TECHNICAL NOTE $5.00

On Cold-Formed Steel Construction

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ROOF FRAMING ANCHORAGE FORCES: MWFRS or C&C

Summary: This Technical Note defines the two levels of force and discusses the effects of using Component and Cladding (C&C) loads versus Main Wind Force Resisting System (MWFRS) calculated uplift loads. Design examples are provided to indicate the difference in roof-to-wall anchorage force for either type of load. Mainstream reference standards and quotes from field experts are cited when discussing the appropriate levels for calculating the uplift forces.

INTRODUCTION

The 2006 *International Building Code* Section 1609.1.1 requires wind loads to be calculated on every structure, and the wind loads are to be in accordance with *ASCE 7-05* Chapter Six. Uplift forces calculated for roof framing to wall connections are often determined using Component and Cladding (C&C) as opposed to Main Wind Force Resisting System (MWFRS) level forces. This Technical Note will define the two levels of force and discuss the effects of using C&C loads versus MWFRS calculated uplift loads. Design examples will be provided to indicate the difference in roof-to-wall anchorage force for either type of load. Furthermore, mainstream reference standards and quotes from field experts will be cited when discussing the appropriate levels for calculating the uplift forces.

Additional discussion will be provided regarding the responsibility of the Engineer of Record and Truss Engineer to calculate the roof-to-wall uplift forces, the level of forces to be used and which one is to specify the anchorage connector. Finally, discussion of measures to ensure the appropriate uplift forces are used will be provided.

MAIN WIND FORCE RESISTING SYSTEM / COMPONENTS AND CLADDING

When determining wind pressures on a structure, the designer must calculate the pressures that apply forces to the MWFRS such as frames, shearwalls and diaphragms and to the C&C of the structure. However, it may be unclear to which category certain elements of a structure resisting wind loads should be assigned. This is often the case when determining roof-to-wall anchorage forces.

Section 1604.8.1 of the 2006 IBC states "Anchorage of the roof-to-walls and columns, and of walls and columns to foundations, shall be provided to resist the uplift and sliding forces that result from the application of the prescribed loads." Although this roof-to-wall anchorage section is clear that anchorage is required, the section is not well codified as to which 'prescribed' load level, MWFRS or C&C, is appropriate. Consequently a clearer understanding of MWFRS and C&C gleaned from commentary of leading professionals and mainstream reference standards is needed to make this determination.

MAIN WIND-FORCE RESISTING SYSTEM (MWFRS)

ASCE 7 section 6.2 defines Main Wind-Force Resisting Systems as "an assemblage of structural elements assigned to provide support and stability for the overall structure. The system generally receives wind loading from more than one surface." A discussion of the assemblage of structural elements in this definition is provided in the commentary to this section in ASCE 7.

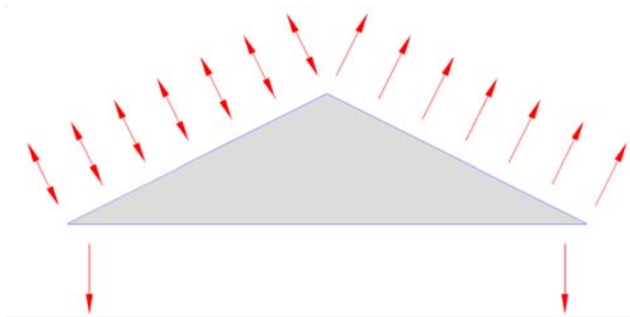
The commentary to the ASCE 7 MWFRS definition in section 6.2 states that it "can consist of a structural frame or an assemblage of structural elements that work together to transfer wind loads acting on the entire structure to the ground. Structural elements such as cross-bracing, shear walls, roof trusses, and roof diaphragms are part of the Main

Wind-Force Resisting System (MWFRS) when they assist in transferring overall loads."

There are two main points in these sections that indicate using the MWFRS level loads for roof-to-wall connection forces.

- First, the commentary clearly states that MWFRS are an assembly of elements (e.g. roof trusses) that transfer loads acting on the structure to the ground. Roof trusses in this commentary could be listed as they often resist drag and chord forces when they are used as part of an overall shear resisting system. However, it can also be seen that roof-to-wall uplift connections are developed through an assembly of roof framing members transmitting forces acting on the entire roof, and this uplift force must transfer down the load path to the foundation of the structure.

