A Design Guide for Standing Seam Roof Panels

American Iron and Steel Institute
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Steel Structural Members
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The following Design Guide has been developed under the direction of the American Iron and Steel Institute Committee on Specifications for the Design of Cold-Formed Steel Structural Members and Metal Building Manufacturers Association Technical Committee. The development of the Guide was cosponsored by the American Iron and Steel Institute (AISI) and the Metal Building Manufacturers Association (MBMA). The AISI Committee and MBMA wish to acknowledge and express gratitude to Dr. James M. Fisher and Mr. Leonard Lewandowski of Computerized Structural Design, Inc. and Dr. Roger A. LaBoube of the University of Missouri-Rolla who were principal authors of the Guide.

With anticipated improvements in understanding of the behavior of cold-formed steel and the continuing development of new technology, this material might become dated. It is possible that AISI will attempt to produce updates of this Guide, but it is not guaranteed.

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PREFACE

The Design Guide for Standing Seam Roof Panels provides information to the designer of standing seam panels. The Guide is based on the American Iron and Steel Institute’s Specification for the Design of Cold-Formed Steel Structural Members, 1996 Edition. Where the Specification is silent on design issues the procedures are based on published references and on the opinions of the authors.

The Guide was co-sponsored by the American Iron and Steel Institute (AISI) and the Metal Building Manufacturer’s Association (MBMA).

AISI and MBMA acknowledge the efforts of Dr. James M. Fisher and Mr. Leonard Lewandowski of Computerized Structural Design, Inc., and Dr. Roger A. LaBoube of the University of Missouri-Rolla in the development of this Guide.

Users of the Design Guide for Standing Seam Roof Panels are invited to offer comments and suggestions. User response will be critical in improving design procedures and for enhancing the use of standing seam roof systems.
# TABLE OF CONTENTS

PREFACE ........................................................................................................................................ iii

TABLE OF CONTENTS ..................................................................................................................... iv

1. INTRODUCTION AND BACKGROUND ...................................................................................... 1
   1.1 Explanation of Systems and Their Components ................................................................. 2
       1.1.1 Roof Panels ....................................................................................................................... 2
       1.1.2 Clips/ Fasteners ............................................................................................................... 2
       1.1.3 Purlins ............................................................................................................................ 3

2. ARCHITECTURAL AND STRUCTURAL ROOF SYSTEMS ........................................................ 3
   2.1 Architectural Metal Roofs ....................................................................................................... 3
   2.2 Structural Metal Roofs .......................................................................................................... 4

3. REVIEW OF COLD-FORMED STEEL PANEL DESIGN REQUIREMENTS ................................. 5
   3.1 Structural Analysis ................................................................................................................ 5
   3.2 Bending ................................................................................................................................ 5
   3.3 Shear .................................................................................................................................... 5
   3.4 Bending and Shear ................................................................................................................ 5
   3.5 Web Crippling ....................................................................................................................... 6
   3.6 Web Crippling and Bending .................................................................................................. 6
   3.7 Connections .......................................................................................................................... 6

4. PANEL DESIGN .......................................................................................................................... 6
   4.1 Gravity Load Design ............................................................................................................. 6
   4.2 Panel Uplift Design .............................................................................................................. 6

5. CLIP DESIGN ................................................................................................................................ 7
   5.1 General Design Considerations ........................................................................................... 7
   5.2 Clip Uplift Strength .............................................................................................................. 8

6. OTHER DESIGN CONSIDERATIONS .......................................................................................... 8
   6.1 Thermal Expansion And Contraction .................................................................................... 9
   6.2 Roof Slope .......................................................................................................................... 10
   6.3 Roof Details ......................................................................................................................... 10
   6.4 Rooftop Penetrations .......................................................................................................... 11

7. SYSTEMS SUBJECTED TO GRAVITY LOADING ...................................................................... 11

8. SYSTEMS SUBJECTED TO UPLIFT LOADING ............................................................................ 13

9. DESIGN EXAMPLES .................................................................................................................... 14
   9.1 Standing Seam Panel Design ............................................................................................... 14
   9.2 Evaluation of ASTM E1592 Test ......................................................................................... 18

REFERENCES .................................................................................................................................... 19

APPENDIX I AISI STANDARD PROCEDURES FOR PANEL AND ANCHOR STRUCTURAL TESTS WITH COMMENTARY ......................................................... 21

APPENDIX II ASTM E1592-95, STANDARD TEST METHOD FOR STRUCTURAL PERFORMANCE OF SHEET METAL ROOF AND SIDING SYSTEMS BY UNIFORM STATIC AIR PRESSURE DIFFERENCE .................................................. 27

APPENDIX III INSPECTION AND MAINTENANCE OF STANDING SEAM ROOFS .................... 37
A DESIGN GUIDE FOR STANDING SEAM ROOF PANELS

1. INTRODUCTION AND BACKGROUND

A typical roof system is composed of four primary components: purlins, roof panels, panel clips and purlin braces. The term system is used to describe the roof assembly because of the interaction and synergism of the components. The purlins are considered the primary load carrying components of the roof system but are commonly called secondary members with regard to the entire building structural system. They support the dead load, gravity load, and wind load, and transfer these loads to the primary structural framing. The roof panel is a multi-functional component. It transfers the applied loads to the purlin, as well as serves as a bracing member for the purlin.

The behavior and subsequently the design of the roof system is primarily dependent on the type of roof panel. There are two general categories of roof panels, the conventional through-fastened panel, and the standing seam panel. The through-fastened panel, although it has its place in the marketplace, is rapidly being replaced by the standing seam panel.

Standing seam roof systems were first introduced in the late 1960’s, and today many manufacturers produce standing seam panels. A difference between the standing seam roof and through-fastener roof is in the manner in which two panels are joined to each other. The seam between two panels is made in the field with a tool that makes a cold formed weather-tight joint. (Note: some panels can be seamed without special tools.) The joint is made at the top of the panel. The standing seam roof is also unique in the manner in which it is attached to the purlins. The attachment is made with a clip concealed inside the seam. This clip secures the panel to the purlin and may allow the panel to move when experiencing thermal expansion or contraction.

A continuous single skin membrane results after the seam is made since through-the-roof fasteners have been eliminated. The elevated seam and single skin member provides a weather tight system. The ability of the roof to experience unrestrained thermal movement eliminates damage to insulation and structure (caused by temperature effects which built-up and through fastened roofs commonly experience). Thermal spacer blocks are often placed between the panels and purlins in order to insure a consistent thermal barrier. Due to the superiority of the standing seam roof, most manufacturers are willing to offer considerably longer guarantees than those offered on lap seam roofs.

The use of exposed metal roof systems has expanded from exclusive use on metal buildings to all types of conventional and specialty buildings because of advancing technology in cold-formed metal fabrication. In addition, the relatively new concept of retrofitting older, conventionally roofed buildings with new, high-technology, metal systems has emerged.

The old-style “tin roof” has long since given way to systems that base themselves on architectural adaptability, durability, and low maintenance. Further, life cycle costing studies have shown metal roof systems to be competitive with any roofing system currently on the market.

When considering the variety of designs, materials, and finishes of metal roofs being offered today, the options can become overwhelming. Nearly every available metal roof system, however, can simply be classified as either architectural or structural.

This Design Guide provides an in depth discussion of the design methodology for standing seam roof panels and their accessories. In addition inspection and maintenance considerations are discussed in Appendix III.
1.1 Explanation of Systems and Their Components

A standing seam roof panel system is a synergistic system composed of the roof panel, panel clip, with attachment fasteners, and purlins:

1.1.1 Roof Panels

Steel roof panels serve as an environmental barrier as well as contributor to the structural integrity of the purlins, which support them. A standing seam panel cross section is shown in Fig. 1.1. The standing seam panel has no fasteners that penetrate the steel membrane, except where the ends of the panels are joined, and at points of fixity. It is necessary to define a point of fixity for the panel system. All movement is relative to this point of fixity. Typically, the point of fixity is at the building eave. The eave point of fixity has the advantage of being reinforced to resist wind loads from the wall and may not require reinforcement for the in-plane frictional forces of expansion and contraction, whereas when the fixity point is moved away from the eave it may be necessary to add additional strength and stiffness at the fixed location. The standing seam panel accommodates thermal expansion and contraction with the aid of a sliding clip.

![Fig. 1.1 Standing Seam Roof Panel](image)

Standing seam panels are either of the vertical rib, trapezoidal type, or batten as shown in Fig. 1.2.

![Fig. 1.2 Typical Standing Seam Panels](image)

1.1.2 Clips/ Fasteners

Fasteners and clips are used to connect the standing seam panels to the purlins. Clips are specially designed connection elements that are embedded in the seam of standing seam roof panels. The clips may be either sliding or fixed (Fig. 1.3). A sliding clip allows thermal movement of the roof membrane. Either self-drilling or self-tapping screws are used to attach the clip to the purlin. The self-drilling screw
combines the functions of drilling and tapping. Some one-piece clips are designed to slide within the panel rib.

![Fixed Clip and Sliding Clip](image.png)

**Fig. 1.3 Typical Standing Seam Clips**

### 1.1.3 Purlins

The roof purlins provide the anchorage for the fasteners. The design of the purlins is not treated in this guide; however, their design is treated in the *AISI Specification*, (AISI 1996a), and in “A Guide for Designing with Standing Seam Roof Panels”, (AISI 1997).

### 2. ARCHITECTURAL AND STRUCTURAL ROOF SYSTEMS

There are basically two types of roof systems, architectural and structural.

#### 2.1 Architectural Metal Roofs

The following information on architectural roofs is presented here for basic information only. This guide will concentrate on structural metal roofs.

An architectural metal roof is basically a decorative, surface treatment and is often not considered a structurally active element. This type of roof is usually installed over a structurally supported wood (plywood sheathing) or steel (metal decking) substrate that has, in turn, been topped with a vapor retarder, insulation board, and moisture-resistant roofing felts. A minimum roof slope of 3 in./ft. of run is typically recommended to ensure water shedding of the metal membrane surface. Even steeper slopes are often specified to maximize the visual exposure of the surface for its aesthetic value.

Architectural metal roofs may be fabricated from steel, aluminum, zinc, copper, lead, stainless steel, or a composite alloy material. The panels are usually continuous (no horizontal end laps) over relative short slope runs (typically 40 ft maximum length). They can be anchored to the wood or metal substrate by direct fastening (through-fastening) or by concealed hold-down clips. Side seams may be interlocked, snapped together, batten-sealed, or seamed mechanically and may or may not incorporate a sealant material.

Since the application of an architectural metal roof is essentially decorative, maintenance is primarily concerned with the care of the surface finish.
2.2 Structural Metal Roofs

The structural metal roof is a multifunctional system that serves a variety of purposes. Weather protection is, of course, its paramount and most obvious function. But it also provides a host of almost equally desirable, yet less apparent, characteristics. Load transmission and support element stabilization are two functions that are extremely valuable from an engineering standpoint. The structural metal roof has superior structural properties, i.e., section moduli, which allows the roof to span further or to support higher loads than the architectural metal roof. A structural substrate is not required. In addition, because of its superior structural characteristics as compared to the architectural roof, the structural metal roof has greater ability to torsionally and laterally brace purlin systems without a substrate system.

The main difference between architectural and structural metal roofs is the requirement of a structural substrate for the architectural panel. Structural metal roofs do not require an underlying substrate for the provision of strength or for moisture protection. The metal panel itself acts as weather barrier and load distributor. Roof live loads and, in some cases, lateral loads are transmitted directly to the spanning structural members by the roof panels.

