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ECONOMY AND GOOD BEHAVIOR IN RESIDENTIAL FRAMING

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ECONOMY AND GOOD BEHAVIOR IN RESIDENTIAL FRAMING

by

Peter J. Verna, Jr., P.E.

PART I - ROOF FRAMING

To have an economical framing design for residential construction, the builder and designer have many decisions to make - decisions that must be based upon the builder's own likes, dislikes, available labor pool, and material.

Economical framing begins at the roof, not at the foundation. The designer must decide how the roof load is to be carried to the ground. All loads must be carried to the ground, just as all blood in our body must flow to our heart. In like manner, loads flow from the roof through the framing to the ground. The most economical flow of loads has the least interruptive route. If a load can flow straight to the ground without interruption by an opening at lower levels that causes the load to flow horizontally during its course to the ground, then fewer and lighter beams are required. The more interrupted the flow of loads, then the greater the number of beams and the more the expense to frame.

Care must always be exercised in locating where braces for roof framing are landed. There is a most economical location for this bracing, as follows:

1) It is first to a corner or jack stud.

2) Second to a partition landing over one stud. This requires a minimum addition of a second stud, creating the need for a double stud support.

3) Third, to a beam or header, landing as close as possible to its support. This location will probably not increase the size requirement of the header or beam.

4) Fourth, onto the middle section of a header or beam, which may increase the required size of the beam or header, due to the increased brace load.

5) Fifth, to a hog on the ceiling joists below. If the hog is generally located within the end one-third of the ceiling joist span, it probably will not increase the structural load on the joists. In effect, one can receive a free ride, because in this one-third end zone, the ceiling joists have unused moment and shear capacity. Therefore, they carry the brace load for free, so to speak.

Hogs on ceiling joists should be a minimum of 6' long, preferably 8'-12', to distribute the brace load. Never use any hog less than 6' long. Always avoid bracing any ceiling joists in the middle third of their spans.

A word about braces from roof framing - many framers, builders, designers, and inspectors believe that roof braces must be vertical. This is not correct. Braces can be effective at any angle of 45° or greater with the ceiling joists. Similarly, as you view the brace vertically, it can be anywhere in a 360° circle, centered on the brace location at the rafters level. When this latitude is understood, it gives the designer and builder an opportunity to brace as economically as possible with the least loading effect on the structure below.

The builder/designer has to decide on whether they want trusses or stick framing. Some favor trusses because they don't have framers who can cut in all hips and valleys. If one doesn't have capable framers who understand how to lay out a stick-built roof, they are then forced to use trusses. Trusses are easy to install, but have a number of problems that can render their use unacceptable. Some of these problems are as follows:

1) A crane is generally required, at great expense.

2) Longer lead times to procure. In a fast market like Mecklenburg County, NC, order time can delay the start weeks at a time.

3) Cost in place is almost always more than a well-designed, stick-built roof.

4) Much care must be exercised in erection, to avoid roof surface out of planeness and bumps and dips in both the roof surface and in the ceiling surface below. If care isn't taken to level the bottom of jack trusses, framing into roof girder trusses, very serious bumps will occur in the ceiling of the room below and simultaneously the roof planeness is faulted.

5) Jack trusses must be secured firmly to their girder trusses. Oftentimes, they are end nailed or toenailed only, without metal truss hangers. This lack of hangers can cause cracking in the ceiling below. It is always recommended to use metal truss hangers to avoid these erection and behavior problems.

6) Roof trusses must be braced permanently and laid out to properly receive the roof sheathing.

7) Generally, very little of the attic space can be used for storage, and it is difficult to maneuver to access HVAC equipment, which is usually mounted in the attic.

8) Trusses are generally not desirable in custom houses where high slopes, long spans, and complicated roof shapes are used. Costs can escalate quickly.

Roof trusses have some very good qualities, as follows:

1) Simple roofs can be erected more quickly than stick-built roofs.

2) Less skilled framers can be used.

3) A house can be sheathed and dried in quickly, keeping the framing drier during construction, thus resulting in lower replacement costs of lumber damage due to excessive moisture exposure.