- Secondly, ASCE 7 states that the MWFRS generally receives load from more than one surface. Evidence of roof framing and ultimately the wall anchorage receiving loads from more than one surface can be seen by the dual-slope roof detail below.



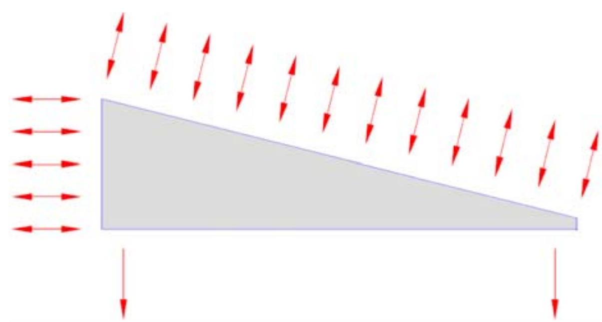
The roof to wall anchorage forces in the detail shown are based on positive or negative pressures on the windward side and negative pressures on the leeward side of the roof being analyzed. These anchorage forces are generally determined by resolving moments about each end on a two point bearing truss. Upon inspection of this detail it is clear that the forces are generated from loads occurring on more than one surface of the truss which is the stated definition of MWFRS.

Often, designers use roof to wall connections to resist not only roof uplift forces, but also out of plane lateral loads from walls directly below or in plane shear loads from the diaphragm. When a roof to wall connector is used to resist multiple loads occurring simultaneously, connector manufacturers require a unity check be performed on the connector. The unity check is an equation that is a sum of the demand/capacity ratios set equal to one (1). When checking unity on the connectors, it would not be appropriate to combine demand forces of differing levels such as MWFRS and C&C. Unity should be analyzed with all MWFRS or C&C loads.

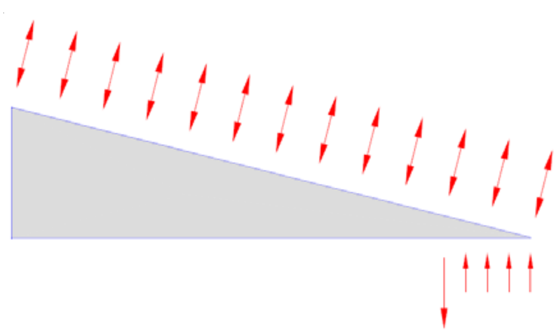
Out of plane lateral loads on walls are determined using C&C level equations. When designing the connector to resist loads from multiple sources, it falls under the MWFRS definition. Therefore lateral force wall connections, roof to wall uplift connections and diaphragm to wall shear connections resisted by the same connector should be determined by MWFRS loads. Alternatively, if additional clips or fasteners are provided at roof framing connections to resist the wall lateral loads and a roof to wall uplift connector for uplift, then the alternate clip or fasteners should be designed with C&C loads and the uplift connectors designed for MWFRS on the dual slope roof.

MONO-SLOPE ROOF

It may be argued that mono-slope roof assemblies do not follow this same load analysis and therefore do not receive load from more than one surface and wall anchorage forces must be designed using C&C level forces. A detail of a mono-slope truss is shown. The wall anchorage forces in the detail are derived by solving moments about the two point bearing truss using positive or negative pressures along with the horizontal pressures on the roof. The wall anchorage forces generated are clearly from loads occurring on more than one surface of the truss.



Taking this discussion one step further and looking at jack trusses on a hip roof, it appears that loads on more than one surface do not apply. That argument may be true for jack trusses without an overhang. Jack trusses (or rafters) with an overhang will experience loads from more than one surface and also meet the definition of MWFRS.



Finally, ASCE 7 reference standard states that the MWFRS *generally* receives load from more than one surface. It does not state that it "shall" receive load from more than one surface. The use of "generally" in this statement softens the definition in the reference standard and allows for exceptions to this requirement.

