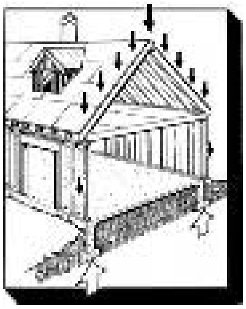
PRACTICAL ENGINEERING



Buckling Under Pressure

by John Siegenthaler, P.E.

Most framers install thousands of wooden studs and built-up posts every year without ever questioning their ability to carry vertical loads. Conventional job-site wisdom says that, in most cases, 2x4s are plenty strong and that 2x6s, used primarily for the extra room they give for insulation, are overkill — even on 24-inch centers.

For the most part, this conventional wisdom is right. Studs and columns rarely fail from compression — that is, being crushed under load. But there are situations where extra wall height or greater than normal loading might cause a stud or a built-up post to fail by *buckling*, or suddenly bowing out to one side.

In theory, a slender column made from elastic material such as wood or metal will buckle into a curved shape at some predictable loading, then snap back to its original shape when the load is removed. You can demonstrate this by standing a yardstick on end. Press down the top and the yardstick bends into a curve parallel to its thin dimension; let up, and it springs back. You can do this over and over with no permanent change in the yardstick.

Figure 1. *A double 2x4 post supports the structural ridge beam of this 16-foot-high cathedral ceiling. Is the post strong enough?*

In a building, however, buckling usually leads to a devastating collapse because the load that creates the buckling continues to press down until the buckled member fails. Buckling failure is prevented by properly designing columns and tall studs.

Take a look at the photo in Figure 1. This shot was taken on the job site of a high-end house in New England. The rafters of the 16-foot-high great room ceiling are resting on a strong LVL ridge beam. But note the post that's holding up the end of the beam — a couple of 16-foot-long 2x4s spiked together. Note, too, that the sheathing behind the post is an insulative fiberboard — not a structural sheathing.

Is this post strong enough to resist buckling? Let's find out.

Preliminaries: Slenderness Ratio

The 1992 *National Design Specification*, or *NDS* (American Forest and Paper Association; 202/463-2733), widely accepted by building codes for the design of wood members, states that the ratio of the *unbraced* length of a stud or column divided by its width in the direction of buckling cannot exceed 50 (except during construction, when it is temporarily allowed to be as high as 75). This index is called the *slenderness ratio*.

The *NDS* (Appendix A.11.3) also states, in effect, that stud walls with adequately fastened structural sheathing on at least one side are protected from sideways buckling and thus only need to be evaluated for buckling in their stronger direction — the $3\frac{1}{2}$-inch dimension of a 2x4, for instance (see Figure 2). The sheathings the *NDS* refers to are the common structural sheathings such as plywood and OSB, but not drywall, thin paneling, foam sheathing board, or other nonstructural insulative sheathings.

Now apply this to the double-stud column in the photo, which is 16 feet tall. Let's evaluate it in its weaker direction first — the 3-inch dimension:

$$\frac{16\text{ ft.} \times 12\text{ in./ft.}}{3\text{ in.}} = 64$$

The post definitely fails the test in its weaker direction, meaning that it might have a tendency to buckle sideways under load. Even evaluated for the $3\frac{1}{2}$-inch dimension, it has a slenderness ratio of 55 — still too high. Solid horizontal blocking or structural sheathing could fix the problem for the weaker direction by shortening the unbraced length of the post. Or you could add an additional stud lamination, making the post $4\frac{1}{2}$ inches wide in its sideways dimension. Calculating the slenderness ratio for a triple 2x4 post:

$$\frac{16\text{ ft.} \times 12\text{ in./ft.}}{4.5\text{ in.}} = 42.7$$

Now the post is okay in the sideways direction. But there's no easy way to

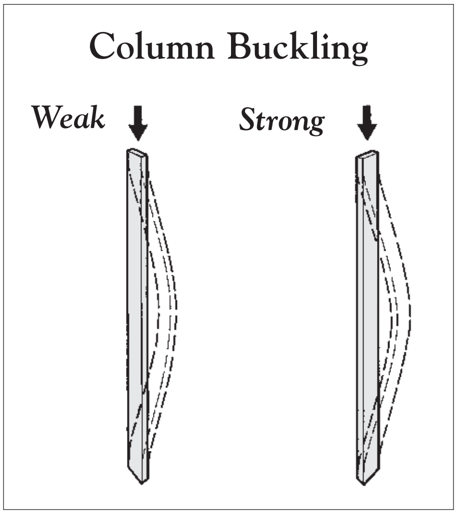


Figure 2. *A stud or post must resist buckling in two directions — sideways (the lumber's weaker direction) and perpendicular to the wall plane (the stronger direction). Structural sheathing or horizontal blocking will prevent sideways buckling, so often the "stronger" direction is the problem.*