4) Trusses roofs will generally load the exterior of a residence, thereby allowing loads to flow more directly to the ground.

Stick framing is almost always used on custom houses and sometimes on tract houses. In general, the most economical house will frame with the smallest-sized members. The use of larger-sized members for rafters will almost always result in higher-cost roof framing. This means that for any normal roof covering (not tiles, slate, or concrete), 2×6's are the generally accepted minimum-sized members. The reason for this is that for roofs over 3:12 pitch, the spans for 2×6 rafters at 16" on

center in the Mecklenburg area with 80 MPH wind design load, 20 pounds per square foot roof live loads and seven pounds per square foot dead loads allow a clear horizontal dimension of 14'-6" for spruce #2 and 15'-0" for southern yellow pine #2. These are reasonable spans and for a great number of residences, these spans don't require rafter bracing except for those spans which exceed these values. For 2×8's at 16" on center, spruce allows a clear span of 19'-1" and southern yellow pine #2 allows 19'-9" clear span. For 2×10's at 16" on center, spruce allows a 24'-5" span and southern yellow pine #2 allows a 25'-2" span.

Rarely do you use these allowable spans for rafters, because these spans are based upon the Code allowable deflection in inches of the horizontal span divided by 180. This means that if you use the Code-allowed spans, your deflections will be as follows:

SYP RAFTERS	*HORIZONTAL SPAN*	*TOTAL DEFLECTION*	*DEAD LOAD DEFLECTION*
2×6 @ 16	15'-0"	1.00"	0.25"
2×8 @ 16	19'-9"	1.32"	0.33"
2×10 @ 16	25'-2"	1.67	0.42"

It is best to use good behavior as the design criteria, rather than the Code-allowed limits. A design limitation of 0.25" deflection for dead load is generally an acceptable upper limit. This is equivalent to a total load deflection of 1". Based on this criteria, the recommended allowable horizontal spans for the rafters are as follows:

SYP RAFTERS	*HORIZONTAL SPAN*	*TOTAL DEFLECTION*	*DEAD LOAD DEFLECTION*
2×6 @ 16	15'-0"	1.00"	0.25"
2×8 @ 16	18'-5"	1.00"	0.25"
2×10 @ 16	22'-8"	1.00	0.25"

To demonstrate the economy of stick-built roof framing, the following two figures use the same roof layout, with rafters unbraced and rafters braced. This example shows the maximum economy possible where decisions are made to use materials which meet the Building Code and use good structural engineering and design for good behavior.

To achieve this economy, you should do the following:

1) Have a roof framing plan.

2) Use 2 × 6 rafters and 2 × 8 ridges, hips and valleys.

3) Cut in all hips and valleys.

4) Do **not** overbuild rafters if the overbuild is more than 6'.

5) Use 2 × 6 hogs as a beam with hog splices over a brace. Hog 2 × 6 beams can safely span 6'; therefore, to minimize braces, use a 6' spacing along a hog for braces.