The use of MWFRS level forces for roof-to-wall connections has precedence with several mainstream reference standards and leading professionals including:

1. The SBCCI *Standard for Hurricane Resistant Residential Construction* (SSTD 10-99) Appendix B, section B1.1 states "Design of the following structural systems and connections were based on the coefficients given in Tables 1606.2B and 1606.2C for MWFRS." **The fifth item listed for these structural systems with MWFRS load is rafter and truss connectors to walls, bond beams or wood top plates.** SSTD10-99 has been re-written by ICC and published as ICC-600 (Standard for Residential Construction in High Wind Regions). This new state of the art standard uses the same analysis for these connections as SSTD10.

2. The AISI *Standard for Cold-Formed Steel Framing Prescriptive Method for One and Two Family Dwellings*, table F7-1 (Required Uplift Capacity for Roof Truss or Rafter to wall) is derived from MWFRS loads as confirmed by Dr. Roger LaBoube and Dr. Sutton Stephens. Dr LaBoube and Dr. Stephens are currently authoring the commentary to this prescriptive standard.

3. The *2006 International Residential Code* (IRC), table 802.11 (Required Strength of Truss or Rafter connections to resist Wind Uplift Forces) is based on Figure 6-2 in ASCE 7 as stated in note 'e' under the table. ASCE 7 Figure 6-2 is a table of design wind pressures for Main Wind Force Resisting Systems.

The references cited above are not opinions, but rather published reference standards that are established through years of analysis and wind tunnel testing. There are other references regarding this issue from leading professionals that may be seen as an engineering judgment or opinion. One such reference is from an article titled, *Wind Loading for Roof Trusses using ASCE Standard* by Charles Hoover Jr., P.E. and Dr. James McDonald, P.E. (May 1997). It states, "the MWFRS load cases produce reactions on the trusses that are resolved into vertical and horizontal components. The horizontal component is collected and resisted by the roof diaphragm. This diaphragm load is then transferred to the shear walls. **The vertical MWFRS component is the uplift at each truss bearing that is used to design the connection between the roof truss and the supporting structure.**"

COMPONENTS AND CLADDING (C&C)

ASCE 7 section 6.2 defines Components and Cladding as "Elements of the building envelope that do not qualify as part of the MWFRS." This definition is not very helpful and further review of the commentary to this section is necessary.

According to the commentary for the C&C definition, components receive wind loads directly or from cladding and transfer the load to the MWFRS, while cladding receives wind loads directly. Roof covering would be an example of *cladding*. The negative pressures on the roof covering and its fasteners would be calculated according to C&C level loads.

An example of a structural element designed for both MWFRS and C&C would be roof decking. When checking out of plane loads on the roof deck, one should use C&C level forces, while the use of MWFRS level loads would be appropriate for the diaphragm design. An example of a *component* would be members of a roof truss (truss chords or webs). The components or members of a roof truss receive wind load from the cladding and therefore each component of a truss would be designed according to C&C level forces.

MWFRS VS. C&C

It may seem counterintuitive to design truss webs and chords for C&C loads and uplift connections for lower MWFRS loads. A synopsis of Applied Technology Council's SEAW/ ATC 60 *Commentary on Wind Code Provisions* Section 8.7.1.6, explains that patterns and variations in wind pressures differ along all surfaces of a building. When one is analyzing a member that is resisting pressures in a localized area then C&C level loads more accurately reflect these localized pressures.

C&C loads will become more like MWFRS loads over large areas and one may even use MWFRS loads when the tributary area is greater than 700 square feet. With the many variations in wind pressures over the roof span, this tributary area reduction method of C&C loads does not go far enough to average the applied varying pressures. A reduction in design level forces based on the multi-surface pressures or MWFRS loads more accurately captures this variation. This variation in pressures is captured in wind tunnel testing and is the basis for this argument.

Alternatively, the ATC 60 document provides support for the use of C&C loads at roof uplift connections. Section 8.7.1.6 further states "wind load combinations that include strut loads and uplift on the body of a roof purlin would be designed using MWFRS loads. For a load case where it is just receiving wind uplift, it would be designed using C&C loading." In this case, the reference to a roof purlin suggests a horizontal member not experiencing forces from multiple surfaces.

ENGINEER OF RECORD AND TRUSS ENGINEER/DESIGNER

Currently, the most popular method of light roof framing design is to allow the Truss Engineer/Designer to provide a design for roof trusses. The ANSI standard for *Cold-Formed Steel Framing Truss Design* requires the designer's drawings to provide all reactions on the truss. (Reference Section B1) Furthermore, the standard requires the truss designer to provide all truss to truss, truss ply-to-ply and field assembly of truss connection requirements. The roof-to-wall connection is not included in this list of requirements. Section B2 of the standard requires the Engineer of Record to design and detail all truss supports and anchorage.