Structural metal panels are typically fabricated from coiled carbon sheet steel that is galvanized, or aluminum-zinc-coated by a hot-dip method. Zinc coatings provide sacrificial (self-healing) corrosion protection. The sheet may also be finish-painted with a polyester, siliconized polyester, or fluorocarbon coating, or laminated with an adhesively bonded acrylic or fluorocarbon plastic film. Paint and laminate films are applied to enhance appearance and increase barrier protection for corrosion resistance. The coated and recoiled material is later roll-formed into its final profile and cut to length.

The side seam and end lap joints of standing seam roof (SSR) panels contain either factory- or field-applied sealants. It is the judicious use of joint sealants that renders the membrane moisture-proof. As a result of their water tightness and strength capabilities, structural metal roofs can safely and effectively accommodate slopes down to 1/4 in./ft of run. End lap joints are achieved by stitching the sheet ends together with either sheet metal screws or toggle-type fasteners. Some systems also employ clamp strips and backer plates to increase joint stiffness and provide a tighter seal. A variety of metal and neoprene closures, sealant materials, and sheet metal fasteners are used to weatherproof the eave, ridge, and rake lines, and other surface break or transition conditions.

When properly constructed, standing seam metal roofs can virtually eliminate the leak potential associated with through-fastener penetrations in the drainage plane of the membrane surface. Standing seam metal roofs employ a sophisticated, concealed, clip mechanism to secure the roof sheets to the building substructure. Side seam joints are battened, snap-locked, or machine-rolled and "stand" 2 or more inches above the roof's drainage surface.

Some manufacturers offer the option of a "fixed" anchorage SSR for smaller-area roof surfaces. Limiting the length of the continuous membrane reduces forces due to expansion or contraction. A fixed SSR is similar to a through-fastened roof with respect to its sensitivity to the relative stiffness of its underlying support system. The elevated seam is promoted for its leak resistance in fixed systems.

Most SSR installations are the "floating" (laterally independent of the support structure) type. In this case, the maximum length of uninterrupted slope run is dependent on the degree of expansion/contraction freedom afforded by an anchorage clip mechanism. The common uninterrupted slope run is 100-200 feet. The advantage that a mechanized clip anchor provides is that it effectively makes the roof surface "float" above the support structure. This floating roof eliminates the possibility of high thermal shock stress development within the system. The absence of this distress mode significantly reduces or eliminates the need for potentially troublesome expansion/contraction relief joints in the roof surface. As a result, SSR's can be used over stiff subsystems such as steel roof joists. They also offer greater latitude with respect to the incorporation of high-efficiency insulation systems.
The concept of the floating roof is by no means a panacea. It does impose some disadvantageous conditions upon the design. In this floating state, the roof surface has limited lateral load resistance capability. Therefore, the lateral load and stability forces acting upon and within the building must be carefully evaluated. As a result, the design and installation of an SSR becomes more complex than a screwed-down roof system. There are relatively higher material and installation costs. Even with its increased complexity, the standing seam roof generally offers the lightest weight, lowest maintenance, and most cost-effective roofing solution available today.

3. REVIEW OF COLD-FORMED STEEL PANEL DESIGN REQUIREMENTS

3.1 Structural Analysis
Elastic analysis assumptions and techniques are applied when determining the internal design forces and moments in a standing seam roof panel under gravity load.

In subsequent discussions, Figure 3.1 defines positive and negative moments.

![Fig. 3.1 Moment Definitions](image)

- **Simple Span**
- **Continuous Span**

3.2 Bending
The nominal flexural strength of a panel is determined by AISI Specification, (AISI 1996 a), Section C3.1. The elastic section modulus of the effective section is calculated using the provisions of Chapter B.

3.3 Shear
The shear capacity of a panel web is determined by AISI Specification, (AISI 1996 a), Section C3.2. Each panel web is considered as a separate element carrying its share of the shear force. For vertical panels, shears are carried by the vertical elements. For trapezoidal panel shapes, the shears are normally assumed to be carried by the vertical projection of the major rib. Shear forces are distributed to the vertical elements in proportion to the vertical projection of the element lengths.

3.4 Bending and Shear
The interaction of bending and shear must be considered by using AISI Specification Section C3.3. The bending capacity is based on initiation of yielding per AISI Specification Section C3.1.1(a). Shear capacity is determined by using Section C3.2.
3.5 Web Crippling
The web crippling capacity is determined by using AISI Specification Section C3.4. If the standing seam clip supports the panel in a manner in which web crippling cannot be a limit state, then web-crippling calculations are not required.

3.6 Web Crippling and Bending
At interior supports and overhangs of continuous span panels, combined web crippling and bending can occur if the standing seam clip does not support the panel. However, AISI Specification Section C3.5 exempts the application of the combined bending and web crippling interaction equation. It has been shown that combined bending and web crippling is not a strength limit state. A panel has the ability to redistribute moments and the ultimate failure of the panel is attributed to flexure in the positive moment region of the panel. If the designer is concerned with local deformations at interior supports of continuous span panels, the web crippling and bending interaction equation may be employed.

3.7 Connections
The common attachment of a panel clip to the flange of a purlin/ joist or the attachment of a panel to the eave member is by a self-drilling or self-tapping screw. AISI Specification Section E4 summarizes the design rules for screw connections. Section E4 applies to screws with diameters greater than or equal to 0.08 in. and less than or equal to 0.25 in. The Specification states that: “The screws shall be thread-forming or thread-cutting, with or without a self-drilling point”. If a particular application uses screws, which are not covered by Specification Section E4, then the design values for the particular application, shall be permitted to be based on tests according to Chapter F of the AISI Specification.

4. PANEL DESIGN

4.1 Gravity Load Design
Although standing seam roof panels are composed of thin structural elements (Fig. 1.2) that may distort and/or buckle in cross section when subjected to gravity loading, the panels can be designed using the AISI Specification. The Specification, in Section B1.1, recognizes the tendency of the panel to deform by noting that stiffened elements having w/t ratios larger than 500 may be used. The Specification indicates however, that substantial deformations of such elements usually will invalidate the design equations of the Specification. For standing seam roofs this is true for panels under uplift conditions. The AISI Commentary goes on to state that the intent of the Specification is to caution the designer, not to preclude the use of compression elements having w/t ratios greater than 500. For gravity load situations, panel deformation is normally not serious enough to preclude the use of the AISI equations.

The design of a standing seam panel to resist gravity load follows the same methodology and design considerations as any flexural member. That is, the panel must be investigated for the following design considerations: (1) bending, (2) shear, (3) web crippling, (4) combinations of bending and shear, and (5) deflection. The combination of bending and web crippling is explicitly exempted from design consideration by the exception clause of Specification Section C3.5. Design Example 9.1 demonstrates the application of the Specification to the design of a standing seam panel.

4.2 Panel Uplift Design
Panels and fasteners must be designed for the appropriate wind uplift pressures of the applicable building code. They must be checked for the different pressures as defined by the code for the field of the roof, rakes, eaves, corners, overhangs and ridge areas. Most building codes specify pressures that vary inversely with influence area. Thus, fasteners are usually required to resist greater pressures than the
panel in each of the areas defined. It is usually incorrect to evaluate fasteners with the same pressure as
the panel.

Through-fastened panel resistance may be checked using the AISI defined section properties. This
approach is deemed sufficient for through-fastened roofs, but is not appropriate for standing seam roof
panels. In the case of standing seam roof panels, disengagement of the panel from the clip, seam
unlatching and panel buckling are limiting failure mechanisms. Although the resistance of screws used
in roof systems may be calculated using pullout or pullover allowable strengths as defined in the AISI
Specification, the panel seam disengagement strength cannot be computed. Thus, the uplift resistance of
a seam and clip must be determined experimentally.

Several experimentally based rating methods are currently available for roof panels. The primary goal of
these methods is to evaluate attachment strength. These include Underwriter’s Laboratories UL 580,
ASTM E1592, and Factory Mutual Research Corporation (FM) Approval Standard 4471. UL 580 is a test
method currently available to the industry to evaluate composite systems for negative loading simulation.
It also is a test procedure for evaluating a panel assembly against fatigue loading conditions. UL 580
doesn’t give realistic panel strength values for comparing to design wind pressures that a roof may
experience on an actual building. It is considered a main field of roof simulation but due to the specimen
size and lack of test restrictions to the perimeter of the test specimen, the panels behave like a pre-tension
membrane that results in un-conservative strength results. However, the test method does provide a
measure of quality assurance of the assembly.

FM 4471 and ASTM E1592 are very similar in the evaluation of a test specimen for negative static
loading. FM 4471 only allows one size specimen with both ends fixed using a typical eave detail
assembly. ASTM E1592 allows varying specimen lengths and widths with varying end conditions to
include open-open; open-fixed; and closed-closed. The AISI Specification has stipulated the use of
E1592; therefore it is the best method available for evaluation of roof assemblies until further research
finds a more accurate method to simulate the dynamics of wind loading. All of the test methods use a
uniform pressure distribution. None of the tests take into account the dynamic, non-uniform nature of
actual wind loading. All currently available test methods for determining wind uplift ratings must be
used recognizing that they do not give an actual measure of a roof panel system’s ability to resist
specified design wind loads.

To enhance the structural performance of a standing seam roof panel, a seam clamp is sometimes
employed. The panel seam clamp is affixed to the seam at the location of the panel clip. The clamp
forces the rib of the panel tightly around the tab of the clip increasing the tab’s resistance to pull-out
from the rib. The seam clamp has been shown to be an effective means of preventing seam
disengagement. When panel clamps are present, the limiting structural failure mechanism is typically
flexural failure of the standing seam panel or pull-out of the screw clip-to-purlin fastener. Although,
ultimate failure will be panel blow-off.

5. CLIP DESIGN

5.1 General Design Considerations

The design of the clips, which connect the standing seam panel to the supporting structure, is beyond the
scope of this guide. Most clip designs have evolved over time. Purlin flange width, insulation thickness,
thermal block shape and thickness, strength requirements for uplift and gravity loading, ease of sliding,
sliding length and compatibility with the panel seam are just a few of the design parameters that must be
considered. Clip tabs should slide easily and not bind in the clip slot. Centering devices to ensure that
the tabs are centered before and during installation are often used. It should also be mentioned that with
the proper design of the clip, the requirements of web crippling and combined web crippling and bending
can be eliminated as design considerations for the vertical rib panel. Many clip manufacturers provide a
horizontal top flange on the clip, which allows the panel to directly bear on the clip thus eliminating web crippling. See Figure 1.3b.

5.2 Clip Uplift Strength

Two of the most important design parameters when determining the strength of the clip attachment to a given substrate are:

1. What is the prying force on the clip fastener(s)?
2. What is the proper factor of safety or resistance factor that should be used with various substrate materials?

No recognized analytical procedure exists for determining prying action forces for a clip fastener, thus designers are left with using a rational procedure. If a rational procedure is not used the authors' recommend that the fastener force be taken as one hundred percent greater than the calculated direct tension force.

Having determined the fastener forces, an appropriate factor of safety or resistance factor must be determined based on the substrate to which the clip is fastened.

Based on the 1996 AISI Specification with 1999 Supplement No. 1, (AISI 1999), standing seam roof systems must be tested using the ASTM E1592 test procedure. If the ASTM E1592 test is conducted on a steel substrate (purlins or metal deck), then prying forces, although not known, are automatically included, and the AISI procedure for evaluating the factor of safety and the resistance factor are to be used (See Section 8 of the Guide). The ASTM E1592 test can be conducted on substrates such as metal deck or plywood by perforating the substrate material to allow air passage through the substrate material. The plastic sheeting can be pleated and positioned on top of the substrate material and under the clip system.

