IS ROOF EAVE BLOCKING REQUIRED TO TRANSMIT WIND/SEISMIC FORCES?

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ABSTRACT

The use of wood blocking between wood rafters or trusses has been historically accepted by engineers as necessary to act as a wood roof diaphragm boundary edge member, to transfer chord forces to the chord and to transfer wind and seismic shear forces to the shear walls.

However, the use of eave blocking has been abandoned by many design engineers who argue it is not specifically code-required and that empirical testing has shown it is not needed. They argue that chord and shear forces can be resolved through the use of other framing members and metal connectors. However, engineering mechanics and metal connector manufacturers' limits dictate that eave blocking cannot be omitted.

In low load, low heel height cases, it could be argued that eave blocking may not be needed, but where roof diaphragms transfer wind and seismic forces, design engineers omitting eave blocking do so in denial of basic engineering principles.

INTRODUCTION

Blocking between wood rafters or trusses at roof eaves (commonly known as eave blocking) has historically been standard framing practice in wood construction, particularly at open eaves. Blocking typically consists of nominal two inch wide material, normally of a depth matching the height from the bottom of the roof sheathing to the top plate of the wall.

The installation of edge blocking serves several purposes. The blocking encloses the attic space, preventing birds and vermin from entering, and it is used as a means to assure accurate dimensional spacing between the rafters or roof trusses. It also provides a load path from the roof diaphragm to the exterior walls to transfer wind or seismic forces. However, as fire requirements and aesthetic considerations have resulted in the increased use of enclosed eaves, the installation of eave blocking has been abandoned by many design engineers.

The resultant construction cost savings in both material and labor has been justified by the argument that eave blocking is not specifically required by the code (Crandell, J., Rice, R., Foley, B, and Woeste, F., 2009). This argument has been shored by results from testing sponsored by the U.S. Department of Housing and Urban Development (HUD, 2002) that appears to show edge blocking may not be "empirically" needed (as opposed to required by engineering mechanics).

Whether or not the installation of eave blocking is actually required depends on a number of factors. These may be prescriptive, required by building code statute; or, when dependent on manufactured metal connectors to transfer shear and overturning forces, by limitations placed by the connector manufacturers' specifications; or finally, as an integral part of the lateral load-resisting system, as a means to maintain a complete load path from the roof diaphragm to the shear walls.

BUILDING CODE REQUIREMENTS

Lateral Support Against Rotation

One function of eave blocking is to prevent lateral rotation of the rafters/trusses at the wall supports. The International Residential Code (IRC) did not specifically require any eave blocking to prevent rotation of rafters/trusses under the 2006 edition. Some conditions are provided in the 2009 IRC under which eave blocking is required by Section R602.10.6.2 for lateral support against rotation, but only at sections above braced wall panels. Low wind/seismic regions require partial height (to allow attic venting per R806) eave blocking, but only at rafter/truss heel heights above 9.25 inches. High wind/seismic regions required eave blocking per Figures R602.10.6.2(1), R602.10.6.2(2) or R602.10.6.2(3) for all heel heights.

That the required blocking is only partial-height for attic ventilation seems unnecessary in that the blocking is only required over braced wall panels and not elsewhere along the wall line. IRC Figures R602.10.6.2(1), R602.10.6.2(2) and R602.10.6.2(3) do not provide a load path and serve solely to prevent rotation of the rafter/truss.

Similarly, the 2009 International Building Code (IBC) under *Conventional Light-Frame Construction* Section 2308.10.6 requires the use of blocking per Section 2308.8.5, which uses heel height limits to require lateral support against rotation of the roof framing. The heel depth-to-thickness ratio for roof framing is held to a maximum unblocked ratio of 5:1. This requirement exists only to resist rotation of the roof framing and does not address the transfer of wind or seismic forces.

In conclusion, the IRC does not at present prescriptively require eave blocking to resist rotation for rafters/trusses heel heights less than 9 1/4 inches, while the IBC does not prescriptively require eave blocking for heel heights less than 6 3/8 inches.

