penetrated the glazing gasket. The intercepted water would drain from an opening between the sill flashing and the sill face cap. Sealant had been applied between the sill flashing and the sill face cap, thereby blocking drainage of water that penetrated the gaskets *(Figure 5)*. Application of the sealant exacerbated the window leakage problem. The window leakage was due to lack of upturned ends on the sill flashing, as will be discussed later.

As the window leakage continued, leaks began to develop in other areas of the building. At the time of the author's investigation

Figure 5: In a misguided attempt to solve the window leakage problem, the general contractor applied sealant (noted by arrow) at the drainage slot between the sill flashing and sill face cap.

Figure 6: View of the down-slope end of the sill flashing after removal of the face caps and glazing. The only provision preventing water running down the sill from entering the building was a fillet-profile sealant joint between the sill flashing and EIFS. The double arrows show a piece of the sealant joint. The sealant was not well adhered to the EIFS or sill flashing. Water was able to flow past the sealant, where it had an unobstructed path into the building.

in February 2001, in addition to the clerestory leakage in the sanctuary, leakage had occurred at the north end of the TPO roof, the southwest portion of roof 6, roof 11, and roof 12 (at the wall juncture).

The author was retained by the building owner to investigate the leakage, determine the causes, and recommend corrective action.

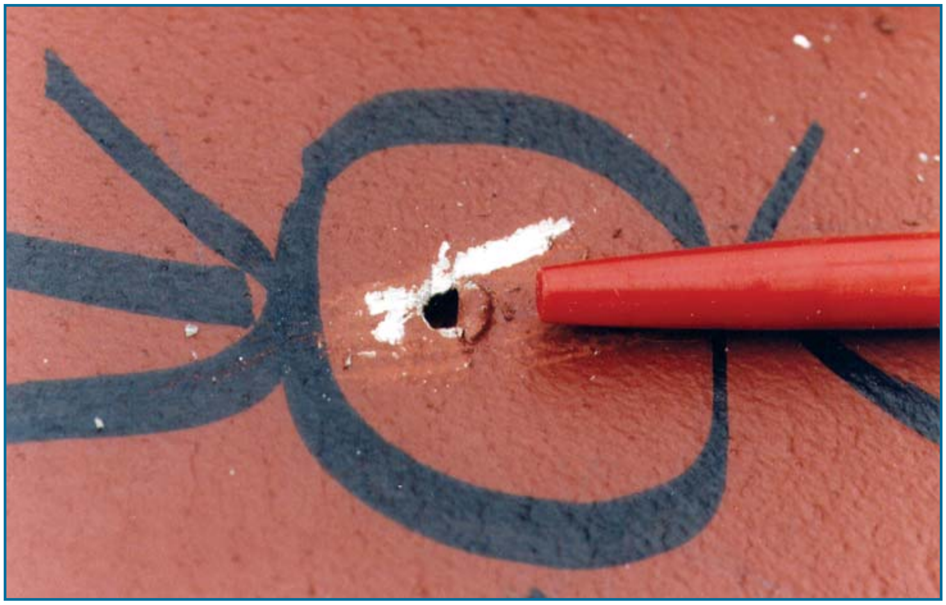
PAINT PROBLEMS

The terne manufacturer's specifications require the panels to be field painted "immediately after application or as soon as proper painting conditions prevail." Painting soon after application is important to avoid corrosion, for the thin lead/tin coating offers very limited corrosion resistance. The panels were installed during the winter and temperature conditions were much too cold for painting. Rather than tent over the building, painting was delayed until May, at which time widespread peeling failure was experienced. The author was not involved in that problem, but was advised that after arbitrating the dispute, the roof was repainted in the fall of 2000. During the author's leakage investigation in February 2001, the new paint had also peeled in several areas.

AUTHOR INVESTIGATIONS

During the author's initial investigation, a technical representative of the window manufacturer was on-site, as well as representatives of the general contractor, roofing contractor, and glazing contractor. The author directed the glazing contractor to remove some of the glazing caps. After removing the caps, it was apparent that due to lack of upturned ends on the sill flashing, water was

Figure 7: A hole through the terne at roof 6. This hole was caused by mechanical damage.



able to flow past the window frame *(Figure 6)*.