When a standing seam roof system is to be used on substrates other than steel, the designer must determine the clip fastener forces, including the prying forces, and use an appropriate factor of safety or resistance factor for the proposed substrate material. For example, if the substrate is to be wood, the designer should refer to the National Design Specification for Wood Construction (NDS 1997).

Unfortunately, design standards do not exist for all possible substrate materials. Until such time that reliable test data is developed, the authors recommend a factor of safety of four be used on substrate material other than steel or wood.

6. OTHER DESIGN CONSIDERATIONS

Each mechanical component used in a structural metal roof system is factory-mass-produced to stringent quality standards. The very same fabrication standards and controls that ensure product excellence limit that product's application flexibility as well. By complicating the roof design with re-entrant corners, oblique angles, and multiple transitions, the installer is forced to employ his own resourcefulness in compromising the limits imposed by factory standardization. This approach will often result in a measurable degree of compromised performance.

In addition to standard design considerations regarding code compliance, load capacities, and insurance ramifications, a metal roof system has unique characteristics that merit careful deliberation. The metal roof system must perform the multiple functions of a structural component as well as a protective covering. Careful consideration must be given to its compatibility with the underlying support structure (type and module), eave, ridge, and rake line junctures and any accessory components that are incorporated into or penetrate the membrane.
The choice of a structural metal roof must be completely integrated into the building's overall design concept.

### 6.1 Thermal Expansion And Contraction

For a conventional screwed down roof panel, nature's forces of expansion and contraction are often the cause of roof leaks. As temperatures change, the roof expands or contracts. If the roof is not designed to accommodate movements resulting from expansion or contraction, fasteners may loosen or fatigue or the steel roof panel may develop a slot at the location of the fastener.

The standing seam roof panel was developed specifically to minimize roof leaks. Thus, the panel is intended by design to accommodate the forces of expansion and contraction. However, a standing seam roof panel will expand differently in its two directions. The sliding clip attachment will accommodate panel movement in the direction parallel to the panel's corrugation, whereas the panel will absorb movement in the other direction by slight flexing of the corrugations and the panel flats. To ensure that a panel can accommodate expansion and contraction, the panel clip is often designed with a self-centering mechanism.

The effects of temperature induced expansion and contraction on screwed down metal roofs has been documented. Based on analytical investigations, field studies, and correlation with full-scale laboratory experiments, University of Idaho researchers Perry, (1985) developed a procedure for estimating the surface skin temperature of a wall or roof panel. It was shown that the surface skin temperature was influenced by the sheeting coating color, the incident irradiation, and the ambient temperature. The sheeting coating color was shown to be a major contributor to increased surface temperature, for example the surface temperature of a dark brown roof panel was 1.50 times greater than a white panel.

In the design of a standing seam roof panel, thermal expansion parallel to the direction of the panel corrugation is typically assumed to be linear. Therefore, the dimensions of the panel increase or decrease according to the following equation of physics:

\[
\Delta L = \alpha L \Delta T
\]

where, \( \Delta L \) is the change in panel length resulting from either expansion or contraction, \( \alpha \) is the coefficient of linear expansion, \( L \) is the original length of the panel, and \( \Delta T \) is the change in temperature.

To accommodate \( \Delta L \) the designer may choose to anchor (fix) the roof panels at the building eave or at the ridge allowing the panels to expand or contract in one direction. When \( \Delta L \) becomes too large for the sliding clip then the designer may anchor the roof at mid-span of the panels allowing the panels to expand and contract in two directions. In some cases designers provide an expansion joint. An expansion joint typically consists of a flexible closure to accommodate the panel movement and an artificial eave, which serves as the fixed location for the next continuous length of panel. Each solution requires special flashing details at the eave, ridge and rake of the building.

Example Problem:

If a standing seam panel clip has the capability for 2 inches of movement, \( \alpha = 65 \times 10^{-7} \, (^{\circ}F)^{-1} \), and \( \Delta T = 100^{\circ} F \), the maximum length of continuous panel length is,

\[
2 = 65 \times 10^{-7} \times 100 \times 12
\]

\[
L = 256 \, ft
\]

Thus a continuous length of panel greater than 256 ft. would require anchoring the panels at mid-span or providing an expansion joint incorporated in the roof system.
6.2 Roof Slope

The life expectancy of a roof is heavily dependent on efficient removal of moisture from the metal membrane surface. The most effective way to prevent moisture penetration is to quickly shed the water from the roof over as short a path as possible. Minimum recommended slopes are 1/2 in./ft of run for screwed-down roofs and 1/4 in./ft for standing seam systems. Free drainage planes should be unimpeded. Length of slope run and potential wind and accessory penetration damming are important contributing factors. Fitting the roof system with flow diverters to channel the water around large penetrations is an important consideration.

Drainage system capacity (gutter size, length and number of drops) should be carefully analyzed to prevent ponding and overflow situations from developing. Valley gutter conditions should be avoided. The designer should remember that increased roof slope will reduce leak potential; however, the increased slope will result in additional material cost and will increase HVAC (heating, ventilating and air conditioning) requirements.

6.3 Roof Details

In order to ensure the performance of the roof system, it must be fabricated and erected in strict accordance with the design.

Roof sheet, end lap conditions should be factory-fabricated. All required eave, rake, and ridge condition materials should be included as part of a total roof system installation package. Each flashing and trim component should be specifically designed for integration into the selected roof.

The most important aspect is transition joint compatibility. If the roof panels are anchored with a device that facilitates expansion and contraction, but are positively attached to flashing and trim materials that do not permit movement, a condition of differential restraint exists. Something must give when an element wants to move relative to one whose position is fixed. All thermal movements must be accommodated. Compound joints (joints that absorb multidirectional thermal movements) must be provided where compound thermal forces are expected such as rake line/ridge line intersections.

Systems that limit the number of through-fastener penetrations to an absolute minimum are important. Two-piece clip mechanisms with a self-centering expansion/contraction tab are also important. The self-centering feature keeps the tab in a neutral position regardless of sheet temperature at the time of installation, which ensures that tab run out and resultant clip binding will not become a problem with extreme temperature variations. Thermal movements should not effect the seam sealant in any way in such systems.

All field-installed closure and sealant materials should be specifically tailored for use with the selected roof system. Closures should be form-fitted and chemically compatible with contact surface finishes. Sealants must also be chemically compatible with contact surfaces, have good flow characteristics, and maintain their resiliency. Both closures and sealants must be resistant to degradation from sun, moisture, ozone, and marine or industrial contaminants.

Designers and installers must be careful not to include materials in the roof details that react with the roof surface coating. For example uncoated steel members, uncoated fasteners, and copper react unfavorably with galvalume surfaces. These materials must be isolated from the roof surface.
6.4 Rooftop Penetrations

Rooftop penetrations can be a major source of roof leakage. In many instances where the penetration is properly identified as the culprit, the original roof installer may be blameless since it is common for roof-penetrating equipment to be installed well after the roof itself is completed. The sealing of the membrane around the protrusions may have been left to tradesmen who lack the proper skills, equipment, and materials necessary to provide a weather tight joint. A continuous joint borders a roof penetration. The joint must meet all the requirements of an eave, rake, and ridge joint. Transition flashings, trim, and sealants must be compatibly integrated with the mechanics of the roof membrane. Do not compromise the integrity of this critical location. Use experienced installers for all roof modifications. Roof penetrations should be kept to an absolute minimum. Vent through the wall if at all possible. If a unit must be structurally supported, use an above-panel frame with round pipe columns that are directly supported by the building substructure. Avoid using generic curbs unless the unit is light enough to be supported directly by the panel and small enough to fit between the lines of substructure. When specifying above-panel accessory framing, be sure to include a protective coating that provides adequate protection against runoff staining.

Metal roof curbs for equipment weighing less than 2000 pounds are often fabricated from 14 gage steel and are premounted on base panels which match the roof panel configuration. The curbs follow the roof thermal movement. Metal roof curbs for equipment weights from 2000 to 4000 pounds are often heavy metal curbs and are fabricated using two piece construction. A steel supporting frame is attached to the building structural members and a flashing curb is premounted on a base panel, which matches the roof panel configuration. The flashing curb follows roof thermal movement and is counter flashed to the supporting frame. A typical two piece metal curb is shown in Figure 6.1.

7. SYSTEMS SUBJECTED TO GRAVITY LOADING

Bracing is critical to the successful performance of a purlin roof system. Typically, when a purlin has a roof panel attached to its top flange, the tendency is to assume that the flange has full lateral support for bending behavior. This is an acceptable assumption when the panel is a through-fastened roof panel.
However, when the panel is a standing seam panel, the presence of lateral support can only be verified through testing using the AISI Base Test Method (AISI, 1996-b).

The load carrying capacity of a C- or Z-purlin system attached to roof panels is dependent on the ability of the roof panels to torsionally and laterally restrain the purlins. The torsional restraint is provided by the bending strength and stiffness of the sheeting, and the clip/fastener assembly, which connects the roof panels to the purlins. Lateral restraint is provided by the diaphragm capacity of the panels and any discrete point bracing designed into the system.

Brace forces and diaphragm forces accumulate and must be transferred to other structural elements, i.e. rigid frames, vertical bracing, etc. The designer must demonstrate by calculation or tests that the diaphragm can deliver the accumulated purlin anchorage forces to the anchorage points.

Purlins having their compression flange attached to deck or sheathing are designed as laterally supported members. Forces, which are developed in the bracing system and the deck or sheathing, must be calculated and anchored in accordance with AISI Specification Section D3.2.1 unless the AISI Base Test is conducted allowing the sheeting to float (no eave anchorage). The brace forces in the AISI Specification are contingent upon having a roof diaphragm system that meets the span divided by 360 requirement of AISI Specification Section D3.2.1. Diaphragm deflections are evaluated from shear deflection equations using the tested diaphragm shear stiffness. The load on the diaphragm is calculated from AISI Section D3.2.1 and distributed into the diaphragm in a manner consistent with the anchorage system employed.

In order to determine if the roof diaphragm system satisfies the span divided by 360 requirement, the diaphragm properties of the roof system must be determined. These properties are determined by a diaphragm test (AISI, 1996-b).

The majority of diaphragm stiffness loss comes from side seam slip. Many designers provide an eave member to which the panels are secured. The fasteners that are used to attach the panels to the eave member provide significant restraint, thus they can significantly increase the diaphragm strength and stiffness.

The effect of the eave attachment can be determined from a diaphragm test. The problem of including the eave attachments in a diaphragm test is that the benefit of the fasteners in the eave can lead to unconservative assumptions relative to the diaphragm strength and stiffness if the results are not evaluated properly. For example, if the cantilever test method is used to determine the strength and stiffness, and the values obtained from the test are then used to predict the strength and stiffness of a larger diaphragm, the effects of the eave member on the strength and stiffness will be overstated. Stating this in another way, assume that a particular roof system has no ability to resist side seam slip, then the total stiffness is derived from the fasteners in the eave member. The strength does not necessarily increase when the size of the diaphragm is increased, the resistance can decrease if the diaphragm depth increases and the width remains constant.

If the attachment to the eave member is intended to be used to help provide additional strength and stiffness to the diaphragm system, then the benefits from the eave in a test attachment must be isolated from the basic diaphragm strength and stiffness. The benefit from the eave member can then be added to the basic behavior of the diaphragm without the eave member. For further discussion on this behavior refer to “A Guide for Designing with Standing Seam Roof” (AISI, 1997).