Compressive Stress Calculation

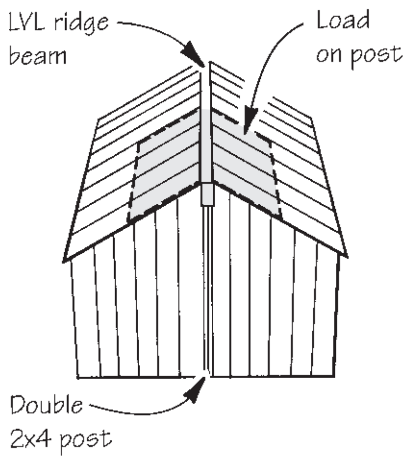


Figure 3. *The load carried by the double 2x4 post is one-fourth the total roof load for the space.*

brace the post in its 3½-inch direction, unless we use a larger stud size. With a 2x6 post, the slenderness ratio is 35, but now the builder has a post sticking out of the wall.

Figuring the Actual Compressive Stress

The high slenderness ratio gives us an idea that the column may not perform well under load. But we still haven't looked at the actual load the column is supposed to carry. Column design gets a little more difficult at this point. The process involves determining the *allowable compressive stress parallel to the grain* (F_c), reduced according to *NDS* design criteria for columns, and comparing this reduced F_c to the *actual* compressive stress (f_c) the column or stud will experience under maximum loading, to make sure the actual stress is less than the allowable.

Determining the actual compressive stress is a matter of basic load calculation: figuring out how many pounds per square inch of load are pressing down on the top of the stud or column. Let's find the stress on the post in Figure 1. The ridge beam the post is carrying is 16 feet long and supports the rafters for a room 16 feet wide. So the tributary area for the end of the beam supported by the post is 8x8 feet, or 64 square feet (see Figure 3). Since the house is in an area that gets a lot of snow, we'll assume a total roof design load of 50 psf. That means that under maximum loading, 3,200 pounds are bearing down on the top of that post.

The top of the post is 3x3½ inches, or 10½ square inches. So the actual compressive stress is

$$f_c = \frac{3{,}200 \text{ lb.}}{10.5 \text{ in.}^2} = 305 \text{ psi}$$

That's the actual maximum stress; now we have to figure out the *reduced* allowable stress and compare them.

Comparing With the Allowable Stress

The *NDS* procedure for determining the stability of columns requires you to adjust the listed allowable compressive stress, F_c, for the species and grade of lumber you are using by multiplying by a *column stability factor* (C_p). Sounds simple enough, except that the formula for calculating C_p is quite complex. Rather than plow through the algebra, I have simplified the C_p calculation into a graph that applies to sawn wood studs and columns used *under normal service conditions*. (For unusual conditions, such as high temperatures or moisture levels, refer to the *NDS* for additional correction factors.)

To determine allowable stress for a column or stud, use the following procedure:

Step 1: Look up the values for the modulus of elasticity (E) and compressive stress parallel to the grain (F_c) for the lumber you are using. These are found in the *NDS Supplement* and other lumber references.

Step 2: Calculate the value of x using the following formula:

$$x = \frac{0.3(E)}{(F_c)(L/d)^2}$$

where

L = the length of the stud, or length between lateral bracing points, *in inches*
d = the width of the stud in the direction of potential buckling *in inches*
E = the modulus of elasticity for the species and grade of lumber (psi)
F_c = the allowable compressive stress of the lumber (psi), modified by other correction factors from the *NDS* as necessary for nontypical applications

I derived this formula from more complicated formulas found on pages 14 and 104 of the *NDS*. (Note that we are talking about visually graded sawn lumber used in normal service conditions.)

