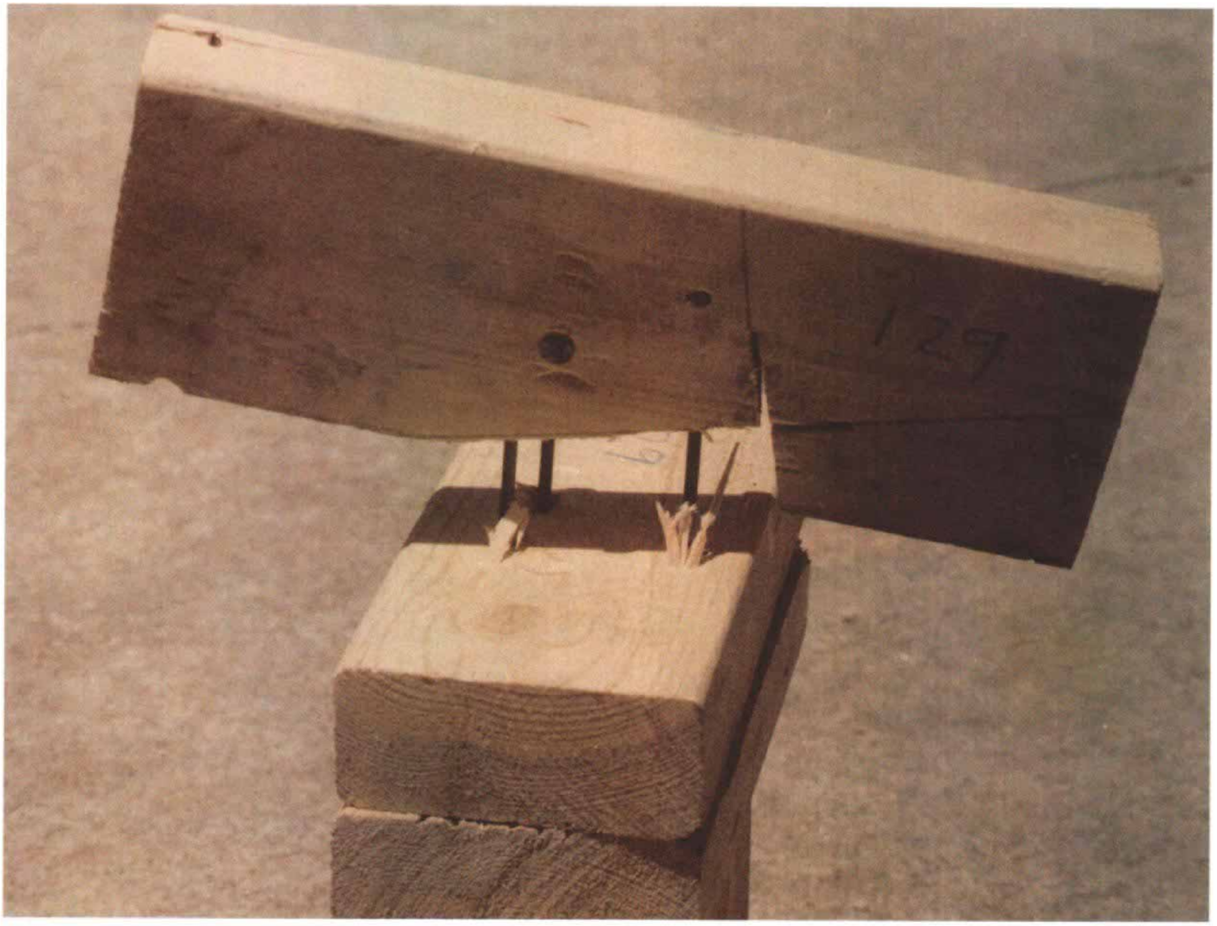
Fine Homebuilding
April/May 1992 No. 74

# Strengthening Plate-to-Rafter Connections

## It may be time to abandon the time-honored toenail



Failure of a toenailed connection.

