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FREQUENTLY ASKED QUESTIONS CONCERNING THE AISI BASE TEST METHOD AND THE USE OF THE AISI ANCHORAGE EQUATIONS

Answers Provided by the AISI Task Committee on Base Test and Anchorage Questions

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Introduction

The purpose of this paper is to answer questions that have been raised by designers relative to two provisions of the 2001 North American Specification for the Design of Cold-Formed Steel Structural Members (1). Specifically those questions pertaining to the use of the "Base Test Method" for determining the strength of purlin supported standing seam roof systems and the application of the anchorage equations in Section D3.2.1 as they apply to the stability of roof systems. These items are two distinctly different design issues. Many of the questions are answered in the AISI Design Guide CF97-1 (2); however they are further clarified and modified herein.

Prior to discussing specific questions, a brief background and several comments are made relative to the Base Test Method and the Anchorage Equations.

Background and Comments on the Base Test Method:

The AISI Base Test Method was first introduced into the 1996 AISI Specification (3). In the 1999 Supplement to the 1996 Specification (4), the use of the Base Test for purlin uplift was introduced.

Section C3.1.4 of the Specification provides a method for determining the nominal positive or negative moment strength of a C-or Z- section under gravity or uplift loading in the plane parallel to the web with the top flange supporting a standing seam roof system. A positive moment is defined as a moment, which causes compression in the top flange of the purlin. A standing seam roof system is defined as a roof system in which the roof panels are secured to the purlins by means of concealed hold down clips that are mechanically interlocked with the panel side seams and are attached to the purlins with mechanical fasteners. Most insulated sandwich panels will also fall under this definition.

Section C3.1.4 specifies that the nominal positive moment or negative strength of a purlin supporting a standing seam roof system may be determined by a reduction factor times the fully restrained strength. The reduction factor, R, can only be determined experimentally using the "Base Test Method for Purlins Supporting a Standing Seam Roof System". The test method is contained in Part VIII of the AISI Cold-Formed Steel Design Manual (5). The method requires six tests of two purlin thicknesses to determine the reduction factor relationship (R versus nominal purlin strength) for a particular panel/clip/purlin depth/bracing set of parameters.

In lieu of using Specification Section C3.1.4, the Specification permits strength determination using the laterally unbraced beam provisions in Section C3.1.2.

The purpose of the Base Test Method is to determine the gravity load or uplift load moment strength of purlins supporting standing seam roof systems with specific purlin restraints. The method is not intended to determine or verify bracing strength, bracing anchorage strength, or diaphragm strength.

Tests can be conducted with:

1. Anchorage devices at the ends of both purlins.
2. Anchorage devices at the ends of only one of the purlins.
3. Discrete point bracing at interior locations along the length of the purlins.
4. Any combination of the above.
5. Purlins with their flanges opposed.

If anchorage devices are provided at the ends of both purlins in the test, then all purlins in the actual construction must have anchorage devices at their ends, of equal or greater strength and stiffness, as those in the test set-up. This requirement is due to the fact that the anchorage devices in the base test set-up may offer some in-plane end rotational restraint, and thus may affect the R-value.

Conversely, if tests are performed with anchorage devices at the supports of only one of the purlins, the as-build assembly need not necessarily have anchorage devices at every other purlin line assuming the following.

a. The purlin in the test specimen that fails is the purlin without the anchorage devices.
b. The designer establishes that the number of anchorage devices used in the as-built systems has the ability to resist the anchorage forces calculated per D3.2.1.

Testing with the purlin flanges opposed is akin to a system with virtually infinite diaphragm stiffness and it can be shown that it will always produce significantly higher R-factors. The Committee discourages testing with the purlin flanges opposed.

Comments on Purlin Anchorage:

In addition to adding Section C3.1.4 in the 1996 Specification, Section D3.2.1 "Anchorage of

Bracing for Roof Systems Under Gravity Load With Top Flange “Connected to Sheathing” was changed, so that the anchorage force equations contained in the Section can be used for standing seam roof systems as well as through fastened systems.

The AISI D3.2.1 anchorage force equations were developed in conjunction with experimental data. Tests were performed on roof systems consisting of through-fastened and standing seam steel roof panels on C and Z-shaped members. All of the tests were performed in the horizontal position, which simulates the behavior of a system on a flat roof (i.e. zero roof pitch). The original equations were originally written to be only valid for systems constructed with Z purlins, with their flanges facing up-slope. The original anchorage force equations were subsequently modified by the 1999 AISI Supplement to include roof slope effects, specifically accounting for the downslope component of the roof gravity load. The 1999 AISI Supplement also added Equation D3.2.1-1 for calculation of lateral forces for C-shapes with flanges facing up-slope or down-slope. The AISI Specification contains no provisions for anchorage of systems subjected to uplift loads. It is the consensus of the Committee that such provisions are not necessary.