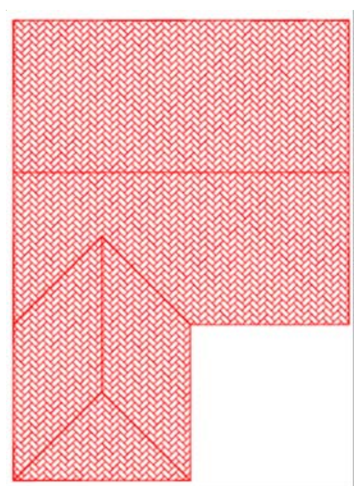
A conflict may often arise when the truss details include end reactions, as required by the standard, using C&C level forces, while the Engineer of Record may have calculated the roof-to-wall anchorage forces using MWFRS level loads.

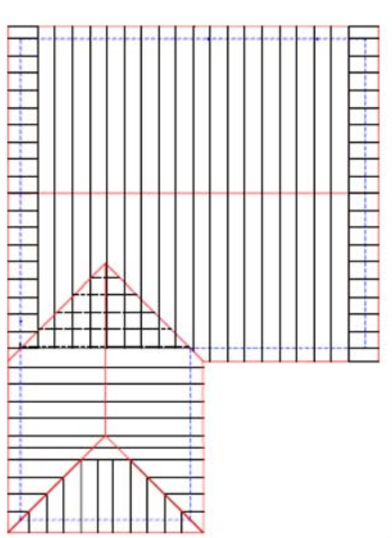
Building departments faced with this conflict in loads may require the truss detail anchorage forces be used in lieu of the Engineer of Record design forces. This should not be the case since the Engineer of Record is responsible for the connection as required in Section B2 of the Cold-Formed Steel standard. The Engineer of Record may decide to use the truss design anchorage forces, but any discrepancies in force must be resolved by the Engineer of Record.

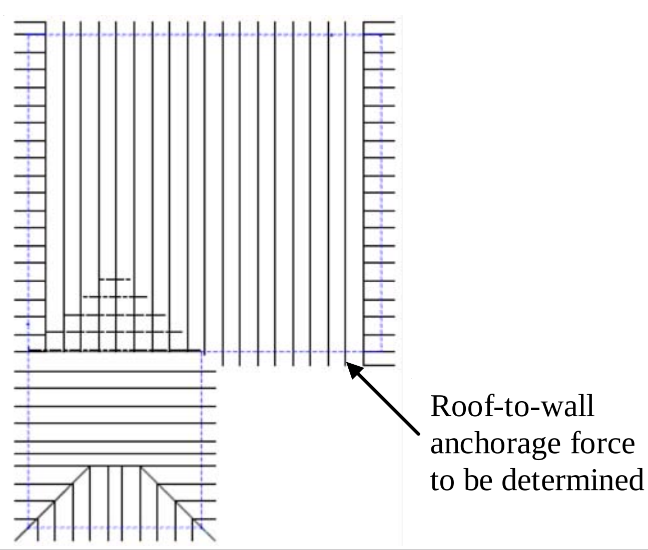
It is highly recommended that the Engineer of Record develop a relationship with the Truss Designer to provide details that include end reactions based on MWFRS level loads and the truss components design using C&C. Moreover, the Engineer of Record should resolve any difference in the forces as calculated by themselves and the Truss Designer. Using the higher C&C level forces can significantly impact the cost of the roof-to-wall anchorage connections.

DESIGN EXAMPLE

An example of the level of forces for the two component classifications for a common roof truss of a residential structure is provided below.







DESIGN EXAMPLE *(CONTINUED)*

Design Criteria:

2-story home	Roof Span 36'
25' mean roof height	Trusses @ 2' o.c.
Roof Slope of 6:12	18" Eave and 1' Gable Overhangs
Gable Roof	Plate Heights: 10' 1st; 9' 2nd
Exposure B	End Zone Width = W/10 = 40'/10 = 4'
Basic Wind Speed =120mph	Importance Factor = 1.0
Roof Dead Load = 12 psf (Roof/Ceiling)	Enclosed Building

Note: The load combination of 0.6D + W will be used to determine wall anchorage forces.