At two locations over the sanctuary, very small corrosion-induced holes through the metal panels were found. The author initially attributed these holes to lack of paint, but as discussed below, they developed from underneath the panels. The holes were temporarily patched.

At the north end of the TPO roof and roof 11, the author believed the leakage problems were related to the built-in gutters or the drain lines. Instructions were prepared for the owner to plug the outlet tubes and fill the gutter with water. When both gutters were water tested, it was discovered that when the plugs were removed, leakage occurred due to a piping error. The drain line from the gutter emptied into an open funnel at the end of a major drain line. Other drain lines from the sanctuary roofs also emptied into the funnel. Thus, during a deluge of water, water overflowed the top of the funnel.

At the leakage area at roof 6, two small holes through the metal panels were found *(Figure 7)*. These were caused by mechanical damage. A tear was found through the nearby TPO. At another TPO area, the membrane was torn by a nail head emerging from the OSB. The leakage at the canopy

Above: Figure 8: View of corrosion-induced holes through the terne on roof 3. Holes occurred on both sides of the rib. These holes occurred a few inches upslope of an endlap. Note the buckled rib. See Figure 9.

Right: Figure 9: View of the underside of the panel shown in Figure 8. The circle indicates the upper end of the down-slope panel. A panel clip with two nails occurs in the lower right portion of the photo.

roof was due to inadequate flashing between the roof and wall.

During the summer of 2001, additional holes were discovered through the metal panels. The author performed a follow-up investigation in August 2001. During this investigation, several metal panels and ridge cap flashings were removed. Severe corrosion was observed on the underside of the panels *(Figures 8 and 9)*. Wind-driven water and water from power washing prior to painting had driven past the ridge cap flashing and flowed underneath the panels. Water was also driven underneath the endlaps *(Figure 10)*. Water had also leaked through some of the ribs on the low-sloped roofs. Enough water had reached the underside of the panels and enough time had elapsed by August 2001 that the corrosion was penetrating the panels in numerous areas. In addition to panel penetration, the corrosion had significantly impaired several of the concealed clips, hence the roof was vulnerable to wind blow-off.

