Heel Blocking

Released January 22, 2008

Applicability:

This *Tech Note* will prove to be of relevance to Building Designers who are concerned about creating a structural system by efficiently connecting the roof diaphragm to the walls, and thus creating a load path for lateral loads acting on the structure.

Issue:

Heel blocking has been one of the most commonly used methods to achieve the transfer of lateral loading from the roof diaphragm to the shear walls. Structural engineers often question the capacity of the Heel Blocks to achieve desired load transfer and about who is responsible for the attainment of the required strength. Also, identification of situations where the use of partial or absence of Heel Blocking can suffice is an issue that needs clarification.

Recommendations:

A low grade heel block or "bird block" with a large horizontal ventilation opening will more than suffice as perimeter blocking, provided the building designer properly details the roof-to-block and the block-to-wall connections. However, the Building Designer should always make sure that the blocking can provide sufficient capacity, especially before using Partial Height Blocking. Partial Height Blocking can be used as long as it is required to achieve the sufficient shear transfer. If it is not, either full height blocking at the wall or full height blocking in the eave overhang should be considered. Alternatively, approved proprietary connection hardware in place of or in addition to Partial Height Blocking should be used.

The Building Designer should also be aware that it is his responsibility to account for the capacity of the Heel Blocking (or any other method he chooses to use) to transfer the lateral forces from the roof diaphragm to the shear walls; the Truss Designer has to account only for the in-plane strength of the truss. The Building Designer must be aware that the lateral load capacity will also be limited by the capacity of the roof sheathing (diaphragm). Lateral load capacity of the roof sheathing will be reduced due to insufficient perimeter nailing caused by the absence of blocking as a nailing surface.

WTCA • 6300 Enterprise Lane • Madison, WI 53719
608/274-4849 • 608/274-3329 (fax) • www.sbcindustry.com

Key Definitions:

Building Designer: The owner of the building or the person that contracts with the owner for the design of the framing structural system and/or who is responsible for the preparation of the construction documents. When mandated by the legal requirements, the Building Designer shall be a registered design professional.

Cross-grain Bending: When a wood member is loaded such that it tends to bend in a direction against or across the grain, it is said to be in cross-grain bending. Wood is weak in bending about this axis.

Heel Block/ Bird Block/ E Block: It is a term used for the block installed between roof truss heels at the top of the exterior wall.

Partial Height Blocking: When a heel block in not provided throughout the combined height of the raised heel and the bottom chord member, it is called Partial Height Blocking. The shear transfer capacity of this kind of blocking is less than that of full height blocking, but it provides room for insulation ducts, etc.

Perimeter Blocking: Blocking along the perimeter of the roof diaphragm which has the ability to transfer loads into the side walls or shear walls.

Truss Designer: The person responsible for the preparation of the truss design drawings.

Weak-axis Bending: When a structural member is loaded such that it tends to bend about the axis of lower moment of inertia, it is said to be in weak-axis bending. The member is weak in bending about this axis.

Background:

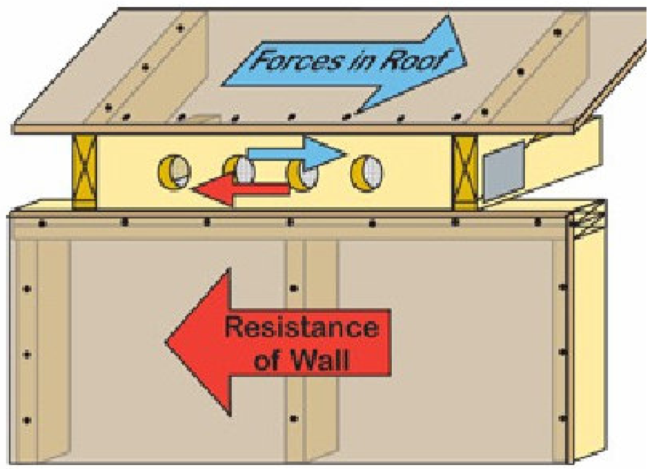
A Bird Block or Heel Block or E Block is installed between roof truss heels at the top of the exterior wall to carry and transfer lateral forces from the roof diaphragm to the braced wall. In cases where these blocks have ventilation holes drilled in them, they typically have a piece of wire mesh attached on one side to prevent birds or other animals from traveling through the holes into the attic space. Some truss manufacturers may supply heel blocks with roof truss deliveries; it is a nice service to the framer and a way for the truss manufacturer to put scrap lumber to good use. A manufacturer in California, who supplies heel blocks on a regular basis, received a call from the project structural engineer asking for the capacity of the block to transfer lateral loads as part of the roof diaphragm design and he called WTCA with this issue.