The strength of the anchorage system used to stabilize C or Z purlin systems for gravity loads must always be calculated in accordance with the AISI anchorage equations. If the deflection requirements of the AISI Specification Section D3.2.1 are met, then the bracing equations in Section D3.2.1 can be used to calculate the required bracing strength and support requirements. If the deflection requirements are not met, then the bracing system must be designed using Section D3.2.2 of the Specification.

For all roof systems (both through fastened and standing seam roofs) the designer must demonstrate how the required anchorage forces are delivered to the bracing system, i.e. determine how the load in the diaphragm accumulates at an anchorage device(s).

For standing seam roof systems, it must be demonstrated that the stability forces contained in the diaphragm can be delivered into the flange of the purlin and ultimately the anchorage devices. To do so by calculations is probably impractical because the load path from the standing seam deck to an anchorage device is one that cannot be modeled analytically, thus tests are required.

If the deck is anchored at a fixed point, e.g. an eave strut system, the designer must show how the anchorage forces can be delivered to the fixed point. This can be calculated, if screws are used (through fastened roofs) between the sheeting and the fixed point.

Summary of Base Test and Anchorage Requirements:

1. The Base Test must be used to determine the gravity load and uplift load bending capacity of purlins supporting standing seam roofs, unless the purlins are designed based on discrete point bracing.

2. If the Base Test is conducted with anchorage devices at each purlin, the actual roof system must be built with anchorage devices at each purlin.

3. Anchorage requirements must be calculated for all gravity loaded cold-formed purlin systems. Note: This statement supersedes Test Condition 8 as given on page 21 of the AISI Design Guide CF97-1.
4. For standing seam roof systems, tests must be conducted to determine the ability of the gravity load bracing forces to be transferred from the roof sheeting into the purlin at the anchorage device locations, except for cases where the paneling is through-fastened at the location of the anchorage device, where calculations can be made to determine force transfer adequacy.
5. To use the AISI Specification anchorage equations (Section D3.2.1), diaphragm strength and stiffness values must be known for the sheeting system, and the stiffness requirements of section D3.2.1 must be met.

Base Test Questions:

1. The Base Test Method is performed in a horizontal position (i.e. zero roof pitch). Is it necessary to account for the effects of roof pitch in the actual roof system?

   Answer: The Base Test only provides an R-value for the moment capacity of the purlins. The effects of roof pitch are accounted for in the bracing requirements for the purlin system using either Sections D3.2.1 or D3.2.2.

2. Can discrete bracing be placed in the purlins as part of the "system" without anchoring these braces, as long as one tests and supplies the same condition?

   Answer: Yes.

3. The Base Test Method requires the "longest purlin" to be tested. Can one deviate from testing the longest purlin to be supplied in a system?

   Answer: Yes, but the deviation in length should not be more than ten percent of the length tested.

4. Since the Base Test Method requires the use of the "longest purlin", it seems excessively conservative to use the same discrete bracing pattern e.g.- 1/3 points) for a 30 ft bay as well as a 15 ft bay in the field. Can the bracing requirements be reduced for the shorter bay without testing?

   Answer: No. Criteria does not exist, as of yet, to permit this type of extrapolation.

5. If the Base Tests are conducted with the purlins facing the same direction and

   (a) Anchorage devices are used on one purlin in the test, or
   (c) Anchorage devices are used with both purlins in the test,

is the diaphragm strength a consideration in the actual constructed system?

Answer: Yes, calculation of anchorage requirements in accordance with Section D3.2.1 is required.

6. The Base Test Method allows the test to be conducted using an edge angle with the ends restrained from moving horizontally. If the Base Tests are conducted in this manner does the eave strut in the actual system need to be prevented from moving horizontally at its ends?

Answer: Yes. Calculations or tests must be provided that the eave anchorage system has the capability to resist the anchorage equation forces for all of the purlins relying on the eave condition. It must also be demonstrated that the system is able to transfer the anchorage force to the eave strut anchorage points.

7a. Is the 3x3x1/4 angle as described in the Base Test Method the maximum size angle that can be used for testing?