Using the Low Rise Provisions of ASCE 7 section 6.5.12.2.2 for MWFRS and resolving the moments about the two-point bearing common truss, the maximum end zone uplift reaction with a positive internal pressure coefficient is calculated at 546 lbs by summing the moments about the leeward roof-to-wall intersection as shown below.

$$p = q_h[(GC_{pf}) - (GC_{pi})]$$ equation 6-18

Where,

q_h = velocity pressure evaluated at the mean roof height

(GC_{pf}) = external pressure coefficient, Figure 6-10

(GC_{pi}) = internal pressure coefficient, Figure 6-5

GC_{pi} = +/- 0.18

$q_h = 0.00256K_zK_{zt}K_dV^2I$ (equation 6-15)

K_z = 0.7 (Table 6-3)

K_{zt} = 1.0 (section 6.5.7.2)

K_d = 0.85 (Table 6-5)

V = 120 mph

I = 1.0 (residential structures)

$q_h = 0.00256\ (0.70)(1.0)(0.85)(120)^2(1.0) = 21.93$ psf

From Figure 6-10, Interior Zone & Wind Parallel to Ridge (Roof angle = 0-5°)

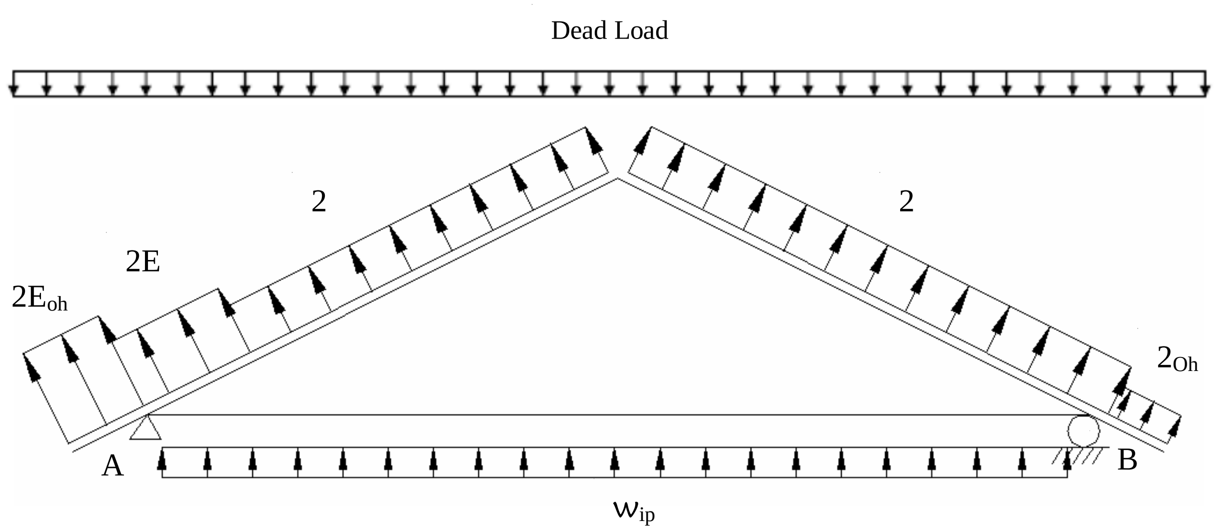
Zone 2: GC_{pf} = -0.69

Zone 3: GC_{pf} = -0.37

Windward Overhang GC_{pf} = [0.85(-0.8) + -0.69 (Figure 6-10)] (reference Section 6.5.11.4.1)

Leeward Overhang GC_{pf} = -0.69

Internal Pressure GC_{pi} = -0.18



DESIGN EXAMPLE *(CONTINUED)*

Roof Pressures

$2E_{Oh}$ = 21.93(0.85(-0.8) -1.07) = -38 psf
2E = 21.93(-1.07 -0.18) = -27 psf
2 = 21.93(-0.69 -0.18) = -19 psf
2_{Oh} = 21.93(-0.69) = -15 psf