In another instance a building inspector had a question regarding Heel Blocking - Do Truss Designers account for the forces that cause rotation and lateral displacement at the bearing in their truss design or is it the responsibility of the structural engineer or Building Designer?

Analysis:

The Role of Heel or Bird Blocks

Let us first understand the function of roof diaphragms. Structures can be designed to take a considerable amount of lateral (or sideways) load from high wind or earthquake events. In simple terms, lateral loads in the roof system are transferred through the roof diaphragm, which is the structural plane created by the roof sheathing. To design the roof diaphragm, building designers determine the thickness and grade of the roof sheathing panel, the nail size and frequency, the size of the supporting framing members and the amount of blocking required for the panel. The perimeter of the diaphragm then must have the ability to transfer loads into the side walls or shear walls. Shear walls then act essentially like the roof diaphragms, only installed vertically. Horizontal blocking between truss heels can function as the perimeter blocking of the roof diaphragm and become the load path from the roof diaphragm into the shear wall.



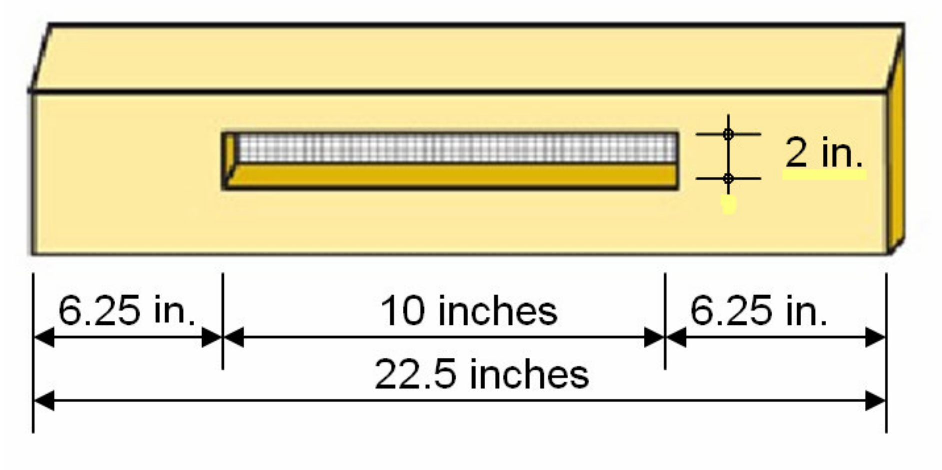
Shear forces acting on heel block
FIGURE 1

The Building Designer cannot assume heel blocking will perform adequately as perimeter blocking for the roof diaphragm, especially if they are uncertain of the blocking material and how it is being installed. The block will be subject to two opposing horizontal forces like the ones shown as red and blue arrows in **Figure 1**.

The ability of the block to resist these forces depends on the adjusted shear design value parallel to grain (horizontal shear) of the lumber grade and species as well as the amount of material removed to create the ventilation holes.