The reader is also referred to the “A Guide for Designing with Standing Seam Roof Panels” (AISI, 1997) for a detailed discussion on determining the diaphragm strength and stiffness of standing seam roofs.
8. SYSTEMS SUBJECTED TO UPLIFT LOADING

The use of calculated section properties to determine standing seam panel uplift performance is not reliable. Section properties based on the undeformed panel geometry do not correctly represent the panel properties under uplift. Also, calculations cannot accurately predict standing seam clip disengagement.

The 1996 AISI Specification currently contains no criteria for the design of standing seam panels subjected to uplift loading. However, the following design procedure, has been approved by the AISI Committee on Specification as a design approach for standing seam panels subjected to wind uplift loading and has been adopted in the 1999 Supplement to the 1996 AISI Specification.

The nominal strength of standing seam roof panel systems under negative pressure shall be established by test in accordance with ASTM E1592-95 (Appendix II). However, ASTM E1592 does not provide guidance on the proper method of evaluating the test results and the determination of the appropriate factor of safety or strength reduction factor. Therefore, the AISI Committee on Specifications developed a standard procedure for panel and anchor structural test evaluation (Appendix I).

Except when the number of physical tests is less than three, safety factors and resistance factors shall be determined in accordance with the procedures of Section F1.1 (b) with the following definition for the variables:

\[
\begin{align*}
\beta_0 &= \text{Target reliability index for panel flexural limits} = 2.0 \\
\beta_0 &= \text{Target reliability index for anchor limits} = 2.5 \\
F_m &= \text{Mean value of the fabrication factor} = 1.0 \\
M_m &= \text{Mean value of the material factor} = 1.1 \\
V_M &= \text{Coefficient of variation of the material factor} = 0.08 \text{ (for anchor failure mode)} \\
&\quad = 0.10 \text{ (for other failure modes)} \\
V_F &= \text{Coefficient of variation of the fabrication factor} = 0.05 \\
V_Q &= \text{Coefficient of variation of the load effect} = 0.21 \\
V_p &= \text{Calculated coefficient of variation of the test results, without limit} \\
n &= \text{Number of anchors in the test assembly with the same tributary area (for anchor failure), or number of panels with identical spans and loading to the failed span (for non-anchor failures)}
\end{align*}
\]

Experience has shown that panel systems, when load tested, yield consistent, repeatable failure loads. Therefore, it is recommended that the computed value of \(V_p\) be used when evaluating the factor of safety or the resistance factor. The use of a smaller value differs from the 1996 AISI Section F1 requirements.

When determining the number of anchors for the evaluation of \(C_p\) in Section F1.1(b), it is permissible to include all fasteners with the same tributary area as that associated with the failed anchor. When determining the number of panels tested for the evaluation of \(C_p\), it is permissible to include all panels with the same tributary area as that associated with a failed panel.

When the number of physical tests is less than three, a safety factor, \(\Omega\), of 2.0 and a resistance factor, \(\phi\), of 0.5 shall be used.

When panel deformation, which is a serviceability consideration, is a design issue, a smaller factor of safety or larger resistance factor may be used. This recognizes that a small buckle, although esthetically unpleasant, does not create a safety hazard. The following safety factor or resistance factor is recommended:

\[
\begin{align*}
\Omega_{\text{serviceability}} &= \Omega_{\text{strength}} / 1.25 \\
\phi_{\text{serviceability}} &= \phi_{\text{strength}} \times 1.25
\end{align*}
\]
9. **DESIGN EXAMPLES**

9.1 **Standing Seam Panel Design**

Given:
1. Four span standing seam roof panel.
2. Dead Load = 2.0 plf, Snow Load = 70 plf, Wind Uplift = 28 psf
3. $F_y = 50$ ksi
4. Panel thickness = 0.024 in., Corner radius = 0.048 in.
5. Use ASD approach.
6. Uplift Capacity from ASTM E1592 Test = 35.7 psf (See Example 9.2).

![Fig. 9.1 Panel Cross Section](image)

![Fig. 9.2 Shears and Moments](image)

**Required:**
1. Calculate Section Properties.
2. Check the design for gravity loads.
3. Check the design for uplift loads.

**Solution:**

1. **Calculation of Section Properties**

Based on the design procedures of the AISI Specification, the following section properties were obtained:
\[ S_f = 0.113 \text{ in.}^3 \text{ (top), 0.612 \text{ in.}^3 \text{ (bottom)} \]
\[ S_e = 0.101 \text{ in.}^3 \text{ (top), 0.618 \text{ in.}^3 \text{ (bottom)}} - \text{Positive Bending} \]
\[ = 0.086 \text{ in.}^3 \text{ (top), 0.085 \text{ in.}^3 \text{ (bottom)}} - \text{Negative Bending} \]

Note: When computing effective section properties, the AISI Specification permits w/t ratios larger than 500. This is the situation for the computations of \( S_e \) (bottom) in the negative bending area.

2. Check gravity loads

a. Strength for Bending Only (Section C3.1.1)

Required Strength:
\[ M = M_D + M_S \]

Maximum positive moment: \( M = 0.004 + 0.135 = 0.139 \text{ kip-ft.} \)

Maximum negative moment: \( M = 0.005 + 0.187 = 0.192 \text{ kip-ft.} \)

Positive moment is defined as a moment producing compression stresses on the top of the panel.

Allowable Design Strength:

Positive Moment:
\[ M_n = S_e F_y = (0.101)(50) \frac{1}{12} = 0.421 \text{ kip-ft.} \]  Eq. C3.1.1-1
\[ M_a = M_n / \Omega = 0.421 / 1.67 = 0.252 \text{ kip-ft.} > 0.139 \text{ kip-ft. o.k.} \]

Negative Moment:
\[ M_n = S_e F_y = (0.085)(50) \frac{1}{12} = 0.354 \text{ kip-ft.} \]  Eq. C3.1.1-1
\[ M_a = M_n / \Omega = 0.354 / 1.67 = 0.212 \text{ kip-ft.} > 0.192 \text{ kip-ft. o.k.} \]

b. Strength for Shear Only (Section C3.2)

Required Strength:
\[ V = V_D + V_S = 0.006 + 0.212 = 0.218 \text{ kips} \]

Allowable Design Strength

For \( t = 0.024 \text{ in.}, h = 1.856 \text{ in.}, h/t = 77.3 < 1.415 \sqrt{E_{k_v} / F_y} = 79.4 \)

\[ V_n = 0.64t^2 \sqrt{F_y E} \]  Eq. C3.2-2
\[ V_n = 0.64 \times 0.024^2 \sqrt{5.34 \times 50 \times 29500} = 1.035 \text{ kips} \]
\[ V_a = V_n / \Omega = 1.035 / 1.67 = 0.620 \text{ kips per web} \]
\[ V_a = 2 \times 0.620 = 1.240 \text{ kips} > 0.218 \text{ kips} \text{ o.k.} \]

c. Strength for Combined Bending and Shear (Section C3.3)

Required strength:

For the first interior support
\[ M = M_D + M_S = 0.005 + 0.187 = 0.192 \text{ kip-ft.} \]
\[ V = V_D + V_S = 0.006 + 0.212 = 0.218 \text{ kips} \]
\[ \left( \Omega_b M / M_{nxo} \right)^2 + \left( \Omega_v V / V_n \right)^2 \leq 1.0 \quad \text{Eq. C3.3.1-1} \]
\[ \left( 0.192 / 0.212 \right)^2 + \left( 0.218 / 1.240 \right)^2 = 0.85 < 1.0 \text{ o.k.} \]

d. Web Crippling Strength (Section C3.4)

Required strength:
\[ P = P_D + P_S \]

Supports

End support = 0.004 + 0.138 = 0.142 kips
First interior support = 0.011 + 0.400 = 0.410 kips

Allowable design strength:

The following assumes a bearing length of 2-1/2 inches.

At end supports use Eq. C3.4-1 of the AISI Specification
\[ P_n = t^2 k C_3 C_4 C_9 C_9 \left[ 331 - 0.61 h / t \right] \left[ 1 + 0.01 N / t \right] \quad \text{Eq. C3.4-1} \]
\[ k = 894 F_y / E \]
\[ = (894)(50)/(29500) = 1.515 \]
\[ C_3 = 1.33 - 0.33 k \]
\[ = 1.33 - (0.33)(1.515) = 0.8300 \]
\[ C_4 = 1.15 - 0.15 R / t \]
\[ = 1.15 - (0.15)(0.048)/0.024 = 0.8500 \]
\[ C_9 = 1.0 \]
\[ C_\theta = 1.0 \]

\[ P_n = (0.024)^2(1.515)(0.8300)(0.8500)(1)(1) \left[ 331 - 0.61 \frac{1.856}{0.024} \left( 1 + 0.01 \frac{2.5}{0.024} \right) \right] \]

\[ P_n = 0.357 \text{ kips per web} \]

\[ P_a = \frac{P_n}{\Omega} = 0.357 \times 2 \text{ webs/1.85} = 0.386 \text{ kip} > 0.142 \text{ kips o.k.} \]

At interior supports use Eq. C3.4-4 of the AISI Specification

If the standing seam clip supports the panel in a manner in which web crippling is not a limit state then the following calculation is not required.

For \( N/t > 60 \)

\[ P_n = t^2kC_1C_2C_9C_\theta[538 - 0.74 \text{ h/t}][0.75 + 0.011 N/t] \quad \text{Eq. C3.4-4} \]

where

\[ C_1 = 1.22 - 0.22k \]
\[ = 1.22 - 0.22(1.515) = 0.8867 \]

\[ C_2 = 1.06 - 0.06 \text{ R/t} \]
\[ = 1.06 - (0.06)(0.048)/0.024 = 0.9400 \]

\[ C_9 = 1.0 \]

\[ C_\theta = 1.0 \]

\[ P_n = (0.024)^2(1.515)(0.8867)(0.9400)(1)(1) \left[ 538 - 0.74 \frac{1.856}{0.024} \left( 0.75 + 0.011 \frac{2.5}{0.024} \right) \right] \]

\[ P_n = 0.663 \text{ kips per web} \]

\[ P_a = \frac{P_n}{\Omega} = 0.663 \times 2 \text{ webs/1.85} = 0.717 \text{ kips} > 0.410 \text{ kip o.k.} \]

e. Combined Bending and Web Crippling (Section 3.5)

\[ 1.2(\Omega_w P/P_n) + (\Omega_b M/M_{n\text{ko}}) \leq 1.5 \quad \text{Eq. C3.5.1-1} \]

The AISI Specification excludes the application of the above equation to deck or panel sections. This implies that combined bending and web crippling is not a strength design consideration.

3. Check uplift loads

Based on the ASTM E1592 test, the allowable uplift load = 35.7 psf. Since the applied uplift load of 28 psf is less than 35.7 psf the panel and clip system is o.k.
9.2 Evaluation of ASTM E1592 Test

Determine the uplift design strength of a standing seam panel using ASTM E1592 and the AISI procedure for defining the factor of safety.

Test Panel: 16 in. wide panel supported on purlins spaced 5 ft. on center.

Test Specimen Width: ASTM E1592 stipulates a minimum of five panels be used to minimize the edge effects during the test. For the test under consideration, five full panels were used in the test.

Test Specimen Length: ASTM E1592 requires the specimen length to be sufficient to ensure that the end seals and attachments do not restrict panel movement at the area of investigation. If the panel is to be attached at each panel end by the standard eave attachment, the minimum panel length is 24 ft. ASTM E1592 permits shorter panel lengths if one or both of the panel ends are free of transverse restraint. For the test under consideration, the panel ends were restrained by the standard eave attachment, and therefore the panel length was taken as 25 ft. The supporting purlins were spaced 5 ft. on center.