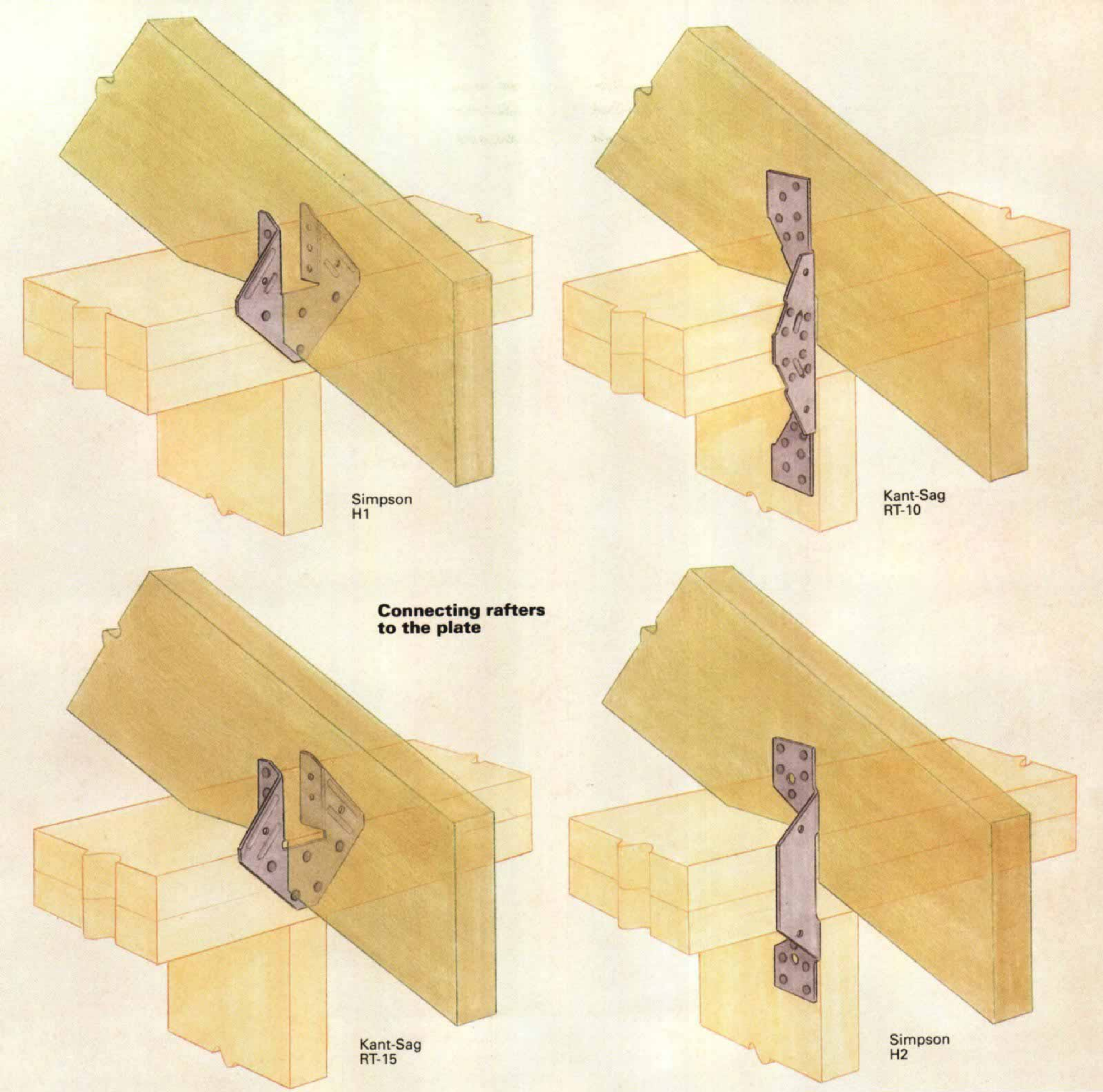
by Stanley H. Niu


Overloaded rafter-tie connection.

Overloaded lag-screw connection.