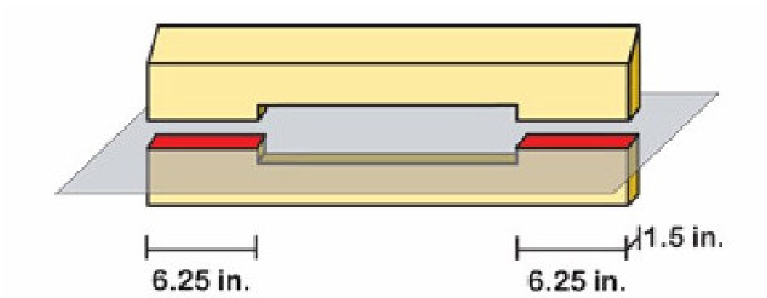
Analyzing the Capacity of a Heel Block

Let us consider, for instance, that the truss manufacturer uses 2x6 beveled blocks in vented roof with a letterbox type ventilation hole that is two inches high by ten inches long as shown in **Figure 2**. Note that the energy/ventilation requirements in IRC: R806.2 and R806.3 need to be met as well. In addition, attics or roofs can be designed and constructed to be either vented or un-vented in any hygro-thermal zone (Fig. 301.1of 2006 IECC). The choice of venting or not venting is a design and construction choice and not a requirement determined by the physics or by the building codes.



A letterbox type ventilation block
FIGURE 2

Imagine a horizontal plane cutting through the block at the location of the least material, see **Figure 3**.



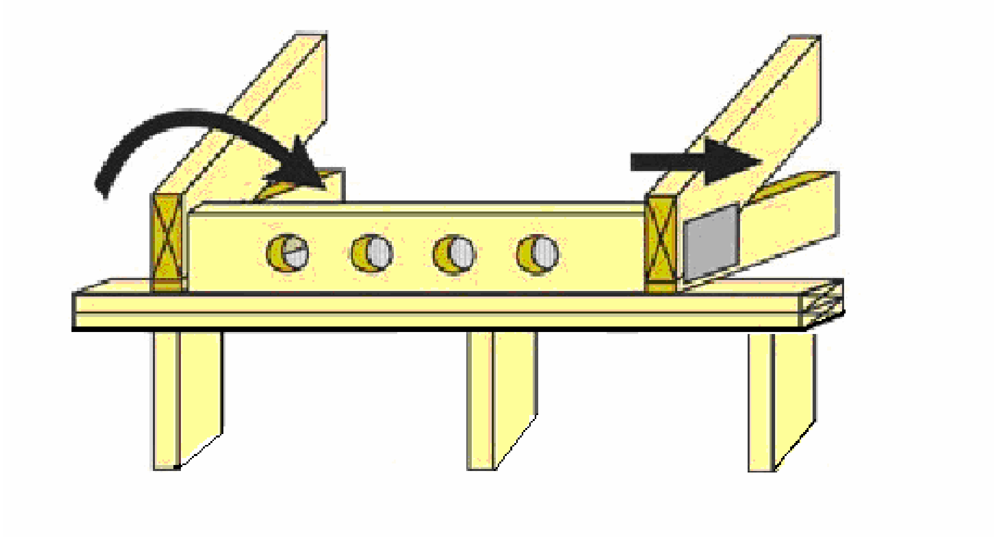
Area of block that resists shear
FIGURE 3

This is the area of block left to resist the shear forces being transferred from the roof diaphragm to the wall below. In this case it's a total of 18.75 square inches. To be conservative, we will use the a referenced value of horizontal shear F_v = 110 psi which is for "Northern Species" according to the AF&PA *National Design Specification® (NDS®) for Wood Construction*, Design Values for Wood Construction – *NDS Supplement* (2005)[1]. The only adjustment factor to consider is load duration factor (Table 2.3.2 of the 2005 *NDS*). We will use the 1.6 factor since these forces are either caused by wind or seismic events:

Shear Capacity of Block = F_v' x 0.5 x Area
Shear Capacity of Block = (110 psi x 0.5 x 1.6) x 18.75 sq.in. = 1650 pounds

Shear loads are expressed in terms of pounds per lineal foot (plf), so a 22.5 inch block with 1650 pounds of shear capacity would convert to 880 plf (1650 pounds divided by 1.875 ft. [22.5 inches]).