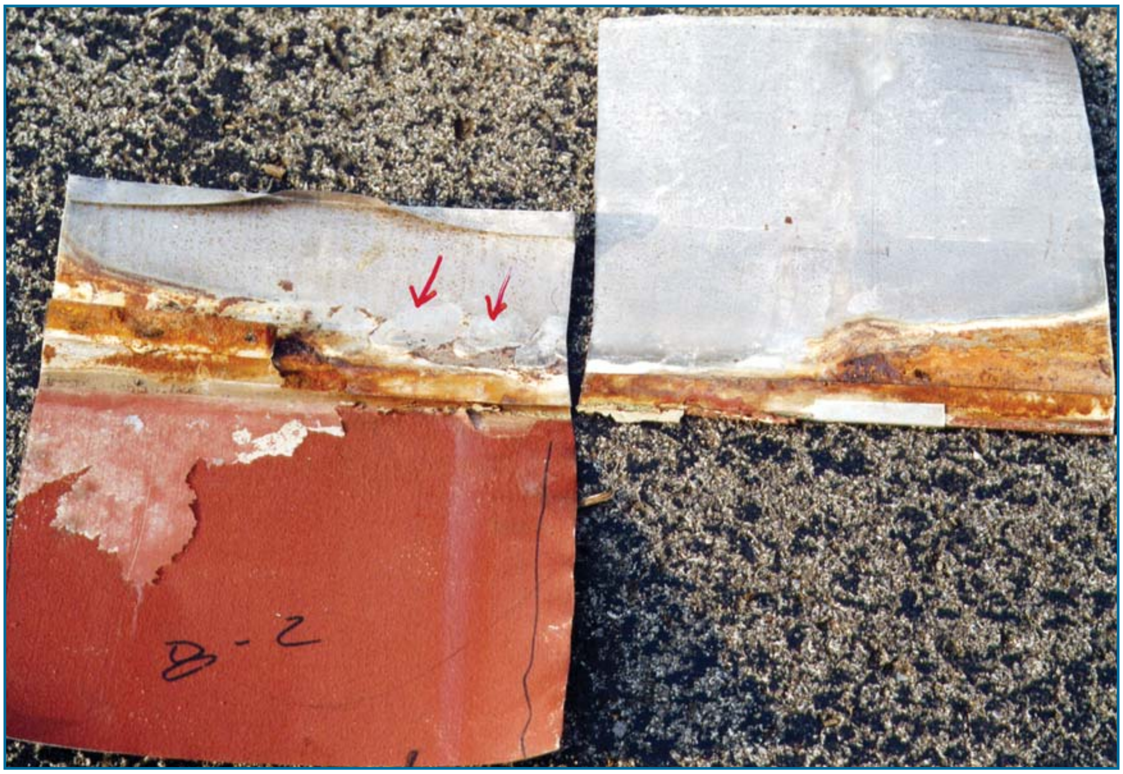


Figure 10: The left panel is the down-slope panel. The arrows indicate solder that was used to attach the lock-strip. Both sides of the lock-strip were very corroded. The right panel is the underside of the up-slope panel.

Because the corrosion attack was coming from the underside of the panels and it was in an advanced state, the panels could not be effectively repaired. To avoid damage to the OSB and wood decking, the author recommended that the entire roof covering be removed and replaced. Reroofing work commenced that fall.

LABORATORY INVESTIGATIONS

Several samples taken by the author were sent to the National Research Council of Canada for various evaluations to further understand the corrosion problem. The thickness of the steel substrate and metallic top and bottom coatings was relatively uniform and without pinholes. The tested specimens complied or substantially complied with the manufacturer's specification. No significant manufacturing deficiencies were found with the terne.

The lab determined that the corrosion was caused by the presence of water and oxygen on the underside of the panels. Analysis of the corrosion products did not indicate the presence of common atmospheric pollutants such as chloride or sulfur. The solder that was used was the correct type. It did not contribute to the corrosion. There was no indication that the flux that was used in the soldering process contributed to the corrosion.

Rosin paper

Leachate from wet rosin paper had a pH between 6 and 7, which is similar to water in the natural environment. The leachate also increased the conductivity of the water, thereby releasing electrolytes. This increased conductivity helps to facilitate electron transfer and accelerate corrosion. When submersed in water, the rosin paper absorbed a substantial amount of water.

Although it did not leach highly corrosive chemicals, the paper had the ability to hold a substantial amount of water, which if present, would increase the relative humidity in the enclosed space between the paper and metal panels. High humidity on the underside of the panel and the presence of electrolytes from the rosin paper create good conditions for corrosion to occur. In addition, when wet rosin paper is in contact with the metal, it provides a moderately corrosive water film (with a potential pH of 4 to 5) next to the panel. A water film generally contains a high concentration of dissolved oxygen, which also increases the corrosion rate. Therefore, when wet, the presence of the rosin paper could accelerate the corrosion process.

Felt

The panel manufacturer's recommendations adamantly and repeatedly recommend against the use of asphalt-saturated felt below terne (only rosin paper is recommended between the metal and the wood substrate). However, felt was installed below the rosin. In a few small areas, the felt was in direct contact with the terne, but in those areas, only minor, superficial "white rust" was found. (White rust was caused by corrosion of the metallic coating. Red rust was caused by corrosion of the steel substrate.)

Leachate from the felt had nearly the same pH as the wet leachate from the rosin paper. However, the felt leachate did not increase the conductivity nearly as much as the rosin paper leachate. The felt also absorbed less water when submerged. The felt unlikely promoted corrosion.

ISSUES

This was a complicated building. To avoid leakage problems, it was necessary to give special attention to: 1) selection of building envelope systems, 2) the design of the details, 3) submittal review, and 4) field observation. The architect failed in all four areas.