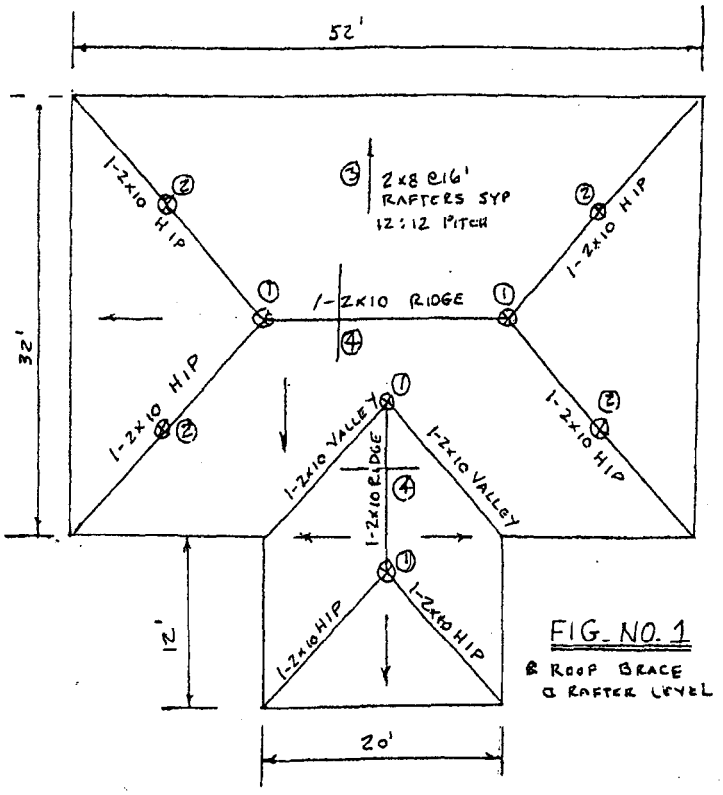
6) Splice rafters over hogs. This is essential in order to have the lowest material cost. Common rafters over 20' in length command premium prices. Some rafters in the 28'-30' range can cost three times the price of rafters in the 14'-16' range.

7) Locate hogs to keep rafter lengths generally less than 16'.

8) Splice valley and hip beams. Locate braces under all splices. Try to equate all splice members' length for maximum economy.

9) If heavy roof covering like tile, slate, or other heavy roofing material is used, use 2 × 8 at 16" rafters to have similar allowable horizontal clear spans for rafters as for regular light shingle roof coverings.

Figure 1 - Example of Stick-Framing Roof Plan without Rafter Bracing



STICK FRAMING ROOF PLAN
WITHOUT RAFTER BRACING

① REQUIRED BRACE AT ALL HIP-VALLEY/RIDGE INTERSECTIONS

② REQUIRED BRACE AT HIPS/VALLEYS IN 11' TO 12' MAX. SPAN HORIZONTAL DIMENSION MEASURED FROM RIDGE OR EAVE

③ NO BRACES REQ'D FOR RAFTERS WITH 2x8 @16" BECAUSE MAX HORIZONTAL SPAN FROM EAVE TO BEARING @ RIDGE HIP OR VALLEY IS LESS THAN 18'-5" SYP.

ALL RIDGES, HIPS & VALLEYS CAN BE 1-2x10.

HIPS AND VALLEYS ACT AS BEAMS SUPPORTED @ BRACE AND RIDGE OR EAVE.

RIDGE IS NOT A BEAM AND REQUIRES NO BRACE

④ 2x6 COLLAR TIES REQ'D ON RAFTERS @ 48" O.C.

BILL OF MATERIALS FOR FIGURE NO. 1:		
Hi Ridge		1-2×10 @ 20'-0"
Hi Hips		4-2×10 @ 27'-8"
Lo Ridge		1-2×10 @ 12'-0"
Lo Valley		2-2×10 @ 18'-7"
Lo Hip		2-2×10 @ 18'-7"
Hi Common Rafter		16-2×8 @ 22'- 8"
Hi Jack Rafters	8-2×8 @ 9'- 5"	8-2×8 @ 20'- 9"
	8-2×8 @ 7'- 7"	8-2×8 @ 18'-10"
	8-2×8 @ 5'- 8"	8-2×8 @ 17'- 0"
	8-2×8 @ 3'-10"	8-2×8 @ 15'- 1"
	8-2×8 @ 1'-11"	8-2×8 @ 13'- 3"
		8-2×8 @ 11'- 4"
Hi Jack Common Rafters	1-2×8 @ 8' - 6"	2-2×8 @ 16' - 0"
	2-2×8 @ 10' - 5"	2-2×8 @ 17'-11"
	2-2×8 @ 12' - 3"	2-2×8 @ 19'-10"
	2-2×8 @ 14' - 2"	2-2×8 @ 21"- 4"
Lo Common Rafters		2-2×8 @ 14'- 2"
Lo Jack Rafters	6-2×8 @ 12' - 3"	6-2×8 @ 4' - 9"
	6-2×8 @ 10' - 5"	6-2×8 @ 2'-10"
	6-2×8 @ 8' - 6"	6-2×8 @ 1'- 0"
	6-2×8 @ 6' - 7"	1-2×8 @ 14'- 2"
Collar Ties		11-2×6 @ 7' - 0"
Braces for Hips & Valleys		4-2×6 @ 16' - 0"
		8-2×6 @ 8' - 0"
		4-2×6 @ 10' - 0"