Number of Tests: The AISI evaluation method prescribes a factor of safety based on the number of tests. For the test program under consideration, three tests of the standing seam panel system were performed.

Test Results: The following summarizes the failure load for the three test specimens:

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Failure Load, ( P_t ) (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61.0</td>
</tr>
<tr>
<td>2</td>
<td>63.5</td>
</tr>
<tr>
<td>3</td>
<td>60.8</td>
</tr>
<tr>
<td>( P_{avg} )</td>
<td>61.8</td>
</tr>
</tbody>
</table>

The coefficient of variation, \( V_P \), is 0.02437.

The failure mode for all tests was separation of a seam at an anchor. This is considered a connection failure mode. Thus \( \beta_0 = 2.5 \). Note that if the opening of the seam had been between the anchors, with the attachment of the anchor to the panel intact, the failure would not be a connection failure mode and \( \beta_0 \) would be 2.0.

Evaluation of Test Results: The following summarizes the analysis of the test results and the determination of the factor of safety using the AISI procedure.

A statistical analysis of the test results is required to determine the coefficient of variation for the test results, \( V_P \). This value is needed in the computation of the \( \varphi \) factor using AISI Eq. F1.1-2.

The coefficient of variation is defined as the standard deviation of the data divided by the mean value of the data, \( P_{avg} \). The standard deviation, \( \sigma \), is computed by the following equation:

\[
\sigma = \left\{ \frac{n \sum x^2 - (\sum x)^2}{n(n-1)} \right\}^{0.5}
\]
where
\[ n = \text{number of data points} = 3 \text{ tests} \]
\[ x = \text{values of the data points} \]

\[
\begin{array}{c|c}
   x & x^2 \\
   \hline
   61.0 & 3721.00 \\
   63.5 & 4032.25 \\
   60.8 & 3696.64 \\
\end{array}
\]

\[ \Sigma x = 185.3 \quad \Sigma x^2 = 11449.89 \]

\[ \sigma = \sqrt{\frac{(3 \times 11449.89 - (185.3)^2)}{(3 \times 2)^0.5}} = 1.5044 \]

\[ V_p = \frac{1.5044}{61.8} = 0.02434 \]

For the calculation of \( C_p \)
\[ \text{n = number of anchors in the test assembly = 4 purlin lines x 4 seam lines = 16 anchors} \]
\[ m = n - 1 = 15 \]

\[ C_p = \frac{(1+1/n) \cdot m}{(m-2)} = \frac{(1+1/16) \cdot 15}{(15-2)} = 1.23 \]

\[
\phi = 1.5(M_m \cdot F_m \cdot P_m) e^{-\beta_0 \sqrt{V_M^2 + V_p^2 + C_p V_p^2 + V_Q^2}} \quad \text{Eq. F1.1-2}
\]

\[
= 1.5[(1.1)(1.0)(1.0)] e^{-2.5\sqrt{(0.08^2 + (0.05)^2 + 1.23(0.02434)^2 + (0.21)^2)}} \quad \text{Eq. F1.1-2}
\]

\[ = 0.924 \]

\[ \Omega = \frac{1.6}{\phi} = \frac{1.6}{0.924} = 1.73 \quad \text{Eq. F1.2-2} \]

Allowable Design Strength = 61.8 psf / 1.73 = 35.7 psf

The allowable design strength can be increased by 1/3 when permitted by the governing building code.

REFERENCES

American Iron and Steel Institute (1996 a), “Specification for the Design of Cold-Formed Steel Structural Members”, Washington, DC

American Iron and Steel Institute (1996 b), Cold-Formed Steel Design Manual, Washington, DC


APPENDIX I

AISI STANDARD PROCEDURES FOR PANEL AND ANCHOR
STRUCTURAL TESTS
WITH COMMENTARY
STANDARD PROCEDURES FOR PANEL AND ANCHOR STRUCTURAL TESTS

1. Scope
This procedure extends and provides methodology for interpretation of results of tests performed according to ASTM E1592-95.

2. Referenced Documents
   2.1 ASTM Standards:
       E1592-95, Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference
       A370-97 Standard Test Methods and Definitions for Mechanical Testing of Steel Products
   2.2 AISI Standards:
       Base Test Method for Purlins Supporting a Standing Seam Roof System, AISI Cold Formed Steel Design Manual, Chapter VIII

3. Terminology
   3.1 Refer to Section 3, ASTM E1592-95.
   3.2 Additional or Modified Terminology
       3.2.1 clip, a single or multiple element device that frequently attaches to one edge of a panel and is fastened to the secondary structural members with one or more screws.
       3.2.2 field, the area that is not included in high pressure edge strip conditions. For purposes of the test, a field condition is modeled when the pan distortions are independent of end and edge restraint.
       3.2.3 pan, the relatively flat portion of a panel between ribs.
       3.2.4 tributary area, the area directly supported by the structural member between adjacent supports.
       3.2.5 trim, the sheet metal used in the finish of a building especially around openings, and at the intersection of surfaces such as roof and walls.
       3.2.6 ultimate load, the difference in static air pressure at which failure of the specimen occurs, expressed in load per unit area, and is further defined as the point where the panel system cannot sustain additional loading.
       3.2.7 unlatching failure, disengagement of a panel seam or anchor that occurs in an unloaded assembly due to permanent set or distortion that occurred when the assembly was loaded. This permanent set is not always detectable from readings taken normal to the panel. It is deemed to be a serviceability failure until a strength failure occurs, as defined in 3.2.6, ultimate load.

4. Summary of the Test Method
   4.1 Refer to the requirements of Section 4, ASTM E1592-95.

5. Significance and End Use
   5.1 Refer to the requirements of Section 5, ASTM E1592-95.
   5.2 The end use of the procedure is the determination of allowable load carrying capacity of panels and/or their anchors under gravity or suction loading for use in a design procedure.
6. Test Apparatus

6.1 Refer to the requirements of Section 6, ASTM E1592-95.

7. Safety Precautions

7.1 Refer to the requirements of Section 7, ASTM E1592-95.

8. Test Specimens

8.1 Refer to the requirements of Section 8, ASTM E1592-95.

8.2 Specimen Width - Edge seals shall not contain attachments that restrict deflection of the test panel in the field in any way. No additional structural attachments that would resist deflection of the field of the test panels are permitted.

8.2.1 The test panel ribs shall be installed parallel to the long side of the test chamber.

8.3 Number of Tests

8.3.1 Tests shall use minimum thickness of support members (secondary structures) and maximum panel span. If results are to be interpolated for other values, the other extremes must be tested in order to justify an interpolation procedure.

8.3.2 Tests shall be conducted to evaluate the field condition.

9. Calibration

9.1 Refer to the requirements of Section 9, ASTM E1592-95.

10. Procedures

10.1 Refer to the requirements of Section 10, ASTM E1592-95

11. Test Evaluation

11.1 Safety factors and resistance factors shall be determined in accordance with the procedures in Chapter F and Section C3.1.5 of the AISI Specification for the Design of Cold Formed Steel Structural Members.

11.2 If a separate test series is performed to evaluate edge conditions and the results exceed the field case by greater than one standard deviation, a separate design allowable is permitted to be established for edge conditions.

11.3 A qualified design professional shall analyze deflections and permanent set data to assure that deflections and permanent set are acceptable at service loads.

12. Test Report

12.1 Refer to the requirements of Section 11, ASTM E1592-95.

12.2 Report the resistance factor and/or the safety factor based on the Section C3.1.5 for the test results. If the factor of safety is defined, report the allowable uniform design strength of the panel system. If the allowable design strengths of the panel and anchors are determined separately, they shall be reported separately.

12.3 If intermediate values are to be calculated for different spacings of anchors or secondary structures, the basis of the interpolation shall be stated in the report. If the failure modes are different on any two tests, interpolation between these two tests is not permitted.

12.4 The design professional shall include in the report the observation as to the acceptability of deflections and permanent set data at service loads.
COMMENTARY ON THE STANDARD PROCEDURES FOR PANEL AND ANCHOR STRUCTURAL TESTS

1. Scope

The scope of the Procedure is for testing single skin panel systems. The procedure is based on ASTM E1592-95 with specific additions to define the required safety factors for a design procedure. Edge strip detail confirmation is permitted by the test method.

2. Reference Documents

The previously developed standards, ASTM E1592-95 and the AISI Base Test Method have been used in the development of this procedure.

3. Terminology

To promote accuracy and understanding, frequently used terms need mutual understanding. This list includes the terms from ASTM E1592-95 with additions and modifications.

5. Significance and End Use

Currently, there are several organizations that have test procedures to determine product performance, but the procedures are limited to one product configuration and do not have provisions to provide the basis for a complete design procedure covering the evaluation of a safety factor for a range of product configurations. Therefore, this new Standard Procedure was developed.

6. Test Apparatus

The apparatus defined in this section is specific enough to accomplish the purpose, yet broad enough to allow many facilities to perform tests. The size of the specimen is the most important criteria. Whether or not the apparatus consists of two sections with the specimen in between is not a major issue.

Measurement of rib spread has dubious value except when seam disengagement is the failure mechanism. In that case, measurements tend to substantiate the failure mechanism.

7. Safety Precautions

In addition to other precautions, care must be exercised in taking the deflection readings required in this procedure.

8. Test Specimens

The size of a test specimen has been found to be an important element in demonstrating product performance. Minimum sizes are defined, but larger sizes are allowed. It is understood that many products are offered to the market that have insufficient usage to justify a large test program yet proof of performance to some degree is required. The procedure is developed to allow a single test with a corresponding penalty due to the reduced degree of demonstrated reliability with only a single test. The procedures of Section F provide for the reward/penalty relationship developed with increasing number of tests and the associated coefficient of variation.

Minimum specimen size is as required in ASTM E1592-95. The minimum specimen length of 24 ft. (7.3 m) for the condition of constraint at both ends is consistent with the requirements of Factory Mutual Procedure 4471 (1995). However, in the FM tests, panels are fastened down at all edges and it is termed a
A purlin space of 5 ft. (1.5 m) requires 5 spans with both ends restrained. If one end is left free, the FM test will meet E-1592-95. The application is also different in many cases because typically FM tests are run with both ends restrained and this is used as a field test. Different results may be obtained when using the three variations of panel end restraints in the test procedure that are allowed by E 1592-95.

When totaling the number (n) of anchors tested for evaluation of $C_p$ under the AISI Specification Section C3.1.5, it is permissible to include all fasteners with the same tributary area as that associated with a failed anchor instead of merely totaling the number of physical tests run on a complete assembly. When totaling the number (n) of panels tested for evaluation of $C_p$ under the AISI Specification Section C3.1.5, it is permissible to include all panels with the same tributary area as that associated with a failed panel instead of merely totaling the number of physical tests run on a complete assembly.

Consideration is given to the minimum spacings and material thicknesses. If allowables developed under this procedure are intended to be used in a design procedure that encompasses different secondary structural support spacings or thinner sections for anchors to attach to, the extremes must be tested in order for interpolation to be valid. This precedent is established in the AISI Base Test Method for validating the performance of purlins braced by standing seam roof panels.

10. Procedures

The procedures for loading the specimen, while not complicated, need to be defined consistent with other existing and recognized standards. A significant difference between this procedure and the AISI Base Test Method is the return to zero load after each load increment.

11. Test Evaluation

See Section C3.1.5 of the Commentary for the AISI Specification.