Roof system selection

Selection of metal panels for roofs 1-5 was appropriate. However, a copper or PVDF painted aluminum-zinc alloy ("Galvalume") standing seam system would have been a better choice. These alternative systems would have been more resistant to underside corrosion, and they would have been less maintenance intensive than terne. According to the manufacturer, terne requires repainting "at least once every eight years." The cost of repainting this roof was considerable.

In the writer's opinion, selection of metal panels for roofs 6-12 was inappropriate. Most of these roofs are low-slope, which present design and installation challenges. These roofs are essentially not visible from the ground; hence, there was no aesthetic justification for selecting metal. A membrane roof would have been more reliable and economical.

The writer also believes that selection of a single-ply membrane was inappropriate because of susceptibility to puncture and tearing. Metal panels were installed after installation of the TPO; hence, during that time, the risk of damage was great. Also, during painting operations, substantial foot traffic presented damage opportunity.

Metal panel specification

This section was very deficient; it was only two pages, whereas the much smaller and less complicated single-ply membrane section was five pages. Flat-locked terne was specified, which complied with the manufacturer's recommendations. However, the SMACNA *Architectural Sheet Metal Manual* recommends stainless steel or copper for flat-locked seamed roofs. Stainless steel would have been more resistant to corrosion and puncture. The spec did not specify special provisions for those panels on slopes less than 3:12.

Drawings

The roof plan indicated that the panels at roofs 1-5 were to have two endlaps (i.e., three panels from eave to ridge). On three of these roofs, the panel lengths were 30.6', 33', and 37'. The manufacturer recommended the use of expansion clips when the panels exceeded 30'. Expansion clips were not specified, nor were they installed.

The endlap detail did not specify the manufacturer's recommendation to field-paint the underside of the endlap. Considering the limited corrosion resistance of the metallic coating, field painting the unexposed portion of the endlap was important and should have been included with the detail. Field painting of the concealed area was not done, and severe corrosion resulted.

There were no provisions for ice dam protection at the eaves of roofs 1-5. The rake and ridge details were only shown schematically, making the design intent unclear.

The transition between the TPO and metal panels was not detailed. Neither the details nor window specification called for upturned legs on the sill flashings.

Submittal review

Expansion clips were not shown for the panels over 30' in length, painting of the underside of the endlaps and the flat locked panels was not noted, the TPO/metal transition was shown (but it did not allow for escape of water that reached the underlayment), no special provisions were shown for the low-sloped roofs (such as sealant tape in the ribs, as recommended by the manufacturer), the ridge rake flashings were poorly detailed, and several special details were not included.

Pre-roofing conference

A pre-roofing conference was specified, but it was not held. Considering the complexities of this roofing project, it is bewildering that this effort was omitted. The architect should have insisted on the conference.

Periodic field observations

The architect performed periodic field observations. Either the person conducting the observations was unfamiliar with the manufacturer's installation recommendations or was not diligent in evaluating the work with respect to it. In either case, the roof observations were inadequate, in this author's opinion.

Submittal preparation

As previously discussed, the submittal was very deficient. While many of the items that should have been shown on the submittals were not addressed in the contract specifications or drawings, they were addressed in the panel manufacturer's specifications, of which the roofing contractor should have been aware.

Workmanship

Workmanship on the exposed portions of the roof generally exhibited good workmanship (with the exception of the field-applied paint, which was applied by a painting contractor). Workmanship errors included lack of paint on the underside of the endlaps and the flat locked panels, poor fabrication of the ridge cap detail, three nail punctures (two through the metal) – either due to nail back-out or they were not flush with the OSB at time of installation, puncture of a metal panel by a small rock underneath the panel, and use of fixed clips on panels in excess of 30'.

As previously noted, the window drainage slots should not have been sealed.

