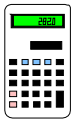
EXAMPLE 7.3 Rafter-to-Ceiling Joist Connection (Heel Joint)



Given

- Rafter and ceiling joist roof construction (without intermediate rafter braces)
- Roof horizontal span is 28 ft and rafter slope is 6:12 (26 degrees)
- Roof framing is Hem-Fir (G=0.43) with a spacing of 16 inches on-center
- Roof snow load is 25 psf
- Rafter & roofing dead load is 10 psf
- Ceiling dead load is 5 psf

Find

1. The tension load on the heel joint connection
2. Nailing requirements

Solution

1. Determine the tensile load on the heel joint connection

Using basic principles of mechanics and pinned-joint analysis of the rafter and ceiling joist "truss" system, the forces on the heel joint can be determined. First, the rafter bearing reaction is determined as follows:

B = (snow + dead load)(1/2 span)(rafter spacing)
= (25 psf + 10 psf)(14 ft)(1.33 ft)
= 652 lb

Summing forces in the y-direction (vertical) for equilibrium of the heel joint connection, the compression (axial) force in the rafter is determined as follows:

$C = (652 \text{ lb})/\sin(26^o) = 1{,}487 \text{ lb}$

Now, summing the forces in the x-direction (horizontal) for equilibrium of the heel joint connection, the tension (axial) force in the ceiling joist is determined as follows:

$T = (1{,}487 \text{ lb})\cos(26^o) = 1{,}337 \text{ lb}$

2. Determine the required nailing for the connection

Try a 12d box nail. Using NDS Table 12.3A, the following Z value is obtained:

$Z = 80$ lb
$Z' = ZC_DC_d$ (Section 7.3.2)

$C_D = 1.25^*$ (snow load duration, Table 5.3)
*NDS uses a factor of 1.15

$C_d = p/(12D)$ (NDS•12.3.4)
p = penetration into main member = 1.5 inches
D = nail diameter = 0.128 inches
$C_d = 1.5/[12(0.128)] = 0.98$

$Z' = (80 \text{ lb})(1.25)(0.98) = 98$ lb

In Section 5.6.1, a system factor of 1.1 for tension members and connections in trussed, light-frame roofing systems was discussed for repetitive member applications (i.e., framing spaced no greater than 24 inches on center). Therefore, the Z' value may be adjusted as follows:

Z' = (98 lb)(1.1) = 108 lb

The total number of 12d box nails required is determined as follows:

(1,337 lb)/(108 lb/nail) = 12.3

If a 16d common nail is substituted, the number of nails may be reduced to about 8. If, in addition, the species of framing lumber was changed to Southern Yellow Pine (G = 0.55), the number of nails could be reduced to 6.

Conclusion

This example problem demonstrates the design of one of the most critical roof framing connections for site-built rafter and ceiling joist framing. In some cases, the ceiling joist or cross-tie may be located at a higher point on the rafter than the wall bearing location which will increase the load on the joint. In most designs, a simple pinned-joint analysis of the roof framing is used to determine the connection forces for various roof framing configurations.

The snow load duration factor of 1.25 was used in lieu of the 1.15 factor recommended by the NDS; refer to Table 5.3. In addition, a system factor for repetitive member, light-frame roof systems was used. The 1.1 factor is considered to be conservative which may explain the difference between the design solution in this example and the nailing required in Table 7.1 by conventional practice (i.e., four 16d common nails). If the slant nailing of the rafter to the wall top plate and wall top plate to the ceiling joist are considered in transferring the tension load, then the number of nails may be reduced relative to that calculated above. If a larger system factor than 1.1 is considered (say 1.3), then the analysis will become more closely aligned with conventional practice; refer to the roof framing system effects discussion in Section 5.6.1. It should also be remembered that the NDS safety factor on nail lateral capacity is generally in the range of 3 to 5. However, in more heavily loaded conditions (i.e., lower roof slope, higher snow load, etc.) the connection design should be expected to depart somewhat from conventional practice that is intended for "typical" conditions of use.

In any event, 12 nails per rafter-ceiling joist joint may be considered unacceptable by some builders and designers since the connection is marginally "over-crowed" with fasteners. Therefore, alternative analysis methods and fastener solutions should be considered with some regard to extensive experience in conventional practice; refer to NDS•7.1.1.4 and the discussion above.