12. Test Report

The definition of items to be included in the report includes the typical list of failure loads and plots of load versus deformation. Of paramount importance is the calculation of the resistance factor and safety factor of design strength or allowable design strength for panels and anchors. This procedure is an addition to those required in ASTM E1592-95. If interpolation is to be a part of the resulting design process, then appropriate interpolation procedure should be set forth in the report.

REFERENCES:

APPENDIX II

ASTM E1592-95
STANDARD TEST METHOD
FOR STRUCTURAL PERFORMANCE OF SHEET METAL ROOF AND SIDING SYSTEMS BY UNIFORM STATIC AIR
Superseeded

Designation: E 1592 – 95

This standard is issued under the fixed designation E 1592; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Computations are the accepted method for determining the structural capacity of most metal products. However, some conditions are outside the scope of analysis by industry specifications.

Methods of computation and a discussion of these conditions are found in the following documents: AISI Specification for the Design of Cold-Formed Steel Structural Members and Load and Resistance Factor Specification for Cold-Formed Steel Structural Members and Aluminum Association Specifications for Aluminum Structures.

This test method is not to be considered as a wind design standard. It is a structural capacity test to determine a panel system’s ability to resist uniform static pressure. Actual wind pressure is nonuniform and dynamic. When these uniform static test results are used in conjunction with commonly recognized wind design standards, they will yield highly conservative results.

When additional fasteners are installed across panel flats at eaves, ridges, or reinforced end laps, the crosswise distortion is eliminated and both flexural capacity and anchor-to-panel attachment strength can vary with the distance from such conditions. This test procedure can be used to evaluate the strength of panels and attachments at any distance from end or edge perimeter conditions. The size of the specimen and limitations on air seals are designed to minimize any interference with the natural response of the panels under load.

1. Scope

1.1 This test method covers the evaluation of the structural performance of sheet metal panels and anchor-to-panel attachments for roof or siding systems under uniform static air pressure differences using a test chamber or support surface.

1.2 This test method is applicable to standing seam, trapezoidal, ribbed, or corrugated metal panels in the range of thickness from 0.012 to 0.050-in. (0.3 to 1.3-mm) thickness and applies to the evaluation of single-skin construction or one layer of multiple-skin construction. It does not cover requirements for the evaluation of composite or multiple-layer construction.

1.3 Proper use of this test method requires knowledge of the principles of pressure and deflection measurement.

1.4 This test method describes optional apparatus and procedures for use in evaluating the structural performance of a given system for a range of support spacings or for confirming the structural performance of a specific installation.

1.5 The values stated in inch-pound units are to be regarded as the standard. The metric equivalents of inch-pound units are approximate.

1.6 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific precautionary statements, see Section 7.

1.7 The text of this standard references notes and footnotes exclusive of those for tables and figures. These notes and footnotes provide explanatory material and shall not be considered as requirements of the standard.

2. Referenced Documents

2.1 ASTM Standards:
A 370 Test Methods and Definitions for Mechanical Testing of Steel Products
B 557 Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products
2.2 Aluminum Association Standard:
2.3 AISI Standards:
Load and Resistance Factor Specification for Cold-Formed Steel Structural Members, 1991 Edition

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1 This test method is under the jurisdiction of ASTM Committee E-6 on Performance of Buildings and is the direct responsibility of Subcommittee E08.21 on Servicability. Current edition approved April 15, 1995. Published June 1995. Originally published as E 1592 – 94.

2 Available from ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. (610) 832-9585.

3 Available from American Iron and Steel Institute, 1101 17th Street NW, Suite 1300 Washington, DC 20036-4700.
Specification for the Design of Cold-Formed Steel Structural Members, 1986 Edition with the 1989 Addendum, Part I of the Cold Formed Steel Design Manual

2.4 Other Documents:
ASCE 7-88 (Formerly ANSI A58.1) Minimum Design Loads for Buildings and Other Structures

3. Terminology

3.1 Descriptions of Terms Specific to This Standard:

3.1.1 anchor, n—a fastener, bolt, screw, or formed device such as a clip that connects panels to the support structure.

3.1.2 anchor failure, n—any failure at the anchor device, including separation of the device from the panel, of the device itself, or of the connection to the structural support.

3.1.3 crosswise restraint, n—any attachment in the flat of a panel between structural elements that controls or limits panel distortion under pressure.

3.1.4 failure, n—unless otherwise specified by the person calling for the test, separation of components, or permanent distortion that interferes with the function of the system, or inability to carry additional load.

3.1.5 interior support, n—any support other than those at either extreme in a series of supports for a continuous panel.

3.1.6 pan distortion, n—displacement under load of normally flat portions of a panel profile as measured normal to the plane of the roof or wall surface.

3.1.7 panel deflection, n—displacement under load measured normal to the plane of the roof or wall surface of a longitudinal structural element as measured from a straight line between structural supports.

3.1.8 permanent deformation, n—the permanent displacement in any direction from an original position that remains after an applied load has been removed.

3.1.9 reference zero load, n—nominal pressure applied to a specimen to provide a reference position free of variations from internal stresses or friction within the system assembly.

3.1.10 rib spread, n—panel distortion under load at the base of a rib or standing seam as measured crosswise to the rib in the plane of the roof or wall surface.

3.1.11 span length, n—the center-to-center distance between anchors or supports measured parallel to the longitudinal axis of the panel.

3.1.12 specimen, n—the entire assembled unit submitted for testing, as described in Section 8.

3.1.13 specimen length, n—the distance from center to center of the end supports; the sum of individual span lengths.

3.1.14 structural element, n—the width of a panel profile as measured between center lines of repeating longitudinal stiffeners for continuously supported panels in a positive load test or the width between anchor attachments to repeating stiffener elements in a negative load test.

3.1.15 test load, n—the difference in static air pressure (positive or negative) between the inside and outside face of the specimen, expressed in pounds-force per square foot (lbf/ft²) or pascals (Pa).

3.1.16 test panel length, n—specimen length plus overhangs.

3.1.17 ultimate load, n—the difference in static air pressure (positive or negative) at which failure of the specimen occurs, expressed in pounds-force per square foot (lbf/ft²) or pascals (Pa).

3.1.18 unlatching failure, n—disengagement of a panel seam or anchor that occurs in an unloaded assembly due to permanent set or distortion that occurred under a previous load condition.

3.1.19 yield load, n—that pressure at which deflection increases are no longer proportional to the increase in pressure. Yielding is not failure.

3.1.20 zero load, n—the absence of air pressure difference across the specimen.

4. Summary of Test Method

4.1 This test method consists of the following: (1) sealing the test specimen into or against one face of a test chamber; (2) supplying air to, or exhausting air from, the chamber at the rate required to maintain the test pressure difference across the specimen; and (3) observing, measuring, and recording the deflection, deformations, and nature of any failures of principal or critical elements of the panel profile or members of the anchor system.

4.2 The increments of load application shall be chosen such that a sufficient number of readings will be obtained to determine the load deformation curve of the system.

4.3 End and edge restraint shall be representative of field conditions, and the unit shall contain sufficient individual components to minimize the effect of variations in material and workmanship.

5. Significance and Use

5.1 This test method provides a standard procedure to evaluate or confirm structural performance under uniform static air pressure difference. This procedure is intended to represent the effects of uniform loads on exterior building surface elements.

5.2 It is also permissible to develop data for load-span tables by interpolating between the test results at different spans.

NOTE 1—When applying the results of tests to determine allowable design loads by application of a factor of safety, bear in mind that the performance of a wall or roof and its components, or both, can be a function of fabrication, installation, and adjustment. The specimen must represent the actual structure closely. In service, the performance can also depend on the rigidity of supporting construction and on the resistance of components to deterioration by various causes, to vibration, to thermal expansion and contraction, etc.

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* Available from American Society of Civil Engineers, 345 East 47th Street, New York, NY 10017-2398.

† Industry design procedures propose different factors of safety on yield and ultimate strength. Some materials do not have a well-defined yield point. The AISI specifications for test require the following: "The load at which distortions interfere with the proper functioning of the specimen in actual use shall not be less than the dead load plus 1.5 times the applied load." Not all permanent deformation is harmful to the performance of the system.

§ This permanent set is not always detectable from readings taken normal to the panel.

9 It is often impractical to take direct measurements on individual elements in an assembly of components. Readings made on a panel surface opposite an anchor clip include deflection of non-axis loads in the anchor base and panel profile as well as any slippage that occurs in the panel connection or between segments of a multiple-piece clip. They may decrease with increasing pressure and produce a bi-linear curve. Subsequent small-scale tests may be required to determine whether nonlinear deflection readings represent tolerable distortions that do not interfere with long-term anchor performance.
6. Apparatus

6.1 The description of apparatus is general in nature: any equipment capable of performing the test procedure within the allowable tolerances is permitted. Major components are shown in Fig. 1.

6.2 Test Chamber—A test chamber, air bag, or box with an opening, a removable mounting panel, or one open surface in which or against which the specimen is installed. Provide at least two static pressure taps located at diagonally opposite corners to measure the chamber pressure such that the readings is unaffected by the velocity of the air supply to or from the chamber or any other air movement. The air supply opening into the chamber shall be arranged so that the air does not impinge directly on the test specimen with any significant velocity. A means of access into the chamber to facilitate adjustments and observations after the specimen has been installed is optional.

NOTE 2—The test chamber or the specimen mounting frame, or both, must not deflect under the test load in such a manner that the performance of the specimen will be affected. In general, select anchor support members sufficiently rigid that deflection under the test load will be negligible.

6.3 Air System—A compressed air supply, an exhaust system, or controllable blower is to be provided to develop the required air pressure difference across the specimen. The system shall maintain an essentially constant air pressure difference for the required test period.

NOTE 3—It is convenient to use a reversible blower or separate pressure and exhaust systems to provide the required air pressure difference so that different test specimens can be tested for the effect of positive pressure or the effect of suction (negative pressure) without reversing the position of the test specimen. The use of the same specimen for both positive and negative testing is outside the scope of this test method. If an adequate air supply is available, a completely airtight seal need not be provided around the perimeter of the test specimen and the mounting panel, although it is preferable. However, substantial air leakage will require an air supply of much greater capacity to maintain the required pressure differences.

6.4 Pressure-Measuring Apparatus—The devices to measure the test pressure difference shall operate within a tolerance of ±2 % of the design pressure, or within 0.1 in. (2.5 mm) of water pressure (0.52 psf or 25 Pa) and be located as described in 6.1.

6.5 Deflection and Distortion Measurement Precision:

6.5.1 The means of measuring deflections of structural ribs between the reaction supports and movement of the ribs at the supports shall provide readings within a tolerance of ±0.01 in. (0.25 mm).

6.5.2 The means of measuring pan distortion shall provide readings within a tolerance of ±1/16 in. (1.5 mm).

6.5.3 The means of measuring rib spread shall provide readings within a tolerance of ±1/32 in. (1.5 mm).

6.6 Reading Locations:

6.6.1 Support deflection gages or measuring devices so that readings are not influenced by movements of, or within, the specimen or member supports.

6.6.2 Measure the maximum mid-span and span end (at anchor support) deflections of at least one structural rib not influenced by the attachment or seal to the test chamber. Additional locations for deflection measurements, if desired, shall be stated by the specifier of the test.

6.6.3 Measure pan distortion in the middle of at least one panel flat (between structural elements) at a minimum of three locations. Additional reading locations are required to validate freedom from end restraint, as described in 8.3.2.

6.6.4 Rib spread readings are optional for measuring panel distortion for profiles with vertical rib faces. Measure rib spread at the base of the ribs in line with the anchors and at mid span, as required, to meet the requirements of 8.3.2.