Late September 1989: Hurricane Hugo clobbers South Carolina. April 26, 1991: Tornadoes knife through Butter County, Kansas. In these and many other instances of extreme weather, wood-frame houses are among the most heavily damaged structures. The mode of failure is predictable: The roof blows off, leaving bare walls to weather the storm.

Many people consider the damage caused by hurricanes and tornadoes to be an act of fate and assume that nothing can be done to prevent the destruction. Perhaps this is true, but I'm convinced that the damage can certainly be reduced, and with minimal expense. If the roof



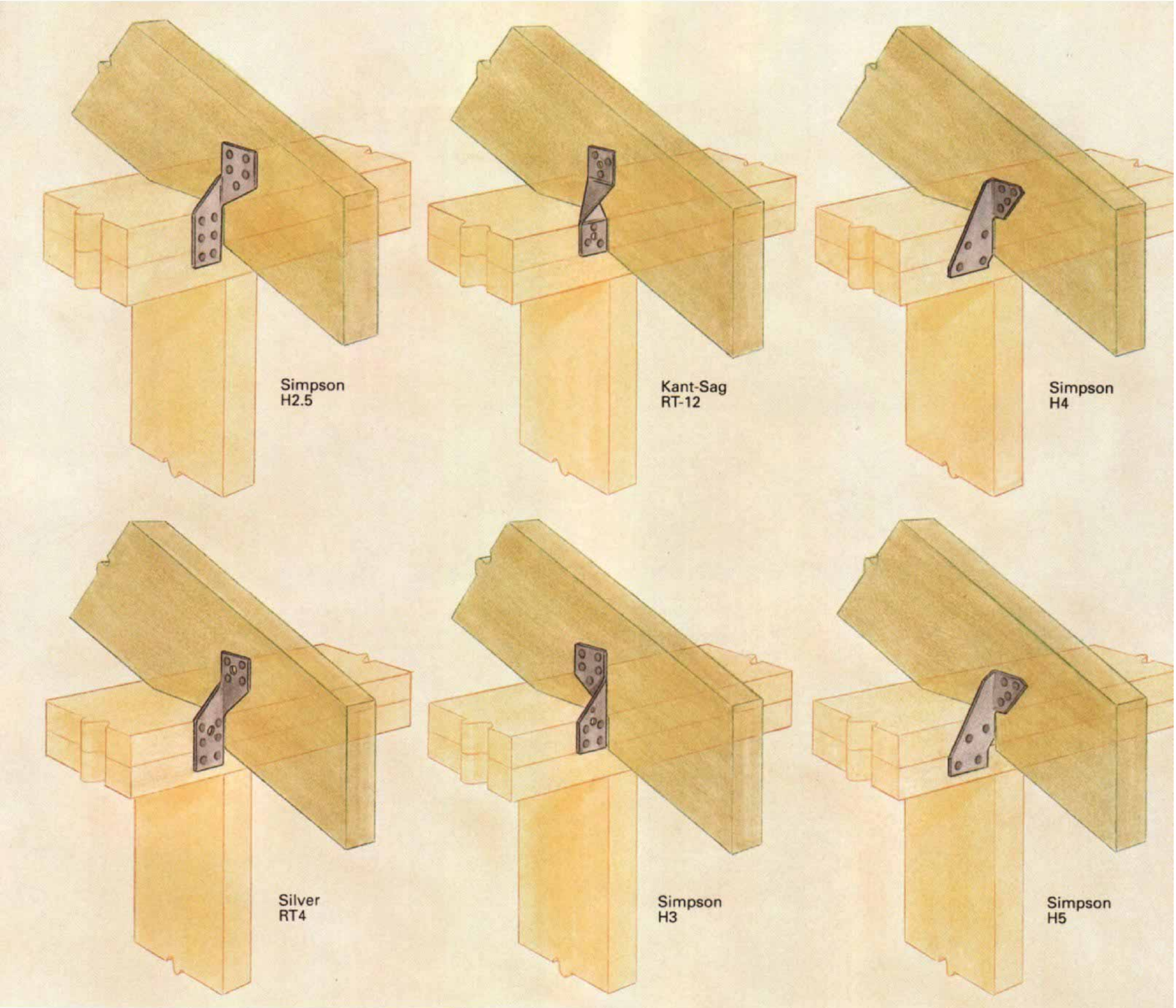

**Connecting rafters to the plate**

stays in place, the rest of the house stands a better chance of resisting the storm. The key is to improve the strength of the connection between the top plates and the rafters. Research I recently undertook with colleagues Laurence Canfield and Henry Liu shows, just how much this connection can be improved.