Load Transfer

The 2006 IBC's *General Design Requirements for Lateral Force Resisting Systems* section prescribed the use of "boundary members" to transmit tension and compression forces (Section 2305.1.2). This has been historically taken by engineers to indicate a requirement for eave blocking. Since wind/seismic chord forces are typically resisted by the wall top plates, an obvious load path would be developed from the roof diaphragm to the top plates through the eave blocking to the shear wall top plate. Load eccentricities from the roof diaphragm to the top plate in this arrangement are resolved through each block's individual end nailing. Under such a configuration eave blocking meets the IBC requirement for boundary members to transmit tension and compression forces.

However, the 2009 IBC deleted Section 2305.1.2 and under newly revised Section 2306.2.1 ("Wood structural panel diaphragms") defaults the design and construction of horizontal wood diaphragms to as in accordance with the American Forest & Paper Association's *Special Design Provisions for Wind and Seismic* (2005).

AF&PA's *Special Design Provisions for Wind and Seismic* Section 4.2.6 ("Construction Requirements") requires diaphragm "boundary elements" to transmit tension, compression and shear forces but does not specifically require those to be eave blocking. In arguing for the omission of eave blocking, it has been put forth that the roof diaphragm should instead be boundary-nailed to the fascia (the new "boundary element") in order to meet the code boundary nailing requirement.

Chord forces are then assumed to transfer from the roof diaphragm to the tops of the rafter/truss (the new "boundary elements"), through the rafter/truss, and through the metal connector holding the rafter/truss to the top plate, transferring the chord forces to the shear wall top plate. The assumption is typically made without the benefit of an engineering analysis, it happens "empirically".

Because the AF&PA does not specifically require for such a transfer to take place by using eave blocking, there is no prescriptive IBC code requirement to use eave blocking to transfer tension and compression forces. While such an arrangement may not be acceptable to engineers in that it places the rafter/truss in cross-grain bending, it has been argued that it technically meets code requirements for boundary elements to transmit tension, compression and shear forces.

The resultant load path would then be from the wood diaphragm to the roof rafter/truss, through the roof rafter/truss to the metal connector, and from the connector to the wall top plates. The resultant eccentricities of this load path are generally ignored by those proposing the deletion of eave blocking, who argue the metal connector can resist the overturning by transferring the force couple through the connector flanges nailed to the sides of the roof/rater truss. This will be further discussed in the following sections.

ANALYSIS REQUIREMENTS

Diaphragm

Figure 1a below shows a standard roof framing detail for a wood framed eave, with eave blocking. Figure 1b shows the same detail, without the eave blocking but substituting standard connection hardware.

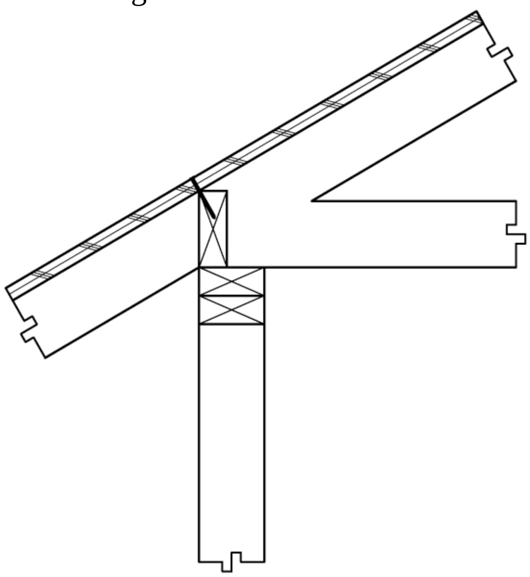

Fig. 1a – Wood Framed Eave With Eave Blocking.