[1] AF&PA National Design Specification for Wood Construction, Design Values for Wood Construction – NDS Supplement (2005) , American Forest & Paper Association, Washington, DC



Blocking prevents rotation and lateral displacement
FIGURE 4

Is that enough? Yes. This is well above the magnitude of lateral loads that we expect will be generated in light frame wood construction. The APA Engineered Wood Association publishes a booklet called *Introduction to Lateral Design*[2] with charts for designing diaphragms and shear walls. In it, the highest recommended load listed is 820 plf for roof diaphragms and 870 plf for shear walls. Therefore, even a low grade "bird block" with a large horizontal ventilation opening will more than suffice as perimeter blocking provided the building designer properly details the roof-to-block and the block-to-wall connections.

Similarly, to calculate the capacity of heel block with holes drilled in it, the effective area that should be used would be given by

$$\text{Area} = L \times B - n \times d \times B$$

where:

L = Length of block
B = Breadth of the block
d = Diameter of the hole
n = Number of holes

The effective area in this case would be more than that in the case of a rectangular slot in the heel block analyzed above; implying that the shear transfer capacity will be higher.

Partial Height Blocking- Analysis

In some instances Partial Height Blocking can be used to leave room for insulation baffles, etc. The use of Partial Height Blocking relies on both weak-axis bending and cross-grain bending of the top chord member of trusses to transfer lateral forces from the roof diaphragm to the wall below.

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[2] APA, 2003. *Introduction to Lateral Design*, The Engineered Wood Association, Tacoma, WA

Section 3.8.2 of the 2005 *NDS*[3] recommends avoiding "designs that induce stress perpendicular to grain". However, it also recognizes that such conditions may be unavoidable and require special consideration. This condition exists with a number of connections in conventional light-frame wood construction[4]. The *NDS*[5] refers to the USDA-FPL *Wood Handbook* for guidance on mechanical reinforcement when tension perpendicular to grain cannot be avoided[5]. The *Wood Handbook* indicates that the stress property limit for cross-grain bending stress ($F_{b,cg}$) is approximately $^1/_{20}$th of the parallel-to-grain bending stress property (F_b). In a study of cross-grain bending stresses in bottom plates of shear walls toward the development of a design checking procedure, testing indicated that use of a ratio of about $^1/_{30}$ ($F_{b,cg}$: F_b) can be used to prevent cross-grain bending (tension) failure from occurring prior to other more favorable (ductile) failure modes such as diaphragm shear failure[6]. However, an analysis model (free-body diagram) is necessary to determine the level of cross-grain bending stresses relative to other design stresses induced on a system of members and connections. This model is not a trivial matter and requires assumptions regarding the amount of cross-grain bending force attributed to a unit length of a member experiencing such a force. This assumption involves judgments regarding relative stiffness, post-yield behavior of connections, and resulting force distribution through a diaphragm and framing system. Thus, the design check is only as good as the assumptions in this regard. Therefore, a more reliable approach is to base the design on relevant test data addressed next.

Fortunately, relevant testing of lateral force transfer from a conventional wood-frame roof diaphragm system to braced walls has been conducted[6]. These tests used no blocking and thus produced a greater cross-grain bending moment on the top chord of the trusses than would be experienced in the raised-heel truss condition with Partial Height Blocking (refer to **Figure 5** below). Therefore, the HUD test results represent a conservative estimate of lateral force transfer capability of a "partial-height blocking only" detail. From the testing, a maximum lateral force transfer of about 550 to 590 lbs/truss was documented with the absence of failure of the top chord due to cross-grain bending, indicating yielding and ductile overall response. Some toe-nails experienced edge tear-out failure, but the overall roof-to-wall connection system failed in a ductile manner due to yielding of toe-nails, yielding of the truss clips and/or yielding of truss plate connections.