**Making a better connection—**Although wind pressures on buildings have been studied extensively, only a few studies have examined the strength of the rafter/plate connection. What is known, however, is that a connection made with metal rafter ties is considerably stronger than one made by toenailing. Unfortunately, not all manufacturers publish information regarding the maximum recommended uplift loads their ties can resist. Without those figures, it's tough to pick the appropriate tie. So in our laboratory, we tested a selection of ties in various shapes from several manufacturers (chart p. 39) to establish the ultimate strength of each tie. We also investigated the uplift resistance of toenailed connections, as well as two different sizes of lag-screw connections (the lags were run through the rafter and 3 in. into the plates; a washer was included).

First, I'll give a couple of notes about our testing procedures. Nails used for the three different toenailed connections we tested included 8d common nails, 16d box nails and ring-shanked, 16d common pole bam nails. The 16d nails often split the rafter during nailing, so we predrilled the rafters with a $\frac{5}{32}$-in.-dia. hole. It is unlikely, however, that carpenters would drill pilot holes in the field. Each toenailed connection used three nails: two on one side and one centered on the other side. The lumber we used for all tests was construction-grade stock obtained from a job site, and we inspected it to ensure that no flaws or cracks would bias the test results. After the appropriate rafter/plate connection was made, samples of the assembly were placed in a

Drawings: Bob La Pointe



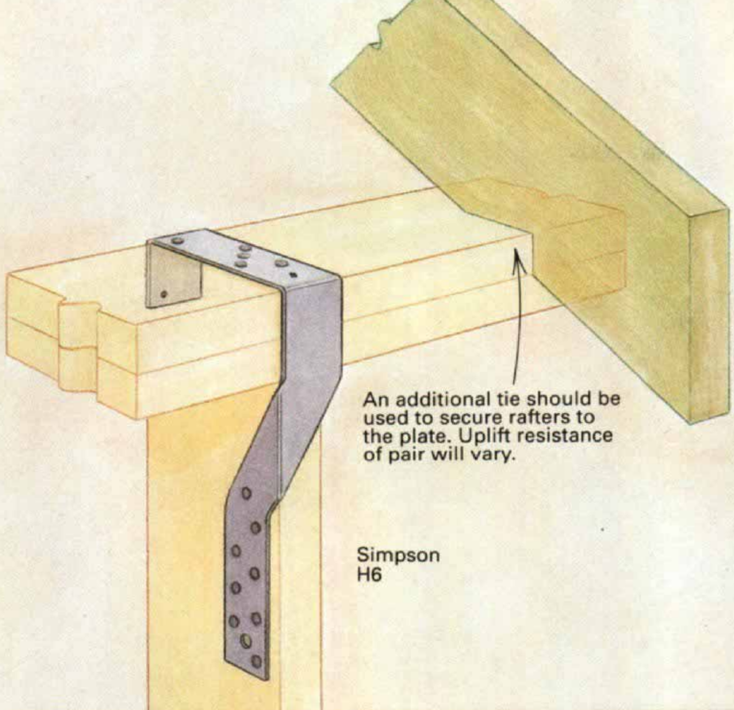

hydraulic test apparatus that pulled the rafter away from the plate. We tested at least 15 connections, pulling until the connection failed.