Answer: Yes.

7b. Can a smaller angle be used in the test?

Answer: Yes,

8. Should the results of base tests with “low” strength sections ($F_y < F_y$ design) be used?

Answer: No, the steel yield used must be at least equal to the design yield of the purlins.

9. Can a base test be run with 4 to 5 continuous spans?

Answer: No, the AISI Specification requires the Base Test Method.

10. The failure load calculation described in Section 8.1 of the Base Test Method contains the term $2P_L(d/B)$. The statics behind this term indicate that the “downhill” purlin will be the more heavily loaded of the two. If a given test results in failure of the opposite purlin should the factor be applied?

Answer: No, the failure of the “uphill” purlin is probably a result of other factors such as differences in geometry or material properties.

11. If a manufacturer has several clip types, purlin flange widths, and panel thicknesses, the number of required base tests can be significant. Is there a procedure so that number of required tests is reduced?

Answer: Yes. A procedure has been developed at Virginia Tech to reduce the number of base tests for when the inventory consists of different clip types, a specific purlin depth and profile but with different flange widths, and identical panel profiles except for thickness. The procedure results in conservative values for all combinations of clip type, purlin flange width and panel thickness. See the Appendix for a detailed description of the procedure.

Anchorage Questions:

1. Can the Base Test Method results be used to determine if the anchorage system in the actual system is adequate?

   Answer: In general no; however, the test results can be evaluated to determine a conservative force that can be transferred into the anchorage system provided in the test. Anchorage calculations per Sections D3.2.1 or D3.2.2 of the AISI Specification are still required for the design of a roof system.

2. If intermediate bracing is used in the base tests and not anchored in any way, are the requirements of Sections D3.2.1 or D3.2.2 required for the design of the bracing?

   Answer: No. Bracing that is not anchored does not constitute a diaphragm boundary/collector, and as such it will not accumulate forces.

3. Is the L/360 requirement computed at service loads or factored loads?

   Answer: Service loads. The AISI Design Manual CF97-1 indicates that one should use factored loads; however, it is the opinion of the committee that service loads should be used.

4. The Base Test Method uses a simple span system to model continuous system behavior. Does this procedure account for the fact that the anchorage devices in continuous systems are subjected to loads from adjacent bays (except at the end bays)?

   Answer: No, the Base Test Method does not evaluate the strength of the actual roof anchorage system. The anchorage requirements must be determined from the Specification requirements.

5. The AISI Specification equations in Section D3.2.2 are not adjusted for the “slope component” (like those in Section D3.2.1). Should they be adjusted?

   Answer: Yes. Equations in Section D3.2.2 can be adjusted for the slope load components by adjusting the load in the plane of the purlin web using the Cosine function and subtracting the down-slope load using the Sine function.

6. Why is the 1.5 factor applied to K' in D3.2.2 (a)?

   Answer: The 1.5 factor was used as a conservative number to cover continuous systems where the interior support forces are larger than those of simple span systems.

7. If the Base Tests are conducted with one of the purlins restrained at its ends (anchorage devices), can the manufacturer then use anchorage devices on every 10th purlin rather than every other purlin in a roof system?

   Answer: Yes, but the designer must demonstrate that an adequate load path exists to transfer the diaphragm forces for the 10 purlin system into the anchorage device and into the support structure to which the anchorage device is attached. This load path is difficult to evaluate analytically. Therefore, testing for standing seam roofs is required. Calculations can be made for through fastened roof systems.

8. The AISI Specification appears not to permit "floating" bracing systems; that is, out-of-plane bracing that is not anchored. Are floating systems permitted?

   Answer: Yes, if the Base Test Method is used to determine purlin capacity.

9. If anchorage devices are used at every purlin, is there a need for a diaphragm test?

   Answer: Yes. When the anchorage equations from the AISI Specification Section D3.2.1 are used to determine the bracing requirements, diaphragm strength and stiffness characteristics are necessary parameters in the evaluation.

10. The anchorage force equations in Section D3.2.1 appear to be conservative for high pitch roofs. Is this true?

    Answer: Yes, research is currently being conducted to eliminate the conservatism.

11a. If anchorage devices are at the eave and at mid-slope between the eave and ridge, how much gravity load is used for the P_L calculation for each?

Answer: One-half of the slope load

11b. What is n_p for each anchorage device?