Similar results were reported without creating any failure in the wall-to-roof connection on a whole building test where the maximum roof diaphragm shear transfer into the wall reached 407 or 756 lbs/truss joint (Paevre, 2002[6], Kasal, at al., 2004[7], HUD, 2001[8]). A cyclic loading protocol was applied to the building allowing forces to transfer cyclically into the walls through the roof diaphragm. The average value of 570 lbs/truss will be used hereafter to ensure the conservative solution.

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3 AF&PA. 2005. *ASD/LRFD Manual for Engineered Wood Construction,* American Forest and Paper Association, American Wood Council, Washington, DC.

4 Crandell, J..H. and Kochkin, V.2003. "Common Engineering Issues in Conventional Construction"*, Wood Design Focus,* Vol.13, No.3, Forest Products Society, Madison, WI.

5 USDA-FPL, 1999. *Wood Handbook, Wood as Engineering Material.* General Technical Report FPL-GTR-113, U.S. Department of Agriculture, Forest Products Laboratory, Madison, WI.

6 Paevere, P.J. *"Full Scale testing, modeling and analysis of light frame structures under lateral loading."* Ph.D. Thesis, Dept. of Civil and Environmental Engineering, The University of Melbourne, Parkville, Victoria, Australia

7 Kasal, B., Collins, M.S., Paevere, P., and Foliente, G.C. (2004) *"Design models of light frame wood buildings under lateral loads."J.Struct.Eng.*, 130(8), 1263-1271.

8 HUD, 2001. *Whole Structure Testing and Analysis of a Light-Frame Wood Building (Three Reports),* prepared by NAHB Research Centre Inc. for the National Association of Home Builders and U.S. Department of Housing and Urban Development, Washington, DC

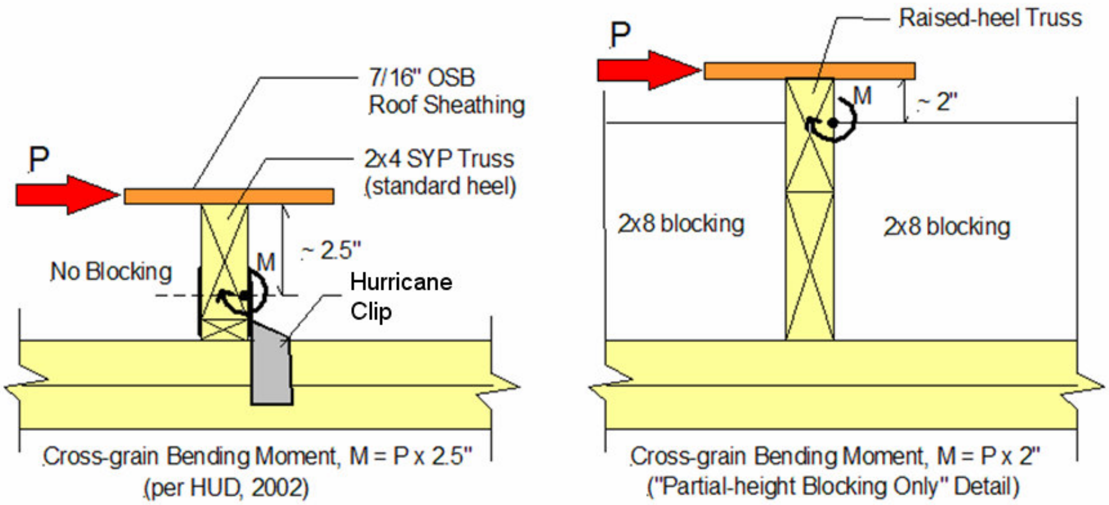
9 HUD, 2001. *Wood Shear Walls with Corners.* U.S. Department of Housing and Urban Development, Washington, DC

10 HUD, 2002. *Roof Framing Connections in Conventional Residential Construction*, U.S. Department of Housing and Urban Development, Washington, DC.

11 IRC. *International Residential Code* (2000/2003/2006 editions). International Code Council, Inc., Washington, DC.

12 IBC. *International Building Code* (2000/2003/2006 editions). International Code Council, Inc., Washington, DC.

13 ASCE, 2005. *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-05), American Society of Civil Engineers, Reston, VA.