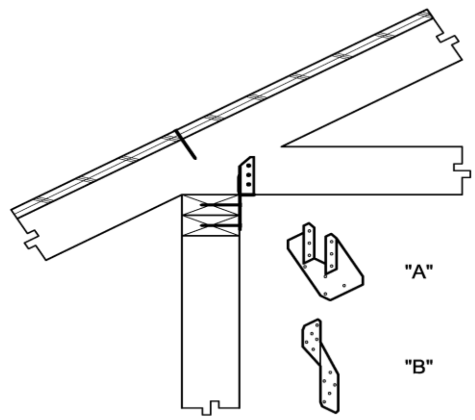

Fig 1b – Wood Framed Eave, No Eave Blocking.

Figure 1c shows again the same detail, without the eave blocking, at a masonry wall condition with standard connection hardware.

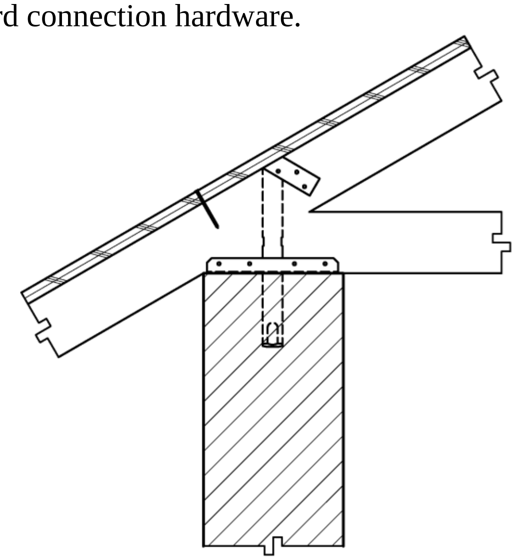

Fig. 1c – Masonry Wall Wood Framed Eave, No Eave Blocking.

In considering the need to transfer wind/seismic forces at roof eaves, two issues need to be addressed. First would be the resolution of resistant forces parallel to the direction of applied wind/seismic forces (the reaction shear forces). Second would be the resolution of resistant forces perpendicular to the direction of applied wind/seismic forces (the chord forces).

The reactive shear forces resisting wind/seismic forces for a flexible, unblocked diaphragm are typically determined from a tributary span length and a tributary wind/seismic load. Table I tabulates reactive shear values for different combinations of wind/seismic loadings (w) and different diaphragm length-to-depth ratios (L/d). Because we are only considering the analysis of eaves perpendicular to the roof framing and the roof trusses are assumed to span across the shorter dimension, the wind/seismic forces would act across the short direction of the diaphragm and we would only investigate the reactive shear forces from wind/seismic forces perpendicular to the roof framing (IBC Table 2306.3.1, Case 3 unblocked diaphragm).

Table I – Reactive Shear Forces.

Shear Flow (plf)					
L/d w (plf)	0.25	0.33	0.50	0.67	1.00
100	13	17	25	34	50
150	19	3	38	50	75
200	25	33	50	67	100
250	31	41	63	84	125
300	38	50	75	101	150

The results show the reactive shear forces fall within most popular sheathing thickness/nail size combinations for unblocked diaphragms. Diaphragm shear capacity would thus not seem to be a concern in eliminating eave blocking when considering reactive shear forces.

Chord forces for flexible, unblocked diaphragms are typically calculated as simple span moments between diaphragm supports, divided by the depth of the diaphragm. Table II tabulates chord forces for different combinations of wind/seismic loadings (w) and different diaphragm length-to-depth ratios (L/d), divided by the length of the diaphragm. Again considering chord forces perpendicular to framing but due this time to wind/seismic forces parallel to framing, we distributed the chord force into a "chord flow" acting along the diaphragm edge, namely, the chord force divided by the length of the diaphragm. We then compare these calculated chord flow forces along the diaphragm edge with the allowable diaphragm loading corresponding to an IBC Table 2306.3.1, Case 3 loading.

Table II – Chord Forces.