Figure 2 - Example of Stick-Framing Roof Plan with Rafter Bracing

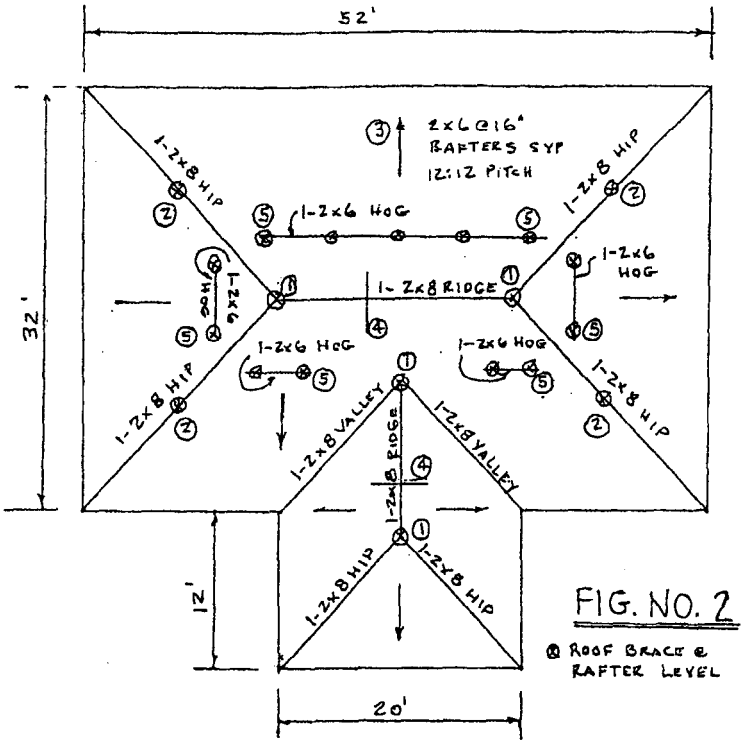


FIG. NO. 2

@ ROOF BRACE & RAFTER LEVEL

STICK FRAMING ROOF PLAN WITH RAFTER BRACING

① REQUIRED BRACE AT ALL HIP-VALLEY/RIDGE INTERSECTIONS
② REQUIRED BRACE AT HIPS/VALLEYS IN 11' TO 12' MAX HORIZONTAL DIMENSION MEASURED FROM RIDGE OR EAVE
③ BRACING REQ'D FOR RAFTERS WHEN MAX HORIZONTAL DIM. FROM EAVE TO RIDGE EXCEEDS 15' FOR 2x6 @16" RAFTERS ALL HIPS, VALLEYS AND RIDGES CAN BE 1-2x8. HIPS AND VALLEYS ACT AS BEAMS SUPPORTED @ BRACE & RIDGE OR EAVE RIDGE IS NOT A BEAM AND REQUIRES NO BRACE
④ 2x6 COLLAR TIES REQ'D ON RAFTERS @ 48" O.C.
⑤ 2x6 HOG ACTS AS A BEAM SPANNING BETWEEN BRACES @ 6' O.C. MAX. HOGS ARE LOCATED TO LIMIT RAFTER SPAN