Vertical and Horizontal roof forces:
$V2E_{Oh}$ = -38(1.5) = -57 lbs
V2E = -27(7.2) = -194 lbs
$V2_A$ = -19(36/2 – 7.2) = -205 lbs
$V2_B$ = -19(36/2) = -342 lbs
$V2_{Oh}$ = -15(1.5) = -23 lbs
$H2E_{Oh}$ = -38(1.5)(6/12) = -29 lbs
H2E = -27(7.2)(6/12) = -97 lbs
$H2_A$ = -19(36/2 – 7.2)(6/12) = -103 lbs
$H2_B$ = -19(36/2)(6/12) = 171 lbs
$H2_{Oh}$ = -15(1.5) (6/12) = -11 lbs

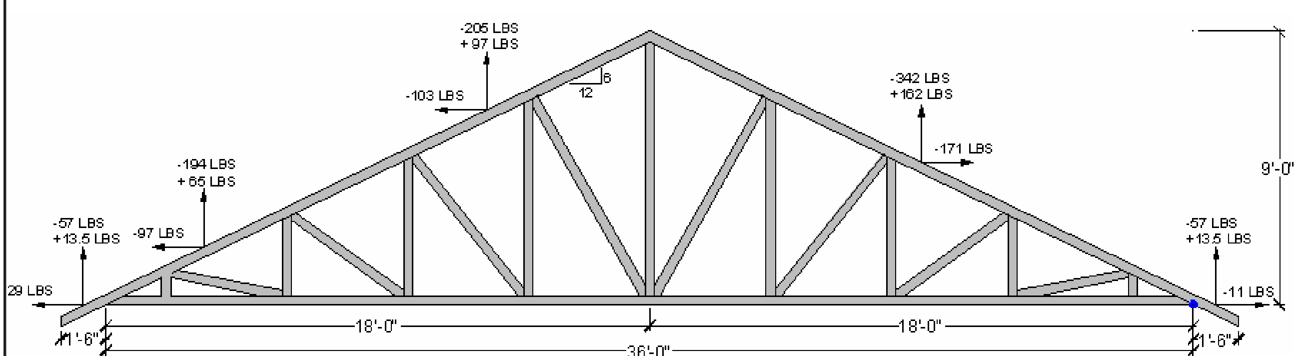
The Dead Load of the roof is: (Using governing load combination 0.6D + W)
$R2E_{Oh}$ = 9(1.5) = 13.5 lbs
R2E = 9(7.2) = 65 lbs
R2A = 9(36/2-7.2) = 97 lbs
R2B = 9(36/2) = 162 lbs
$R2_{Oh}$ = 9(1.5) = 13.5 lbs

Summing the moments about the point shown:

ΣM_B = 0 = [-57 + 13.5][0.75+36] + [-194 + 65][36-7.2/2] + [-205+97][(18-7.2)/2 +18] + [-342+162][9] – [-57 + 13.5][0.75] + [-29(0.375)] - [-97(1.8)] - [-103(6.3)] + [-171(4.5)] - [-11(0.375)] – 36R