Chord Flow (plf)					
L/d w (plf)	4.00	3.00	2.00	1.50	1.00
100	50	38	25	19	13
150	75	56	38	28	19
200	100	75	50	38	25
250	125	94	63	47	31
300	150	113	75	56	38
350	175	131	88	66	44

The tabulated results show that the chord flow shear forces fall within most popular sheathing thickness/nailing combinations for unblocked diaphragms. In considering chord forces at diaphragms without eave blocking, diaphragm shear capacity does not appear to be a concern.

Mechanical Connectors

Typical roof wood rafter/truss to wood wall construction uses metal connectors such as those shown in Figure 1b, while typical roof wood rafter/truss to masonry wall construction uses connectors such as the one shown in Figure 1c. Available from a number of manufacturers, these connectors have load capacities (depending on the model used) of up to several hundred pounds per connector (Simpson Strong-Tie Company, 2009-2010).

The values tabulated in either Table I or Table II compare well with the allowable shear loads for these metal connectors. Provided the proper connector is selected and standard spacings are used, shear force demands from the diaphragm to the exterior walls can be met. These connectors would thus appear to meet the IBC Section 2305.1.2 requirement for the use of "boundary members" to transmit tension and compression forces.

However, where eave blocking is not used, the rafter/truss would receive the wind/seismic load from the diaphragm at the top of the rafter/truss and transfer it to the wall top plates at the base of the rafter/truss. This creates a rotational moment across the rafter/truss. Disregarding for the moment that this rotational moment induces undesirable cross-grain bending on the rafter/truss, in order for the wind/seismic load to successfully transfer into the top plates there would still need to be a free-body resolution of the rotational moment at the base of the roof rafter/truss.

The moment may be resisted by the metal connectors tying the rafter/truss to the top plates. In the case of a connector "A" as shown in Figure 1b, nailed flanges on either side of the rafter/truss could develop a resistive couple. Similarly, a connector "B" as shown in the same figure could be installed each side of the rafter/truss to resist the rotational couple. However, the rated load values for these connectors were developed through testing that restrained the wood members from rotation. The rated load values represent capacities for straight shear transfer and do not assume a combination of shear and rotational loads. As such, the metal connectors are not approved by the manufacturer to resist rotational couples. Manufacturers specifically include catalogue warnings that the connectors are not intended to prevent cross grain bending (Simpson Strong-Tie Company, 2009-2010).

Engineers have the option to bypass the manufacturer's warnings and choose to apply engineering design concepts to analyze the connector. Such a study would have to include a complete free-body analysis and a unity equation check. Consideration would have to be given to the fact that the nails transferring the rotational couple forces would be in cross-grain shear. In addition, those intending to use "B" connectors should also consider the manufacturers' recommendation to use a minimum 2½ inch thick rafter/truss when installing the connectors opposite each other (Simpson Strong-Tie Company, 2009-2010).

Perhaps more importantly, the use of mechanical connectors such as "A" and "B" to transfer both shear and rotational forces requires a complete disregard for cross-grain bending across the rafter/truss. This condition is ignored by no-blocking proponents (Yaxley, Wilbur T., 2004) who will argue empirically for the rotational resistance provided by the fascia board, even though it is end nailed to the rafter/truss and numerically unable to provide the necessary resisting force couple. Similarly disregarded is that shear transfer may happen but only at the expense of rotational failure. A failed connection is still a failed connection.

Test results show that failure modes for anything but low-load/low-heel height conditions are generally not caused by shear failure but by some form of rotational failure (U.S. Department of Housing and Urban Development, 2004). On roof rafters this typically occurs as a cross-grain failure, an undesirable condition due to its sudden and inelastic failure mode. In roof trusses the failure is typically across the connector plates. In addition, there are no code-published allowable stress values for wood in cross-grain bending. Even if some existed, the need for an engineering analysis including a unity equation check for shear and cross-grain bending cannot be ignored.