Cross grain bending moment in top chord of a standard-heel truss without blocking (per HUD, 2002) relative to a raise-heel truss with a "partial-height blocking only" detail.

FIGURE 5

With the bottom edge of Partial Height Blocking adequately fastened to the top plate or wall sheathing, an ultimate in-plane force transfer of at least 570 lbs per truss can be achieved without cross-grain bending failure of the truss top chord member. Applying a safety factor of 2.5 results in a 228 lbs/truss design value for in-plane shear transfer for the "Partial Height Blocking only" detail. With trusses spaced at 24"oc, this design value relates to a design unit shear in the roof diaphragm of 114 plf. For a normal weight roof-ceiling system (e.g., 15 psf) and assuming an S_{DS} of 1.17g (Seismic Design Category D_2 per the IRC[11] or S_s = 1.75g and Site Class D per the IBC[12]), a span limit for roof diaphragm systems with partial-height blocking only is determined as follows (per IBC 2000 Simplified Method or IBC 2006 / ASCE 7-05[13] Section 12.14 Simplified Method):

$$V = 1.2\ (S_{DS}/R)\ W \times 1/(1.4 \times \Omega_0)$$

where:

V = shear force per unit length at the roof diaphragm connection to the wall

W = ½ x (Roof Span) x (1-ft unit length along wall) x (D_r of 15 psf dead load of roof-ceiling assembly) = D_r x (Roof Span)

For Light-frame bearing wall systems sheathed with wood structural panels rated for shear resistance:

R = seismic response modifier = 6.5 and Ω_o = over-strength factor = 3.0

S_{DS} = 1.17g (IRC Seismic Design Category D_2, S_s = 1.75, Soil Site Class D)

1/1.4 = factor to convert from strength design force to ASD design force level.

<u>In this case the over-strength factor Ω_o is used for design load path from roof-to-wall when partial height-blocking is used; it prevents potential occurrence of brittle failure</u>

mode due to cross-grain bending by preventing this potential failure and/or response from being the "weak link" in the lateral force resisting system.

Making the above substitutions and solving for "Roof Span," the following limit equation is determined for the "partial-height blocking only" detail in Seismic Design Category D_2 (S_{DS} = 1.17g):

$$\text{Roof Span} = 2 \times 1.4 \times V \times R / [(1.2 \times S_{DS} \times D_r) \times \Omega_o]$$

Substituting V = 114 plf (design unit shear for Partial Height Blocking), R = 6.5, S_{DS} = 1.17g and D_r = 15 psf, the following roof span limit is determined:

Roof Span = 2 x 1.4 x (114 plf) x 6.5 / [(1.2 x 1.17 x 15 psf) x 3.0] = **33 feet**

Thus, for the stated design conditions, the "partial-height blocking only" detail provides adequate seismic shear force transfer from the roof diaphragm system to walls at the perimeter of the roof for roof clear spans up to **38 feet**. For heavier or lighter roof systems or greater or lesser seismic design ground motions, an applicable span limit can be similarly determined. Note that the above equation includes a seismic over-strength factor (Omega) and that this practice is not necessarily required by ASCE 7-05, IBC, and SDPWS-2005 (ASCE, 2005; ICC; AF&PA-b, 2005). It is used here to alleviate any reasonable concern with the partial-height blocking force transfer mechanism that does not necessarily prevent a brittle failure mode (cross-grain bending), even though this was not observed in available full-scale testing data for the resistance values used in the above analysis. Using the over-strength factor further ensures that the partial-height blocking force transfer mechanism will not result in a "weak link" in the lateral force load path.

