



When Nails Fail

When watching builders put up a light-frame wood house, it's not hard to wonder how such construction would be possible without the use of nails. Nails have been holding things together for a long time. In fact, the earliest recorded use of nails in construction dates to around 3400 BC with evidence indicating their use in shipbuilding and furniture construction.

Nails have been produced through different methods of manufacture and taken on a variety of shapes, but they have never left us. In early American days, they were handmade, wrought by pounding rectangular shapes with a hammer. Later, as the country entered the nineteenth century, cut nails made their appearance and paved the way for the modern nail.

And so, today, we can watch workers with nail guns attach the skeleton of a house--the floor, the sheathing, the bird mouth joints, the rafters and roof deck.

All good. Nails attach.

But they also detach.



One doesn't have to look far to see the aftermath of hurricanes, tornadoes and earthquakes that have ravaged the country in recent years. Video footage shows an earth strewn with the bones of torn houses, walls, and roofs, once firmly bound by nails, now piles of wreckage. These results demonstrate that, while nails are still effective and efficient in constructing wood frame houses, they have their limitations.

Anatomy of Failure

Failure occurs in different ways: nail withdrawal; splitting of the wood around the nail; bending of the nail itself, usually due to improper nail placement or size; or inadequate penetration depth into the wood. An additional issue is an irregular nail schedule including areas where nails miss their connection altogether. In the aftermath of Hurricane Katrina, for example, a damage assessment technical team determined that the most vulnerable part of the structure occurred where just a few nails or screws were missing.



But even when nails have been correctly used, they are still susceptible to failure. The reason is load. In light-frame wood construction, nail failure typically refers to a situation where the nails used to connect wood members like studs and sheathing or bird mouth joints, pull out or bend due to repeated stress, causing the joint to weaken or fail. Such stress typically comes from high winds or seismic events.

In search of more sustainable housing, engineers and scientists have studied how nails perform under stressed conditions. Most tests have been monotonic, which focus on the static performance of nails by measuring direct pullout strength. While such tests provide valuable data, they do not replicate how nails perform under the realistic conditions of wind forces. Some cycling tests have been done, but usually they have involved a low number of cycles with a small number of peak loads. Such tests do not mimic realistic violent weather conditions where the cycles are rapid, frequent, erratic, and sustained. Under such conditions, loads can double or triple in less than a second. Over time, the continued stresses brought by wind or seismic events cause gradual and cumulative withdrawal of the nail.



The Incremental Issue

In their article “Failure Mechanisms of Roof Sheathing under Fluctuating Wind Loads”, authors Henderson, Williams, Gavinsky, Gregory & Kopp (2013) cite studies that report on research involving the application of fluctuating wind loads to oriented strand board and plywood panels fixed to rafters with twisted and ring shank nails. They observed that failure occurred differently depending on the type of nail. With

twist shank nails exposed to large peak pressures, the panels separated from the rafters in small increments while the ring-shank nails failed more suddenly. Regardless of failure progression, they observed that peak gusts that come in short duration leads to nail failure over time.

In full scale tests on a gabled roof house at the Three Little Pigs Project in Ontario, researchers Morrison (2010) and Morrison et al. (2012) noted that “under spatially and temporally varying wind load applied to the roof... the largest displacements were at the toenail roof-to-wall connections.” Additional studies have found that the most common type of failure in typical

roof-to-wall connections is due to nail withdrawal, nail pullout or nail slip.



Incremental nail weakening suggests that, over time, a light-frame wood house, while still standing and appearing secure, can be highly vulnerable. A weakened structure is more likely to fail when the next windstorm strikes.

A Simple Solution

There is plenty of evidence indicating that wood frame houses built with nails gradually lose their integrity after repeated exposure to wind or seismic events. There is currently no practical approach to eliminating nails altogether, but the strength of a wood frame structure can be significantly increased—by as much as three-fold—with the simple addition of a structural adhesive at all the interfaces in the frame. Extensive testing has shown that Climate NS® (Non-Slump) Adhesive, which was formulated to work in conjunction with traditional nail schedules, can dramatically increase structural integrity. Before components are nailed in place, the adhesive bead is applied along all interfaces. The non-slump NS formulation allows the adhesive to hold firm when applied to both horizontal as well as vertical services. The force of nails then spreads the adhesive along the studs, sheathing, rafters, and decking. Because Climate® NS is a 100-percent-solids formulation, there is no evaporation of solvent or shrinkage. Curing takes place naturally by reacting with moisture in the material substrates and atmosphere, usually within 24-48 hours.

Extensive testing at Western Michigan University’s Bronco Labs in Kalamazoo, Michigan, compared sheer walls built with nails only to walls built with nails and Climate® NS Adhesive when exposed to cyclic stresses. In repeated tests, walls built with nails failed at approximately 4,000 lbs. while walls built with nails and Climate NS failed at 14,000 pounds.

Because Climate is highly resilient—it can be elongated to nearly 1000% without tearing—it has extraordinary energy-absorbing properties. Thus, when walls constructed with Climate broke at 14,000 pounds, none of the bond lines failed. Applied forces dissipated along the wall specimens settling at the sill plate which split.



The use of an adhesive provides an exponential increase in building integrity. Nails are strong only at the point where they are applied. Thus, stress from outside sources concentrates at the nail connection, known as point loading. In contrast, the use of an adhesive provides a continuous bond along all surfaces, thus distributing cycle forces along a much larger area.

Additionally, where construction designed to achieve high R-values is a critical objective, nails are problematic because they operate as thermal bridges, allowing heat to travel through walls and roofs. The use of an adhesive reduces the number of nails needed to build a secure wood-frame structure, making for a more energy-efficient building.

Nails will remain the primary fixturing method for constructing wood frame houses for many decades to come. They provide an immediate and efficient attachment system that works well in the field. But as violent weather and earthquakes continue to create havoc in communities around the world, it is important to understand that nailed structures are vulnerable. The simple application of a strong, highly resilient adhesive can markedly increase the ability of a wood frame structure to survive. It has been calculated that the application of Climate Adhesive throughout a building frame typically increases the total cost of material by 1-2 percent. The savings resulting from the prevention of destruction and the potential loss of life, however, is incalculable.

Photos: Aftermath of tornado striking Portage, Michigan neighborhood, May 7, 2024.

References

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