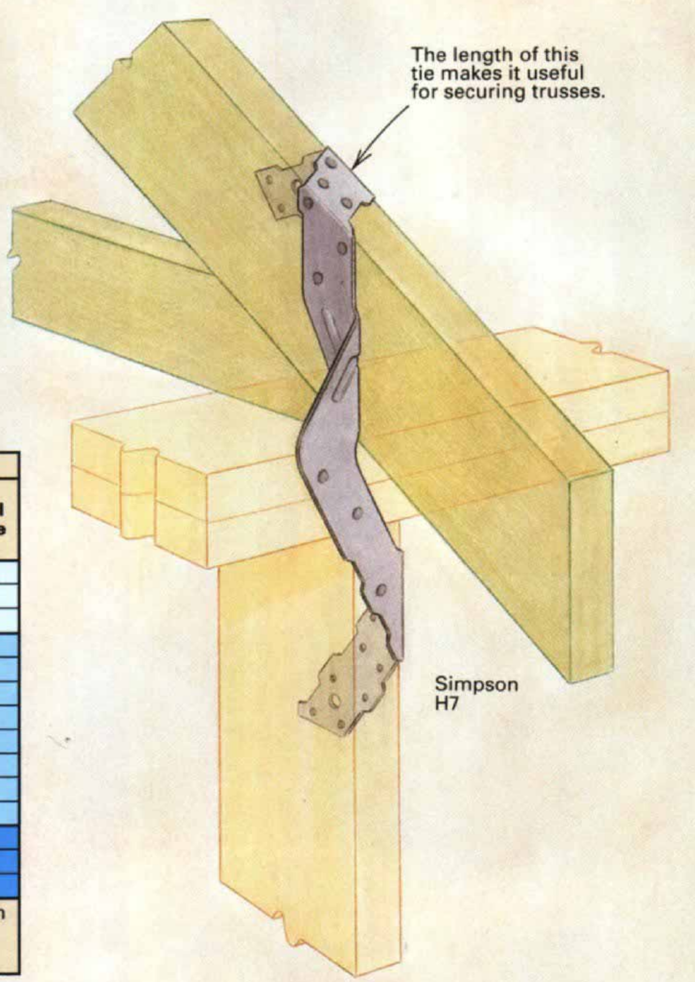
The results of these tests are shown in the chart on the facing page. Ties fell into three groups ranked according to their average load capacity: below 650 lb.; 900 lb. to 1,300 lb.; and above 2,700 lb. (the last group represents the high-performance end of the spectrum, with a load capacity that is double or triple most of the midrange connections). As it turns out, the weakest sample tested was the 8d toenail connection, with an average load capacity of only 208 lb. In contrast, the lowest-capacity rafter tie tested had an average load capacity of 497 lb. When the toenailed connection failed, the nails pulled out of the top plate (top photo, p. 36). In some cases, when the connection failed, the bottom of the rafter split first. When a metal tie fails, it usually tears in half, but the nails stay put (bottom left photo, p. 36). The lag-screw connections failed when the lag pulled free of the top plate (bottom right photo, p. 36). Unfortunately, toenailed rafters are probably the most common rafter/plate connection found in wood-frame houses. In fact, this connection is in compliance with the Uniform Building Code (UBC) and the Building Officials and Code Administrators (BOCA).

**Applying the research—**Putting our results to the test on a hypothetical house shows how important it can be to use the right connection. Consider a house located near Kansas City, Missouri, with a 30-ft. by 50-ft. floor plan and a hip roof. The rafters are located 16 in. o. c., which calls for a total of 86 rafter connections, and the roof has a 3-in-12 pitch with no overhang. The house is located on open terrain surrounded by scattered obstructions having heights of 30 ft. or less. A map of wind speeds shows that the Kansas City area has a basic wind speed of 75 mph (basic wind speed, an engineering term, is the fastest wind speed measured at 33 ft. above the ground with a 2% annual probability of occurrence).

For an 1,800-sq.-ft. roof, the total wind lift on our hypothetical house equals 31,824 lb. Dividing this by 86 connections yields a 370-lb. uplift load per connection. Based on our test results, any of the ties tested would be adequate for this region. However, a connection made with three 8d common nails has a load capacity of only 208 lb. In some weather conditions, this connection would be inadequate.