Also, a similar equation can be developed for transfer of shear forces due to wind acting on the gable end of a roof. Such analysis indicates that for a 120 mph Exposure B condition, the roof clear span should be limited to 28 feet for 12:12 gable roof pitch or 52 feet for a 6:12 gable roof pitch or less. For hipped roofs, the span limits for wind should not control over seismic. For gable roof pitches in between 12:12 and 6:12, the roof span limit can be scaled by interpolation (e.g., span limit of 40 feet for 9:12 gable roof pitch). This analysis is based on ASCE 7-05 wind loads with the assumption that the length of the roof (along ridge) is at least equal to the span of the roof with a gable end tributary area equal to one-half the story height of 8 feet plus one-half the gable end area above the supporting end walls.

For special conditions requiring an even greater amount of force transfer than can be provided by the "partial-height blocking only" detail, the following options should be considered:

1. Provide the additional full-height blocking in the eave overhang (6 in. from the Partial Height Blocking). The force transfer mechanism described above for the Partial Height Blocking exists with or without the additional full-height blocking between the fascia board and the partial-height blocking at the wall line. However, the presence of the full-height blocking in the roof eave may cause more of the force from the roof diaphragm to transfer to the partial-height blocking by weak-axis bending of the top chord rather than cross-grain bending of the top chord. The actual distribution of forces through these two interactive load pathways involves system effects that are difficult to analyze without relying on judgment.
2. Use approved proprietary connection hardware in place of or in addition to Partial Height Blocking.

In addition, where and/or if possible, the following additional options are recommended as well:

1. Conduct the roof system shear transfer tests similar to that described above (HUD, 2002), but conduct the tests using a raised heel truss with the "partial-height blocking only" detail. This should result in a greater force transfer than estimated above from existing tests of standard heel trusses without any blocking.

2. Conduct roof system shear transfer tests as indicated in #2, but with the additional full-height blocking per #1. This should give modestly greater shear capacity than determined above (short of placing the full-height blocking at the wall plate) and demonstrate that the force transfer capacity is greater than that limited by assuming that Weak Axis Bending of the top chord alone controls the force transfer (i.e., there are other force transfer mechanisms besides just Weak Axis Bending at play including the systems effect that should demonstrate that the analysis is overly-conservative).

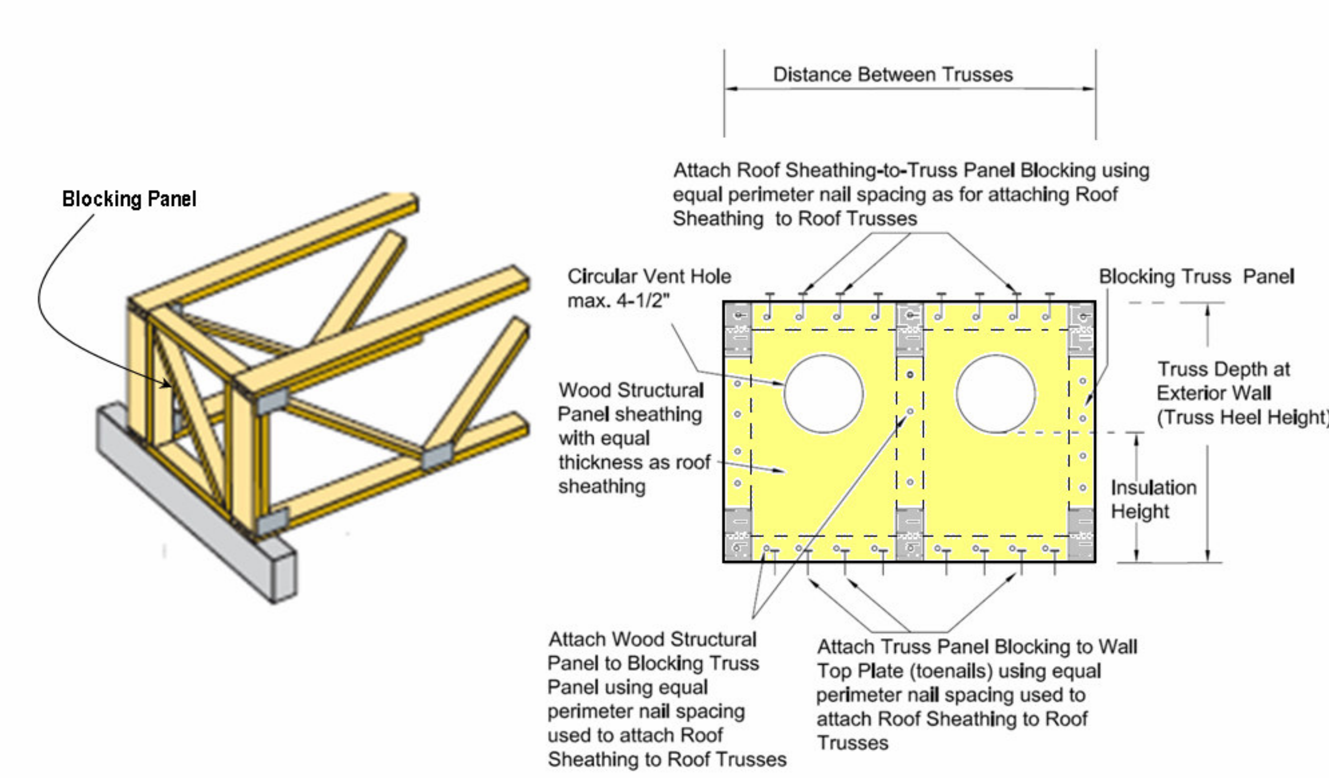
Thus, partial blocking can be used as long as the shear force does not exceed 114 plf along the wall. If it is not, any of the above measures can be employed to ensure sufficient heel block capacity.