6.7 Reading Frequency:

6.7.1 In all cases except for rib spread, readings shall be taken at initial zero or preload, at each increment of load, and again at the zero or preload to determine permanent set. See 10.2.4 regarding the selection of zero load.

6.7.2 Rib spread readings shall be taken at each increment of load unless stipulated otherwise by the specifying authority.

7. Safety Precautions

7.1 Take proper precautions to protect the operating personnel and observers in the event of any failure.10

10 At the pressures used in this test method, considerable energy and hazard are involved. In cases of failure, the hazard to personnel is less with an exhaust system, as the specimen will tend to blow into the test chamber rather than out. Do not permit personnel in such chambers during the application of a pressure difference.
8. Test Specimens

8.1 The test specimens shall be of sufficient size to determine the performance of all typical parts of the system. Conditions of structural support shall be simulated as accurately as possible, and the full length and width, including overhangs, shall be loaded. All parts of the test specimen shall be full size, using the same materials, details, and methods of construction and anchorage as used on the actual building. Except for positive load as in 8.2.2, any partial width sheets shall not be considered in figuring specimen width.

8.2 Specimen Width—Edge seals shall not contain structural attachments that restrict deflection of the test panel any more than the normal gable condition.

8.2.1 For the evaluation of either bending capacity or anchor to panel attachment strength under negative load, the specimen width shall contain not less than three full panels and five structural elements with normal rake or gable supports at both edges (see Fig. 2).

8.2.2 For the evaluation of panel bending capacity in resisting positive pressure, the specimen width shall be as specified in 8.2.1 or be not less than 40% of the clear span and include not less than four structural elements with not less than one half the flat distance to the next adjacent non-included parallel rib, corrugation, or stiffener on each side.

8.3 Specimen Length—For negative (uplift) load tests (or any form of loading that tends to push panels away from the crosswise support), unless the test represents the full length used, the specimen length shall be sufficient to ensure that end seals or attachments do not restrict panel movement at the area under investigation.

8.3.1 For the evaluation of anchor to panel strength free of end influence, the arbitrary minimum specimen length, when both ends have crosswise restraint, is 24 ft (7.3 m). Shorter lengths are acceptable when only one end having crosswise restraint is a minimum of 8 ft (2.4 m) from at least one row of interior anchors. When both ends are free of crosswise restraint, the minimum specimen length is 10 ft (3 m)\(^1\) (see Table 1). When crosswise restraint is removed from both ends, the normal failure mechanism is the anchor connection to the seam. Other modes of failure or performance must be evaluated using one or both ends restrained.

8.3.2 For the evaluation of anchor to panel strength, the results are deemed to be free of end influence when measurements of panel distortion indicate that the sample is outside the effect of the end condition as follows:

8.3.2.1 When maximum mid-span panel distortion readings of an identical 24-ft (7.3-m) panel do not exceed (within the tolerance of the measurement) the maximum readings on the shorter setup; or

8.3.2.2 When maximum mid-span panel distortion readings do not exceed (within the tolerance of the measurement) the mid-span distortion readings at least 4 ft (1.2 m) on both sides of at least one purlin.

8.3.3 For positive load tests, where the panels are supported to resist the applied load at each structural element in the mid-roof area as well as at the ends, the specimen length is not restricted.

8.4 Structural supports used in the test shall be of sufficient strength and rigidity to minimize deflection of the assembly. For supports used in positive pressure tests, due consideration must be given to the width of the support that is in contact with the panel.\(^1\)

8.5 End conditions that simulate eave or ridge flashing situations in which the panel terminates at or slightly beyond the purlin are considered to have crosswise restraint and influence distortion for some distance along the length of the panel. An open-end condition is one without crosswise restraint.

\(^1\) The arbitrary length minimums in this section are based on tests of aluminum panels with structural elements 8 to 18-in. (203 to 457-mm) apart in nominal thicknesses from 0.0165 to 0.040 in. and of steel panels 12 to 24-in. (305 to 610-mm) apart in nominal thicknesses from 30 gage (0.0157 in.) to 22 gage (0.0336 in.). Additional testing or data (such as that listed in 8.3.2) may be required to validate appropriate lengths for products significantly outside these limits. Note that tests with both ends open do not necessarily reflect the panel bending capacity near end conditions.

\(^1\) The size of support members in this test method does not necessarily preclude the use of smaller members in actual installations. For negative loads, fastener withdrawal resistance can be calculated readily by conventional means, taking into account prying forces and actual material thickness and properties. In positive loading, due consideration must be given to the actual bearing area in the test.
8.5.1 It is permissible to reinforce open-end conditions to prevent non-typical failures of clip to panel attachment or of web buckling caused by proximity of the free edge to the support. Acceptable reinforcement includes longitudinal stiffeners in the flats to prevent buckling of flats. Also acceptable are seam fasteners at the ends of ribs to prevent un-seaming from the free end. The reinforcement shall not restrict crosswise panel deformation nor cause the end seal to pull away from the pan as panels distort under load.

8.6 Overhangs at end conditions shall not exceed one-quarter of the span.

9. Calibration

9.1 The calibration of liquid column manometers, dial gages, and graduated scales or tape measures is not required for each test. 13

10. Procedure

10.1 Omit from the test specimen any undue influence from gravity, sealing, or construction material that does not occur during actual installation.

10.1.1 If the test panel orientation is either inverted or vertical, a gravity correction shall be made in the determination of the allowable superimposed loading. Tests run in an inverted position shall include data from pressure reversal or an upright specimen to demonstrate that unlatching will not occur in the normal orientation.

10.1.2 For negative load tests, the interior side of the specimen shall face the higher pressure. 14 Support and secure the specimen by the same number and type of anchors normally used for installing the unit on a building, or if this is impractical, by the same number of other comparable fasteners located in the same way as in the intended installations.

10.1.3 If air leakage through or around the test specimen is excessive, tape or plastic film is acceptable to block any cracks and joints through which the leakage is occurring. Tape or film shall not be used to span a joint where it restricts differential movement between adjoining members. This caution applies specifically to the inside face of standing seam panels which tend to spread apart under pressure. See the instructions for proper film placement in the annex.

10.1.4 In cases in which it will not affect the results, it is permissible to apply a single thickness of polyethylene film no thicker than 6 mils (0.006 in.) (0.15 mm). The technique of application is important so that full load is permitted to be transferred to the specimen and the membrane does not prevent movement or failure of the specimen. Apply the film loosely, with extra folds of material at each corner and at all offsets and recesses including the perimeter of the test specimen. The film shall not span any joint that will tend to separate under pressure. When the load is applied, there shall be no fillet caused by tightness of plastic film that will have a significant effect on the results. 15

10.2 Procedure—The following procedure is designed to produce a minimum of six points on the load-deflection curve. For precision in determination of the yield and ultimate strength, smaller increments are permitted to obtain additional points at the discretion of the test operator.

10.2.1 Check the specimen for proper adjustment, and close all vents in pressure-measuring lines.

10.2.2 Install the required deflection-measuring devices at their specified locations.

10.2.3 At each increment of load, maintain pressure for not less than 60 s and until the dial gages indicate no further increase in deflection.

10.2.4 Apply a nominal initial pressure equal to at least four times but not more than ten times the dead weight of the specimen. If the applied loads are in the same direction as gravity on the test specimen, remove this pressure and record the initial readings at zero load. If applied loads are not in the same direction as gravity, use this nominal pressure as the reference zero and record the initial readings. 15

10.2.5 Unless otherwise specified, the first increment of load shall be nominally equal to one third the anticipated ultimate load.

10.2.6 Reduce the pressure difference to zero and, after a recovery period of not more than 5 min at zero load, increase the pressure to reference zero (if used instead of zero) and take readings to determine permanent deformation for the first increment of load.

10.2.7 Proceed as above with successive increments that do not exceed one sixth the maximum specified test load until failure or the specified ultimate load is reached. 16

10.2.8 When the behavior of the specimen under load indicates that failure is imminent, it is permissible to remove the deflection measuring devices and to increase the load continuously until failure. In such cases, the yield point must be assumed to have been reached at or before the last recorded load.

10.2.9 After initial failure of one or more connections that leaves the majority of the specimen intact, it is permissible to provide external support to prevent further displacement of those locations and continue the loading to develop additional data. 17

Water density varies less than 0.5% over the temperature range from 40 to 90°F (4.4 to 32°C) and the length of metal measurement devices varies even less. Persistent differences in pressure readings at opposite ends of a test chamber indicate uneven airflow within the chamber or leaks in the lines to the manometers. If reducing the rate of increase does not allow the pressure to stabilize, the test readings are suspect. Leaks in manometer lines produce readings that are less than the actual pressures.

In positive load tests, when the specimen is mounted with the exterior side up, it is common practice to apply a preload to set the specimen against the supports. This load is removed, and the gages are set to zero. In negative load tests, it is desirable to maintain a low pressure at zero reading that will take the slack out of the system for accurate readings of permanent set. However, it is important to reach a zero load condition to permit the system to unlatch if it is susceptible to permanent local distortion. If negative load tests are run on an inverted specimen, gravity will possibly prevent this.

13 Failure of the plastic film by stretching between its supports indicates that it was restraining the movement of the test setup.

14 Counting the zero reading, the minimum number of loads called for will provide six points on the load deflection curve. For greater precision, especially at higher ultimate load values, the load increments may be smaller. Except for plotting convenience, they need not be exactly equal; if the pressure overshoots the target value, it should be maintained at the high value and readings taken for that pressure. During each load cycle the test specifier or engineer has the option to record deflection at the level of the previous increment before proceeding to the next higher load. This will assure that unlatching has not occurred.

15 Individual attachment failures may occur before panel buckling. In tests with one open end, clips may have higher strength within the influence of the crosswise end restraint at the other end. Ribs at failed clips may be braced to allow higher pressures.
11. Report

11.1 Report the following information:

11.1.1 Date of the test and issue of the report. State the location of the facility, name of the testing agency (if any), and names of the specific observers of the test. Cite the qualifications of any independent observers called in to certify the test procedure or results.

11.1.2 Identification of the specimen (manufacturer, source of supply, dimensions, model types, materials, and other pertinent information).

11.1.3 Detailed drawings of the specimen and test fixture, showing the dimensions of section profiles, purlin location, measurement locations, panel arrangement, installation and spacing of anchorage, sealants, and perimeter construction details. Note any modifications made on the specimen, including reinforcement in accordance with 10.2.9, to obtain the reported values, on the drawings.

11.1.4 Measured thickness and tensile yield strength of the material used in the test panels. Mechanical properties and thickness shall be measured after the removal of coatings in accordance with the appropriate standards for the material used, that is, Test Methods A 370 for steel and Method B 557 for aluminum. These values will be used to verify conformity with the product specification or make any required adjustment of allowable capacity within the range of a material specification and shall be made in accordance with the appropriate ASTM standard for the material involved.

11.1.5 Tabulation of the number of test load increments, zero load value and pressure differences exerted across the specimen at load increments, pertinent deflections at these pressure differences, and permanent deformations at locations specified for each specimen tested.

11.1.6 Plot of deflections and permanent set related to pressures applied.

11.1.7 Duration of the test loads, including incremental loads.

11.1.8 Record of visual observations of performance and description of the location and type of failure experienced.

11.1.9 When the tests are made to check conformity of the specimen to a particular specification, an identification or description of that specification.

11.1.10 Statement that the tests were conducted in accordance with this test method or a full description of any deviations from this test method.

11.1.11 Statement that the panel and sealing method was observed by the testing engineer with comments concerning whether tape or film, or both, were used to seal against air leakage, and whether, in the judgment of the test engineer, the tape or film could have influenced the results of the test.