Now consider the same house located on oceanfront property in South Carolina. The basic wind speed there is 100 mph, so the load per connector would be 957 lb. on the same roof. Metal connectors from the middle group (load capacity from 900 lb. to 1,300 lb.) would be adequate, though some barely so. However, wind speeds




**Rafter/Plate Connections**

| Connector | Ave. load capacity (lb.) | Installation cost per 100[a] ($) | Load capacity vs. cost (lb./$) | Rafter nails | Top plate nails | Stud nails | Nail type |
|---|---|---|---|---|---|---|---|
| Kant-Sag RT-12 | 497 | 35 | 1,420 | 3 | 3 | 0 | K |
| Simpson H4 | 547 | 49 | 1,116 | 4 | 4 | 0 | S |
| Simpson H5 | 610 | 49 | 1,245 | 4 | 4 | 0 | S |
| Kant-Sag RT-10 | 910 | 119 | 765 | 6 | 8 | 6 | T |
| Silver RT-4 | 928 | 60 | 1,547 | 6 | 4 | 0 | S |
| Simpson H2 | 932 | 60 | 1,553 | 5 | 0 | 5 | T |
| Simpson H3 | 1,002 | 49 | 2,045 | 4 | 4 | 0 | T |
| Simpson H1 | 1,115 | 60 | 1,858 | 6 | 4 | 0 | T |
| Kant-Sag RT-15 | 1,199 | 70 | 1,713 | 5 | 7 | 0 | K |
| Simpson H2.5 | 1,216 | 60 | 2,027 | 5 | 5 | 0 | T |
| ¼-in. by 5-in. lags | 1,283 | 175 | 733 | | | | |
| Simpson H7 | 2,726 | 84 | 3,245 | 4 | 2 | 8 | T |
| ⅜-in. by 8-in. lags | 2,783 | 175 | 1,590 | | | | |
| Simpson H6 | 3,150 | 95 | 3,316 | 0 | 8 | 8 | T |

a: Cost based on 1990 estimate.
Key to nail types: K=Kant-Sag NA-111, 1¼ in. long, 0.123 in. dia., smooth shank; S=Silver 1¼ in. long, 0.121 in. dia., smooth shank; T= Truss nail, 1¼ in. long, 0.143 in. dia., annular rings on shank.

of 125 mph were reported during Hurricane Hugo, and lifting loads during the storm would have been 1,496 lb. per connector. Only the top two connections would have been adequate: the H7 tie and the ⅜-in. by 8-in. lag screw. Of course, the rest of the structure would require sufficient strength to prevent it from being blown off the foundation. But either of these connections would have improved the chances of keeping the roof in place.

**The cost of safety—**Our research was done in a laboratory, so it was easy to see which connection would be the best. But on the job site, "best" often competes with "cost-effective" for the right to determine what gets built. That's why we calculated the installed cost of each connection. In determining the costs, we assumed that a carpenter would take 10 seconds to install each nail and would earn an average wage of $21 per hour. The average house would probably require from 80 to 120 connectors. As you can see from the chart above, the additional cost incurred by using rafter ties is negligible compared to the total cost of the house.

Manufacturer's guidelines suggest that ties be installed with at least four nails each to prevent the tie from rotating. However, more nails ensure a better connection.

**Improving the Improvements—**Though the rafter ties performed well as a group, we identified some modifications that could improve their uplift strength. The H4 and H5 rafter ties could be made from 18-ga. sheet metal instead of the 20-ga. sheet metal currently used, and the nail holes could be slightly larger to accommodate truss nails. The H2 rafter tie has a hole on its face between the rafter and the top plate. In our tests, the tie failed by tearing in half, with the tear starting on the inside edge of the tie and progressing to this hole. Elimination of the hole might improve the strength of the tie. The RT-10 rafter tie, which is similar to the H2, also failed by tearing in half between the rafter and the top plate. This tie would be improved if it were wider (more like the proportions of the H2). Generally, the 18-ga. sheet metal used for most of the ties seems a good compromise between strength and low manufacturing cost. □

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