Who is responsible for the strength, capacity and adequacy of Heel Blocks?

The Truss Designer assumes that the truss will be installed plumb and in-plane and will carry only in-plane loads. The Building Designer is responsible for designing the system to resist any loads and forces not in-plane with the truss, which would include the means to resist rotation and lateral displacement.

Some local code jurisdictions, mostly in the earthquake prone west, require blocking at the truss heels because there is a greater expectation of lateral loads causing rotation and displacement (**Figure 4**). Blocking is not installed in most interior parts of the country because the truss-to-bearing connections and the relatively close roof sheathing attachment are sufficient to prevent any movement. Note that the block may not have to go the full height of the heel to effectively block it and keep it from rotating, nor is a block always required in every space between trusses. In addition, ventilation requirements may need more area than a partial height block can supply. However, this condition should be determined and identified as being required or not by the Building Designer.

Another option Building Designers may specify for high heel or flat truss applications is a blocking panel (**Figure 6**). Truss manufacturers can provide these as long as they have enough information to complete the design. Roof diaphragm, shear wall, truss rotation restraint and the connections needed to resist all loads as well as energy/ventilation requirements, are the issues that the building designer must account for when designing the building. The component manufacturer may already be supplying products like Bird Blocks and blocking panels that can easily provide the design values needed to resist lateral loads. This certainly can be a win-win for everyone—the lateral loads are easily resisted and the component manufacturer gets to supply another structural component that has solid design values while also using up what otherwise may be waste material.



Use of blocking panel for raised-heel or a parallel chord (flat) truss
FIGURE 6

An alternate blocking panel can be field-fabricated using structural sheathing nailed to a frame of 2x dimension lumber and installed between the trusses. A prescriptive detail for such a panel appears in the upcoming *ICC-600 Standard for Residential Construction in High-Wind Regions*[14].

Conclusion:

It can be seen that Heel Blocking can become an important part of the structural load path of the roof to the foundation. It is important to understand how the load transfer actually occurs in order to make a decision about whether the type of blocking being provided is sufficient without compromising energy/ventilation requirements. It is ultimately the responsibility of the Building Designer to properly detail and document that the proper load path and sufficient capacity is provided.

View all WTCA Tech Notes at www.sbcindustry.com/technotes.php

[14] ICC, 2007. *ICC-600 Standard for Residential Construction in High-Wind Regions*. International Code Council, Inc., Washington, DC.