Answer: The number of up-hill purlins between the eave purlin and the up-hill purlin with the anchorage devices at the eaves, and the number of purlins between the mid-slope purlin and the ridge for the mid-slope anchorage devices, (i.e. for this case n_P is same for both anchorage devices). The AISI anchorage forces determined from Section D3.2.1 are a function of the anchorage device location.

12. Can anchorage and on-slope forces (forces down slope (in the plane of the roof) due to gravity loads) be divided between discrete braces and stiffened purlin clips and how?

    Answer: Yes, The distribution between discrete bracing and bracing at the supports is not contained in the Specification, thus rational analysis must be used. The designer must demonstrate that an adequate load path exists to transfer the diaphragm forces into the stiffened purlin clips and into the support structure to which the stiffened purlin clips are attached. This load path is difficult to evaluate analytically. Therefore, testing for standing seam roofs is required. Calculations can be made for through fastened roof systems.

13. Can a portion of the anchorage/on-slope force be "self canceling" at the ridge condition with the balance taken at frame supports?

    Answer: Yes, but a defined force path must be demonstrated.

14. Can a portion of the anchorage/on-slope forces be carried across the ridge condition to be resisted by anchors on the opposite slope?

    Answer: Yes, but a defined force path must be demonstrated.

15. Can a portion of the anchorage/on-slope forces be resisted at each purlin line (by standard purlin clips) and the balance resisted by one or two stiffened purlin clips?

    Answer: Yes, but the designer must demonstrate that an adequate load path exists to transfer the diaphragm forces into the stiffened purlin clips and into the support structure to which the stiffened purlin clips are attached. The relative stiffness of the two different anchorage devices must be taken into account in this evaluation. This is difficult to evaluate analytically, particularly for standing seam roof systems. Therefore, testing for standing seam roofs is required. Calculations can be made for through fastened roof systems.

16. A single support anchorage device capacity is exceeded by the P_L value based on Specification Section Equation D3.2.1-5. Can a second support anchorage device be added to the adjacent purlin line with no further analysis?

    Answer: Yes. However, proof must still be shown that the required anchorage force can be delivered into the added support anchorage device. It is the committee's opinion that two adjacent anchorage devices can be considered as one; however, no more than two adjacent devices can ever be considered as one.

17. If there are 80 purlin lines on a slope and 4 anchorage devices are equally spaced, is "n_p" = 20 and "W" = 25% of the total tributary load?

Answer: Yes.

18. If an endbay is discretely braced and interior bays are “end support anchored” what is the load to the anchorage device at the 1st intermediate frame line?

Answer: Use engineering judgment.

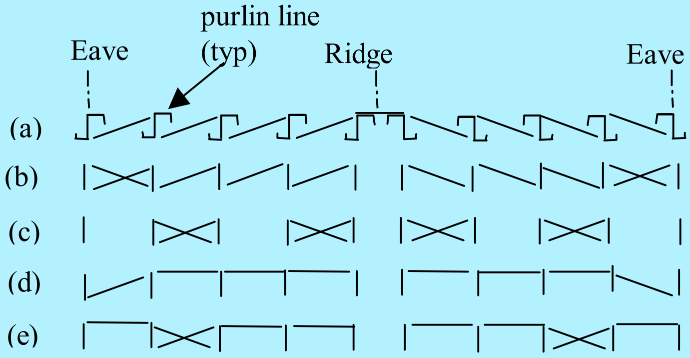
19a. How is an anchorage device force at an endwall with an overhang computed?

Answer: Calculate P_L for the endwall frame and add P_L for the cantilever by assuming the cantilever span is a simple span with the span equal to twice the cantilever length and anchorage devices at each end.

19b. How is the deformation requirement computed for the cantilever span?

Answer: Use the same assumption as for the load as given in 19a.

20. Do the anchorage and on-slope forces “self-cancel” with any of the following intermediate brace configurations?



Answer: No.

21. “There are no code requirements for down-slope forces.” (True or False)

Answer: False. The anchorage equation also provides the down-slope forces.

22. How do you analyze anchorage forces for a system that uses a few “reversed’ purlins to offset the roll of the rest?

Answer: The interaction between uphill and downhill purlins has not been studied. Conservatively, the required anchorage forces can be calculated using, as an example,

$$P_L = C_{tr}\left[\alpha \frac{0.053b^{1.88}L^{0.13}}{n_p^{0.95}d^{1.07}t^{0.94}}Cos(\theta) - Sin(\theta)\right]W \qquad (Eq.\ D.3.2.1\text{-}5)$$

Where: α = +1 for up slope oriented purlins
α = -1 for down slope oriented purlins

Equation D.3.2.1-5 is to be evaluated for the number of up slope purlins and again for the number of down slope purlins. The net anchorage force is then:

$$P_{L(NET)} = P_{L(UP)} - P_{L(DOWN)}$$

23a. What is n_P for determining the anchorage force for a system with anchorage devices at every purlin?