R_{plf} = -273 lbs

$R_{2\ feet}$ = 546 lbs / truss



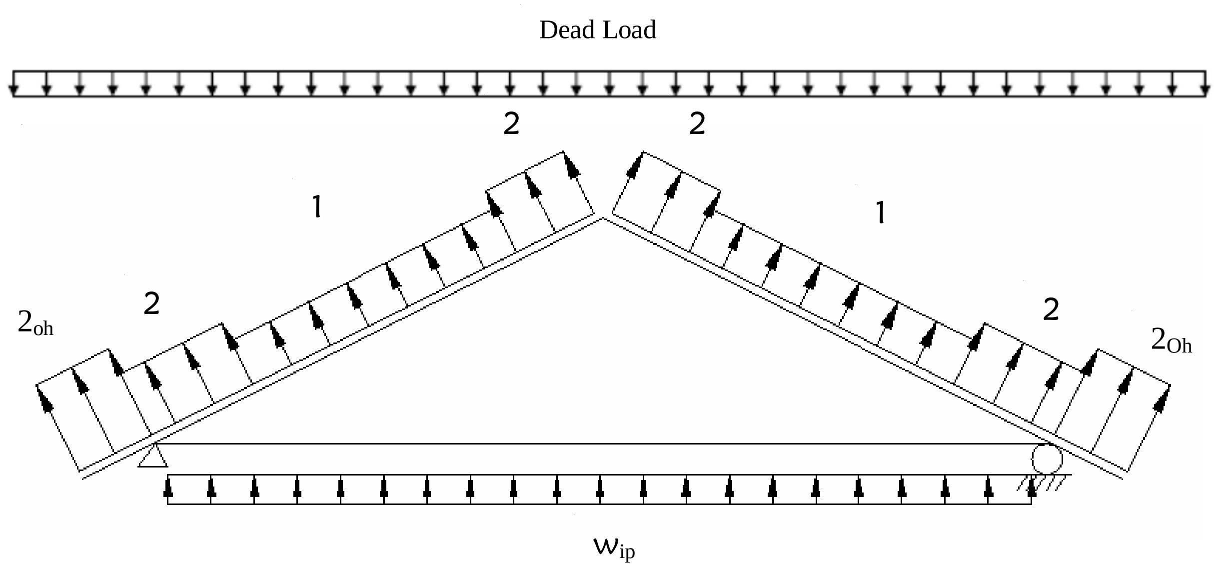
DESIGN EXAMPLE *(CONTINUED)*

In comparison, using the Low Rise Provisions of ASCE 7 section 6.5.12.4 for C&C and resolving the moments about the simple span common truss, the maximum interior zone uplift reaction with a negative internal pressure coefficient is calculated at 725 lbs as tabulated below.

$p = q_h[(GC_p) - (GC_{pi})]$ equation 6-22

Where qh = velocity pressure evaluated at the mean roof height
(GCp) = external pressure coefficient, Figure 6-11C (Based on 78 ft² of effective area)
(GCpi) = internal pressure coefficient, Figure 6-5
GCpi = +/- 0.18
qh = $0.00256 K_z K_{zt} K_d V^2 I$ (equation 6-15)
Kz = 0.7 (Table 6-3)
Kzt = 1.0 (section 6.5.7.2)
Kd = 0.85 (Table 6-5)
V = 120 mph
I = 1.0 (residential structures)
q_h = 0.00256 (0.70)(1.0)(0.85)(120)²(1.0) = 21.93 psf
a = 3.6 feet

From Figure 6-11C, Interior Zone
Zone 1: GC_p = -0.8
Zone 2: GC_p = -1.3
Overhang GC_p = -2.2
Internal Pressure GC_{pi} = -0.18



Roof Pressures

2_{Oh} = 21.93(-2.2) = -48 psf
2 = 21.93(-1.3 -0.18) = -32.5 psf
1 = 21.93(-0.8 -0.18) = -21.5 psf

DESIGN EXAMPLE *(CONTINUED)*

Vertical and Horizontal roof forces:
$V2_{OhA}$ = -48(1.5) = -72 lbs
V2A = -32.5(3.6) = -117 lbs
V1A = -21.5(36/2 – 7.2) = -232 lbs
V2A = -32.5(3.6) = -117 lbs
V2B = -32.5(3.6) = -117 lbs
V1B = -21.5(36/2 – 7.2) = -232 lbs
V2B = -32.5(3.6) = -117 lbs
$V2_{OhB}$ = -48(1.5) = -72 lbs
$H2_{OhA}$ = -48(1.5)(6/12) = -36 lbs
H2A = -32.5(3.6)(6/12) = -59 lbs
H1A = -21.5(36/2 -7.2)(6/12) = -116 lbs
H2A = -32.5(3.6)(6/12) = -59 lbs
H2B = -32.5(3.6)(6/12) = -59 lbs
H1B = -21.5(36/2 -7.2)(6/12) = -116 lbs
H2B = -32.5(3.6)(6/12) = -59 lbs
$H2_{OhB}$ = -48(1.5)(6/12) = -36 lbs