EMPIRICAL TEST DATA

The U.S. Department of Housing and Urban Development (HUD) sponsored tests on roof truss to wall connections and reported the results in 2004. The tests involved four different attachment configurations, none using eave blocking. Two of the configurations used toe nails as the sole means of attachment. The third configuration used a combination of twenty-two toe nails and nine metal connectors. The fourth configuration used only four toe nails and nine metal connectors. The metal connectors were installed on only one side of the truss. All trusses used two-by-four inch members, so that heel heights and the resultant overturning forces were relatively small.

Test results showed a noticeable difference between toe-nail failure and metal connector failure modes. Toe-nail connection failure was defined by lower load capacities, splitting of the wood and lateral sliding of the truss along the top plate, with little out-of-plane truss rotation. Toe-nailed connections had such low capacities that out-of-plane rotations never really had the opportunity to develop to the point of failure. In essence, the toe-nailed connection failed in shear long before allowing the connection to fail in out-of-plane rotations.

Metal connector failures occurred at higher load capacities. In some cases the truss rotated out-of-plane, resulting in truss plate separations. In others, the metal connectors failed, either by failing in tension due to the overturning out-of-plane force couple, or by excessive deformation from localized buckling of the connector.

Metal connectors are load-rated by their manufacturer based on joint slip limits, rather than on failure load capacity. The HUD tests were based on failure load capacity and as such, the results report excessively high failure loads relative to manufacturer rated loads. This leads to excessively positive results that would seem to indicate the metal connectors are much more capable of resisting loads than they have been rated by their manufacturers. These findings have lead to euphoric misplaced calls for the abandonment of metal connectors allowable loads based on joint slip limits rather than by failure load analysis. In the HUD configurations tested, load failure occurred at deformations of over an inch, excessive by any measure and surely a condition that would benefit from the installation of eave blocking.

CONCLUSIONS

Roof eave blocking is not prescriptively required by either the IRC or the IBC to transfer wind/seismic forces. Eave blocking is only code-required to resist lateral rotation of the rafter/truss assemblies when prescribed height-to-width heel ratios are exceeded.

Strictly in terms of shear transfer, wood roof diaphragms in standard configurations do not appear able to develop large enough shear or chord forces to require the installation of eave blocking for additional diaphragm shear nailing. Similarly, metal truss connector shear load capacities appear sufficient to resist standard configuration shear or chord forces.

However, the use of only truss connectors in lieu of eave blocking requires a disregard of rotational bending across the rafter/truss assembly and its resultant cross-grain bending on the roof rafter/truss as well as its resultant force couple on the metal connector. A complete free-body analysis and unity equation check on both the roof rafter/truss for cross-grain bending and on the metal connector seem out of reach due to a lack of allowable wood cross-bending stress values and the fact that metal connectors are prohibited by the manufacturer to resist cross-grain bending and that allowable shear values are based on joint slip limits.

The omission of eave blocking may be possible in some low-load, low heel-height conditions, when toe nails are used. Toe nail shear capacities are so low, cross-grain bending in low-heel conditions does not have the opportunity to develop as a concern. In other words, for low heel-height, light load cases requiring only toe-nailing at the roof rafter/truss connection to the top plate for shear transfer, cross-bending concerns could possibly be disregarded. The system would have to be designed to guarantee shear failure of the toe nailing before reaching a cross-bending failure. With some limits, low-load conditions might be possible without eave blocking.

However, once the decision to use metal connectors is made, the use of connector hardware greatly increases the shear load capacity over that of just toe-nailed assemblies. This increased shear load capacity brings about a rise in the potential for cross-grain rotational failure, either in the roof rafter or in the roof truss assembly. Any system that would use metal connectors between the roof rafter/truss and the wall top plate will require the use of eave blocking in order to avoid rotation as the failure mode.

At higher loads and particularly as the heel height increases, rotational forces and cross-grain bending cannot be ignored. In the absence of eave blocking, cross-grain rotation becomes a primary failure mechanism. Higher loads and higher heel heights also result in assembly deformations too excessive to be acceptable and well beyond the joint slip limits of the metal hardware. In designing higher-load assemblies (such as those in high wind and earthquake zones) the omission of eave blocking is not an acceptable engineering choice.

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