Answer: Four.

23b. Is the 1.1 factor applied to each purlin in determining the anchorage force?

Answer: Yes.

24. Do the roll forces for back-to-back lapped “C” sections self-cancel at the supports?

Answer: Yes. However, the down-slope forces do not cancel.

25. Should eave strut roll be added to the accumulated force in open sidewall buildings?

Answer: Yes.

26. What length of diaphragm perpendicular to the purlins can be considered to deliver an accumulated roll force to a single anchorage device location?

Answer: The length of the diaphragm is generally not the controlling limit state. The connection (load path) between the diaphragm and the anchorage device will generally control the design.

27. For through fastened roof systems, what length along the purlins can be considered tributary to the anchorage device for the purpose of checking the transfer force?

Answer: Without a refined analysis, it would seem reasonable to use one foot on each side of the anchorage device. Thus, if screws were spaced between the panel and the purlins at twelve inches on center, then 3 screws could be used at interior frame locations and 2 screws for endwall conditions. If required, additional screws could be added within the one-foot length.

References:

(1) American Iron and Steel Institute (2001), "North American Specification for the Design of Cold-Formed Steel Structural Members", Washington, DC.

(3) American Iron and Steel Institute (1997), " A Guide for Designing with Standing Seam Roof Panels", Design Guide CF97-1, Washington, DC.

(4) American Iron and Steel Institute (1996), "Specification for the Design of Cold-Formed Steel Structural Members", Washington, DC.

(5) American Iron and Steel Institute (1999), "Specification for the Design of Cold-Formed Steel Structural Members, Supplement No. 1, 1999", Washington, DC.

(5) American Iron and Steel Institute (2002), *Cold-Formed Steel Design Manual*, Washington, DC (to be published).

APPENDIX
Procedure for reduced number of Base Tests

The following example illustrates the procedure to be used to reduce the number of Base Tests: It is assumed that a manufacturer has three clip types, two flange widths for each purlin depth and profile, and two nominally identical panel profiles rolled in two gages, the following procedure will result in a R-value relationship for all combinations with relatively few base tests. This proposed procedure assumes that the combination of one panel thickness, one clip type, and the purlin cross section with the narrower flange width results in the lowest R_t-value for all other combination of parameters. The procedure is:

- The clip type, which is thought to result in the lowest R_t-value, is selected.
- Using this clip type, the thinner panel, and the purlin with the narrow flange width, two base tests are conducted for one depth purlin of the same nominal cross-section. One base test is conducted with the thinnest purlin and one test with the thickest purlin in the inventory.
- With the R_t-values from the two tests a trend line is found. Depending on the details of the system, the trend line can have either positive or negative slope.
- To verify the choice of clip, two additional tests are conducted using the purlin thickness that resulted in the lower R_t-value, one with each of the other two clip types. If the original clip type does indeed result in the lowest R_t-value, the choice of clip type is verified.
- If the original clip does not result in the lowest R_t-value, a test using the clip with the lowest R_t-value and the other purlin thickness is conducted.
- Knowing the controlling clip type, two additional tests are required to validate the choice of panel thickness: one test is conducted using the controlling clip-type, the thinner purlin and the other panel thickness; the other test is conducted using the selected clip-type, the thicker purlin thickness and the other panel thickness.
- Using the combination of clip-type and panel thickness, which resulted in the lowest R_t-value for the two-purlin thicknesses, the remaining four tests required for the Base Test Method are then conducted and the R-value relationship is developed.

Using the proposed reduction procedure and assuming only one purlin depth and one purlin cross-section, the minimum required number of tests, for an inventory with three clip types, two flange widths, and two panel thicknesses, is:

2 – Tests with the initial clip type assumption to determine slope of the trend line (one thin and one thick purlin).
2 – Tests to confirm initial clip-type selection (two remaining clip types).
2 – Tests to determine panel thickness trend (with controlling clip type).
4 – Tests required to satisfy the requirements of the Base Test Method.

That is, 2 + 2 + 2 + 4 or 10 tests. Thus, the required number of base tests is reduced from 78 tests to 10 tests, best-case scenario. The worst-case scenario requires 14 tests.