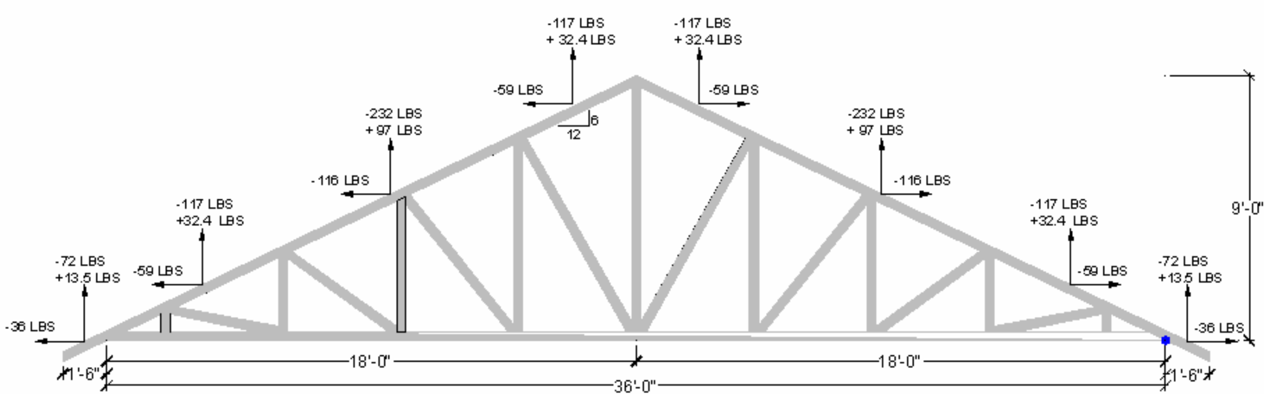
The Dead Load of the roof is: (Using governing load combination 0.6D + W)
$R2_{Oh}$ = 9(1.5) = 13.5 lbs
R2 = 9(3.6) = 32.4 lbs
R1 = 9(18-7.2) = 97 lbs

Summing the moments about the point shown wall:

ΣM_B = 0 = [-72 + 13.5][0.75+36] + [-117 + 32.4][36-3.6/2] + [-232+97][18/2 + 18] + [-117+32.4][18 + 3.6/2] + [-117+32.4][18 – 3.6/2] + [-232+97][18/2] + [-117+32.4][3.6/2] – [-72 + 13.5][0.75] + (horizontal forces - cancel out) – 36R

R_{plf} = -363 lbs

$R_{2\ feet}$ = -725 lbs



DESIGN EXAMPLE *(CONTINUED)*

The C&C roof-to-wall reaction is approximately 179 lbs. higher than the MWFRS reaction or 133 %. Requiring a connector with this much more capacity at each truss will increase the cost of not only the roof-to-wall connector, but also every connection required in the load path to the foundation.

SUMMARY

It has been rationalized that roof-to-wall anchorage forces may be appropriately calculated using MWFRS in lieu of C&C level loads. Documentation in ASCE 7 supports this information. Mainstream reference standards and leading professionals agree that MWFRS level loads are appropriate for roof-to-wall anchorage. The use of C&C level loads for roof-to-wall anchorage may unfairly impact the cost of construction.

In lieu of all the information provided, there is still judgment by the Engineer of Record required on this issue. The use of C&C level uplift loads to accommodate special requirements by the building owner for increased structural performance may be one reason. Possible anchor failure as a result of high local pressures may be better addressed through the use of higher C&C level loads, thus increasing a safety factor. Although a more scientifically based method for increasing structural performance, may be to use MWFRS loads with a higher importance factor and/or a higher design windspeed. Additionally, special requirements by a local Building Official may necessitate C&C level loads for roof-to-wall anchorage. Whatever the case may be, it is up to the Engineer of Record and/or Building Official on determining the correct level of force used and this Tech Note has been provided as a guide to assist in making the choice.

References

1. *2006 International Building Code (IBC)*, ICC.
2. *2006 International Residential Code (IRC)*, ICC.
3. *AISI Standard for Cold-Formed Steel Framing - Truss Design*, American Iron and Steel Institute, Washington, DC, 2004.
4. *Minimum Design Loads for Buildings and Other Structures* including *Supplement No. 1*, ASCE7-05
5. Hoover, Charles Jr., P.E. and McDonald, James Ph.D., P.E. *Wind Loading for Roof Trusses using ASCE Standard,* May 1997.
6. *Commentary on Wind Code Provisions* (SEAW/ATC- 60), Volume 1, Applied Technology Council (ATC), Redwood City, CA, 2004.
7. *Standard for Hurricane Resistant Residential Construction* (SSTD 10-99), SBCCI, 1999.
8. *Standard for Residential Construction in High Wind Regions* (ICC-600), ICC, 2008.

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