BILL OF MATERIALS FOR FIGURE NO. 2:		
Hi Ridge	1-2×8 @ 20'-0"	
Hi Hips	4-2×8 @ 27'-8"	
Lo Ridge	1-2×8 @ 12'-0"	
Lo Valley	2-2×8 @ 18'-7"	
Lo Hip	2-2×8 @ 18'-7"	
Hi Common Rafter	32-2×6 @ 12'- 0"	
Hi Jack Rafters	16-2×6 @ 10' - 6"	8-2×6 @ 9'- 5"
	16-2×6 @ 9' - 7"	8-2×6 @ 7'- 7"
	16-2×6 @ 9' - 0"	8-2×6 @ 5'- 8"
	16-2×6 @ 8' - 0"	8-2×6 @ 3'-10"
	8-2×6 @ 13' - 3"	8-2×6 @ 1'-11"
	8-2×6 @ 11' - 4"	
Hi Jack Common Rafters	1-2×6 @ 8' - 6"	4-2×6 @ 8' - 0"
	2-2×6 @ 10' - 5"	4-2×6 @ 9' - 0"
	2-2×6 @ 12' - 3"	4-2×6 @ 10' - 0"
	2-2×6 @ 14' - 2"	4-2×6 @ 10"- 8"
Lo Common Rafters	2-2×6 @ 14'- 2"	
Lo Jack Rafters	6-2×6 @ 12' - 3"	6-2×6 @ 4' - 9"
	6-2×6 @ 10' - 5"	6-2×6 @ 2'-10"
	6-2×6 @ 8' - 6"	6-2×6 @ 1'- 0"
	6-2×6 @ 6' - 7"	1-2×6 @ 14'- 2"
Collar Ties	11-2×6 @ 7' - 0"	
Hogs	8-2×6 @ 6' - 0"	
	2-2×6 @ 22' - 0"	
Braces for hogs	26-2×4 @ 11' - 0"	
Braces for Hips & Valleys	4-2×6 @ 16' - 0"	
	8-2×6 @ 8' - 0"	
	4-2×6 @ 10' - 0"	

There is approximately 3,100 board measure of lumber in the roof framing without rafter bracing, compared with approximately 2,750 board measure in the roof framing with rafter bracing, or about 12½% less lumber with rafter bracing.

Due to the fact that rafter bracing allows rafter splices, the material cost differential for the framing of this roof can be substantial. It is recommended that each builder obtain prices for the bill of materials of each roof so a real picture of the economics of rafter bracing can be seen.

The labor for rafter bracing can be slightly higher than where no rafter bracing is required, but oftentimes is not because the material handled with rafter bracing is lighter, smaller, and easier to handle. The non-rafter braced framing is heavier, longer, and more difficult to handle. Generally, no additional labor costs result from a rafter-braced system.

Oftentimes, rafter bracing is used on horizontal rafter spans less that 15' with 2 × 6@16" framing. This is a waste of material and labor and is uncalled for. Similarly, flat single 2 × 4 nailed to the bottom of the rafter is also seen, with 2 × 4 braces @ 32" o/c Also a waste! The most economical rafter bracing system is the L-shaped hog brace formed with 2-2 × 6's. This is strong and can safely span 6' between braces. These braces can be a single 2 × 4 up to 4' in height and a double up to 10'. At 10' of height, they should be changed to a double 2 × 6 with a mid-height brace for the brace at all heights over 16'. This mid-height brace should be in two directions at 90° to each other.

Many roofs are seen framed with no brace at the ridge/valley/hip intersections. This is often not noted by building inspectors as a deflect, and the roof is permitted to remain without these vital braces. In time, these ridge/valley/hip points will deflect, squatting, in effect, putting undue horizontal forces on the adjacent eaves. We have seen many homes which develop 6" or more deflections and 1"-2" horizontal

displacements of the eave bearing after 10-15 years have passed. Corrections can be expensive.

It has been the author's experience to have a homeowner's insurance policy restored after having it canceled because of this type of roof framing deflection. The insurance company had canceled its policy on the home because of the deflections and only by jacking and removal of the deflection would the company reinstate the policy.

In summary, a roof plan should always be a part of any house plan, with all brace loads so located as to have the least effect on the framing below. Because of the great flexibility allowed in structural engineering where braces can be at angles above 45° with the ceiling and in a circle of 360° around the brace location at the rafter, most load effects of these rafter braced systems can be so located as to have the least economic effect on the framing below, thus making a rafter braced roof system the most economical system in almost all cases.