11.2 If several essentially identical specimens of a component are tested, report the results for all specimens, with each specimen being identified properly, particularly with respect to distinguishing features or differing adjustments. A separate drawing for each specimen will not be required if all differences between them are noted on the drawings provided.

12. Precision and Bias

12.1 This is a new procedure, and precision and bias of the test method is to be determined.

13. Keywords

13.1 air bags; air seals; anchor strength; crosswise distortion; deflection; flexural capacity; rib spread; sheet metal roof and siding; single stain construction; standing seam; static air pressure; structural performance; test chamber; trapezoidal, ribbed, and corrugated panels; unlatching failure
ANNEX

(Mandatory Information)

A1. PROPER USE OF FILM AND AIRBAGS

A1.1 When plastic film is used to seal joints or transmit air pressure to the surface of a roof specimen at any point other than a restrained end condition, it must contact all surfaces of the panel and must not interfere with the movement of adjacent parts. In an uplift test, friction of film that bridges the gap at the base of a standing seam as in Fig. A1.1 prevents lateral movement and yields non-conservative results whether it be a flat film sealed at the edges or an air bag.

A1.2 Longitudinal pleats that fit up into the rib on both sides of a clip, as in Fig. A1.2, ensure full contact and eliminate restraint.

A1.3 Multiple longitudinal air bags wider than the panel module as in Fig. A1.3 provide the same effect without the need to perforate the air bag with the anchor fastener. Where either of these interfere with proper clip engagement, all seals must be limited to the perimeter of the test specimen.

A1.4 Multiple crosswise air bags as in Fig. A1.4 do not make full contact and will hamper panel distortion. Plastic film must always lie between the panel and the crosswise support structure to provide continuous longitudinal contact. Other methods of sealing that demonstrate equivalent distortion as air pressure are acceptable.

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FIG. A1.1 Improper Seal Where Film Spans Crevice at Base of Rib

FIG. A1.2 Pleats Make Contact with Metal Panel on Both Sides of Clips

FIG. A1.3 Proper Seal at Rib with Multiple Longitudinal Air Bags

FIG. A1.4 Improper Use of Multiple Air Bags Between Supports
APPENDIX

(Nonmandatory Information)

X1. GENERAL DISCUSSION

X1.1 Analysis and interpolation of test results should be by a qualified design professional. Wind forces on building surfaces are complex, varying with wind direction, height above ground, building shape, terrain, surrounding structures, and other factors. For design purposes, wind loads are represented by static uniform loads. Other loads represented as static uniform loads include the weight of the building element itself and other permanent building loads. Live loads represent multiple combinations of temporary concentrated and uniform loads that are superimposed on building elements during the life of a structure. Snow loads are distributed loads of variable magnitude imposed on roofs that are affected by drifts, appendages, parapets, setbacks, etc.

X1.2 Since this test method is based on static pressure difference, individuals specifying design loads must translate anticipated values from internal and external pressure coefficients into a uniform air pressure difference. Some sources are the applicable building code, ASCE 7-88, or recognized model test procedures.

X1.3 Both the specifier of this test method and anyone interpreting the results should understand that static pressure does not cover all aspects of dynamic wind loading and that building code values for minimum design wind pressures do not deal with the load sharing that can occur in multilayer construction. Any evaluation of test results on multilayer specimens should consider the possibility that crosswise or lengthwise flow of air within layers can reduce or eliminate load sharing in actual service.

X1.3.1 For example, spaces in trapezoidal ribs and around blocks of rigid insulation laid between purlins on top of a vapor retarder can allow sufficient lateral air flow under dynamic conditions to invalidate the results of a test in which air pressure exerted against the vapor retarder is transmitted to the panels only by displacement of the insulation. On the other hand, in service, a rigid pressures-tight deck tends to restrict a tight fitting metal roof covering from carrying the full negative pressure. The determination of design or service pressures for roof coverings as compared to the total roof structure is outside the scope of this test method.

X1.4 When product design is based on tests, metal industry specifications (see 2.2 and 2.3) require that the results be adjusted for the minimum anticipated properties (gage and thickness) of the material to be furnished. The factor of safety therefore need cover only variations in workmanship and anticipated service load. For roll-formed panels, tests on production material often differ considerably from those on brake-formed prototypes. Industry standards also require that tests cover the extremes of span and load. They allow interpolation between the results for like failure modes but generally prohibit extrapolation to spans or pressures beyond the range of the tests.

X1.5 Unless the test is being run to confirm computations, industry standards (see 2.2 and 2.3) require that the average of two or three tests be used to substantiate performance for design purposes. When used for the uplift capacity of anchors, the procedure described in this test method is believed to meet the intent of this requirement with a single specimen for several reasons: (1) the minimum size contains sufficient identically loaded components to provide the statistical equivalent of four samples; (2) the use of two manometers affords a measure of confidence in the readings that is greater than an individual reading; and (3) a failure reading is the minimum rather than the average because any further reloading of the specimen will either develop incipient failures from the original load or go to higher values.

X1.6 The analysis of test results should consider the possible effect of specimen size on the mode of failure. Both ends open will produce the most severe condition for an anchor to panel connection but not necessarily the most severe for bending capacity. Under negative air pressure, some shapes assume an arched configuration that is stronger than the less distorted profile near an eave or ridge.

X1.7 Factors of safety are higher for connections than for panel bending. Test pressures may develop bending failures before anchor loads became critical. Tests may be required at several spans to arrive at an optimum design.

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.
APPENDIX III

INSPECTION AND MAINTENANCE OF STANDING SEAM ROOFS
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INSPECTION PROCEDURES

Some engineers or architects do not feel that the appearance of a structural metal roof system adequately complements their architectural statement. They reduce or eliminate casual visual exposure by specifying low slopes and sight barriers such as facades. In addition, a catch phrase in the metal roofing industry is "maintenance-free". All too commonly, the result is an out-of-sight, out-of-mind syndrome, steeped in a false sense of indestructibility. This cavalier neglect usually lasts until the first serious performance problem develops, and the owner discovers that maintenance is anything but free.

An examination of relevant historical data seems to indicate that the maintenance-free roof has not yet been developed. Maintenance requirements are, at best, periodic and, at worse, litigated. All roofs, metal or otherwise, should be inspected on a regular basis.

The first inspection should be made with the contractor and designer immediately upon completion of the building. It gives the owner an immediate basis for comparison. Does this new installation look like the role model on which the original choice was based? Is the workmanship professional, especially at the joints? Has the contractor performed his housekeeping properly? No loose material should be left on the roof, including metal trimmings, tools, extra material, metal shavings, metal particles, or mud. Every panel should have a wiped clean appearance. Gutters should be checked as well. All handling damage should be repaired to the point of being unnoticeable. Finish integrity should be properly restored in all mechanically or chemically distressed areas. It is much easier to get these things rectified before, rather than after, the contractor leaves the site. If everything is in order and the building does not develop immediate leaks, the owner has a clear picture of what a sound, weather tight installation should look like. Photographs of critical areas will preserve this impression for future comparison. After this initial acceptance inspection, regularly scheduled check-off inspections should be incorporated into an overall building maintenance program. Check-off inspections should take place every 6 months. Supplemental inspections should also be made immediately after a severe storm or any significant rooftop activity such as the installation of mechanical apparatus.

A roof inspection, activity, and maintenance file should be established. This file should contain all documentation pertaining to the construction and maintenance of the roof system. It should include plans, specifications, installation instructions, user manual, warranties, and any other data that may be reasonably associated with current or future roof performance. All roof inspection reports should be retained. All roof activity should be logged into the file. Each activity should be systematically documented including information as to the date, time, type, and extent of the activity and the roof area accessed or affected. Keep the file current.

A maintenance policy, even if informal, should include stipulations such as never allowing unauthorized personnel access to the roof; keeping all necessary, authorized traffic to an absolute minimum (safety considerations, however, dictate that no one should be on a roof alone); and permitting only qualified roofing experts to make any future modifications to the membrane surface, especially the cutting in of penetrations for accessories or equipment. An experienced roofer should perform even minor repairs.

Many owners prefer to contract professionals to perform periodic follow-up roof inspections. Professional inspections usually include a detailed examination of existing conditions followed by a comprehensive written report. The report should contain a description of the current condition of the roof as it relates to its life expectancy. Conditions should be cited with regard to leak potential. This
report will should be accompanied by a list of recommendations for the maintenance or improvement of the stated conditions as well as a cost estimate for their implementation. The owner can then make a knowledgeable business decision based on a cost-benefit evaluation. Many professional inspection firms offer full-service routine evaluation and repair packages that are backed by watertight guarantees.

The building owner should perform a spring and fall walkover of the roof. It must be understood that this exercise is intended to supplement a committed program for roof inspection, not substitute for it. As is the case with any technically oriented product, it may take a trained technician to recognize a potentially troublesome and costly situation. A few key conditions can be owner-evaluated and possibly corrected. These include the following:

**Roof Debris:** All debris should be swept up, picked up, bagged, and removed. If a significant deposition of airborne contaminants is noticeable, it is also a good idea to hose or mop down the surface.

**Drainage:** Inspect roof gutters and drains for debris blockage or clogs. Check fittings and splices for tightness and make sure seals are intact. Is there any evidence of ponding sediment?

**Damage:** Look for and carefully document any signs of material distress caused by wind, thermal action, roof traffic, or equipment installation. Check eave, rake, and ridge lines, side seams, end laps and penetration curbs, flashings, and trim.

**Mechanical:** Check all mechanical venting apparatus for proper operation and weather integrity.

**Fasteners:** Look for loose or missing fasteners. Note their location. Washer seals should exhibit uniform compression. There should be no splits, cracks, or spinouts.

**Closures and sealants:** Check closures and sealants at all joints for signs of moisture, sun, or contaminant degradation. Materials should be flexible and resilient. There should be no apparent voids, cracks, or insulation exposure.

**Roof sheets:** Examine the sheet surface condition for perforations, coating peels, cracks, sediment deposition, staining, and corrosion. Note the location of any aberration.

**Stains and corrosion:** Carefully document any evidence of staining or corrosion. Meticulously inspect exposed fasteners and sheet metal seam welds. Look for runoff or condensate staining. Check walls for gutter leak stains. Examine dissimilar material interfaces for sacrificial corrosion. Is there any corrosion around vent stacks? Are finishes at cut metal edges intact?

**Insulation:** Look for interior bagging or drooping and any evidence of moisture absorption. Keep accurate heating and cooling records. Energy efficient losses may be traceable to insulation saturation.

**Moisture damage:** Look for signs of masonry efflorescence or cracks and floor, wall, and ceiling stains or peeling paint.

The installer of the roof should be notified of conditions that appear to be detrimental to long-term performance.

**MAINTENANCE CONSIDERATIONS**

If designed and erected properly, a structural metal roof system will provide years of dependable service with very little physical maintenance. Many of the maintenance procedures are nothing more than a logical extension of the recommended periodic inspection process. If roof debris is present, clean it up; if drains are blocked, clear them; if drain seals are suspect, have them resealed; if accessory finishes are deteriorating, restore them; if fasteners are missing, loose, damaged, or corroded, replace them (replacement should be made with a fastener of compatible mechanical and finish properties that has a slightly thicker shaft than the original to ensure positive material engagement - i.e., a strip-out fastener); if mechanical accessories are defective, have them repaired or replaced; if HVAC runoff or condensation staining is found, provide a means of collection and channel it off the roof through plastic piping; if gaseous emission corrosion is found, raise the stack height and have the corroded surface restored.