REROOFING

The author recommended the following:

Roofs 1 - 6: Remove the existing metal panels and underlayment, replace damaged OSB, install an APP modified bitumen base sheet, red rosin paper, and new standing seam metal panels. A modified bitumen base sheet was specified because it is more robust than a #30 felt. APP was specified because of its great resistance to high-temperature flow. The base sheet laps were to be sealed for a distance of 9' above the gutter for ice dam protection. Two options were given for the metal: PVDF painted aluminum-zinc alloy or copper. At the time the reroofing was about to commence, the price of copper was relatively low, so the owner elected to have copper installed.

All other roof areas: Remove the existing metal panels and underlayment, replace damaged OSB, install a mechanically-attached SBS modified bitumen base sheet and white, granule-surfaced SBS cap sheet set in cold adhesive. Walkway pads were specified in the vicinity of the gutter drip line to avoid damage from falling ice. Pads were also specified at the vertical drops from one roof area to another to avoid water erosion.

The clerestory windows were removed, new sill flashings with upturned ends installed, and the windows were reinstalled.

A local architect, relatively knowledgeable about roofing, was retained by the owner to work with the roofing contractor to develop numerous custom details. The reroofing work was negotiated with a local general contractor and local roofing contractor familiar with standing seam metal and modified bitumen roofing.

Leakage has not been reported since the reroofing and window work was completed in early 2002.

POTENTIAL TERNE PITFALLS

There are potential pitfalls with terne and terne II of which designers and contractors should be made aware:

1. **Repainting:** Owners should be made aware of the manufacturer's recommendation to repaint at least every eight years and the cost implications thereof.

2. **Underlayment:** The manufacturer recommends against inclusion of felt underlayment. However, if the manufacturer's recommendations are followed and only rosin paper is specified, an adequate underlayment will not be achieved. Rosin paper is effective in avoiding bonding between the metal panels and felts, but it is easy to tear during application, and it has limited water resistance. An appropriate underlayment system is a layer of asphalt-saturated base sheet (or a modified bitumen base sheet) and a layer of rosin paper.

   The problem for the specifier is that if the manufacturer's recommendations are followed, a poor underlayment system results. If a good underlayment system is specified, it violates the manufacturer's recommendations, which is not desirable. Based on the results of the author's field observations and laboratory testing, the manufacturer should change its underlayment specification.

3. **Ventilation:** The manufacturer's specification states that "an air space must be provided under roof deck to facilitate ventilation and eliminate condensation." While this recommendation is easy to accommodate when an attic space

occurs below the roof deck, it is difficult and expensive to accommodate when there is no attic space. Had a ventilation cavity been provided on the church roof, the panel corrosion problem would not have been affected. Furthermore, a ventilation cavity below the deck will not necessarily prevent condensation on the underside of the panels. As with the underlayment issue discussed above, the manufacturer should revise its recommendations regarding ventilation so that they are technically valid.

4. **Low slopes:** For slopes below 3:12, the manufacturer should be contacted for special requirements (in 2002, the special requirements were not published in the manufacturer's literature).
5. **Field painting:** Field painting very soon after panel application is important. This should be specified and rigidly enforced. If panel application will occur when it is colder than 50 degrees F, the roof should be tented during painting, panel application delayed, or a panel that does not require field painting should be specified. Specify field painting of the end laps and rigidly enforce this requirement.
6. **Underside corrosion:** The manufacturer's warranty is voided if the terne is "subjected to underside moisture, either from roof leakage or condensation resulting from inadequate ventilation." Specifiers should be aware that terne has a much shorter time-to-failure from underside corrosion than other common metal roofing panels such as aluminum-zinc alloy and copper. ■

FOOTNOTE

1 Because of environmental concerns related to lead, production of terne was discontinued in 1998 and replaced with terne II, which has a zinc/tin coating.

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About the Author

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Asphalt Demand to Grow

Global demand for asphalt (bitumen) is projected to advance to 107 million metric tons, or 654 million barrels of primary asphalt by the year 2007. Of this amount, demand for asphalt in roofing applications is expected to rise 2.5% a year through 2007, to 12.4 million metric tons. That pace will mirror growth during the 1997-2002 period, as gains in developing regions offset a deceleration of demand in the large U.S. market.

— Freedonia Group Inc.