Step 3: Use the value of x to look up the value of C_p from the graph, page 62. Make sure you distinguish between columns and studs when using the graph.

Step 4: Multiply F_c by C_p to get the reduced allowable compressive stress for the stud or column. Compare this with the actual compressive stress; if the actual stress is less than the allowable stress, the stud or column is adequate.

Let's do this for the post in the photo.

Step 1: The lumber is No. 1&2 Spruce-Pine-Fir, which has an E value of 1,400,000 psi and a listed F_c value of 1,265 psi (including the 1.15 size factor increase from *NDS* Table 4A).

Step 2: Plug these values into the formula to solve for x:

$$x = \frac{0.3(1{,}400{,}000 \text{ psi})}{(1{,}265 \text{ psi})(192 \text{ in.}/3.5 \text{ in.})^2} = .11$$

(Note that we're evaluating the post in its stronger orientation, the 3½-inch dimension. If it fails in its stronger direction, it will also fail in the weaker direction if it's not braced.)

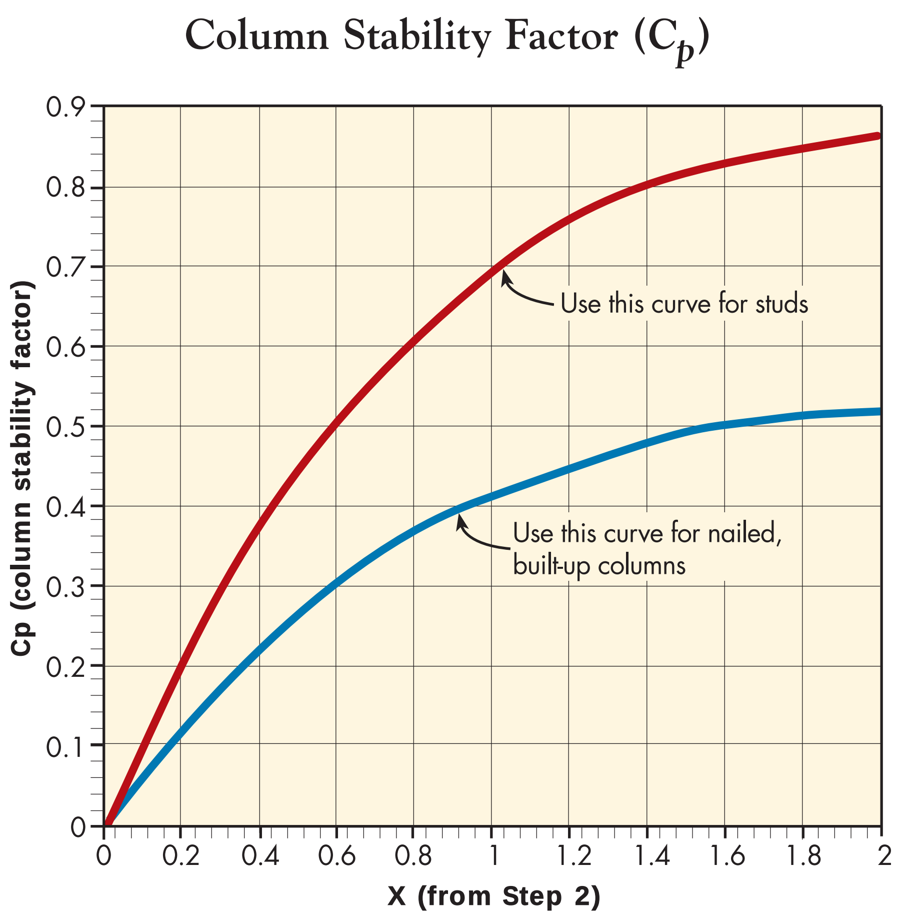
Step 3: Using the blue, or lower, line on the graph for nailed built-up columns, $C_p = .06$

Step 4: Multiplying F_c by C_p, we get the reduced allowable compressive stress on the post:

$$1{,}265 \text{ psi} \times .06 = 76 \text{ psi}$$

Stressed Out

Compared with the actual stress of 305 psi, the post is overstressed by a factor of 4! This post should not be considered stable against buckling. Remember, too, that we looked at



Use the value of x to find C_p. For columns, use the blue, or lower, line; for studs, use the red, or upper, line.

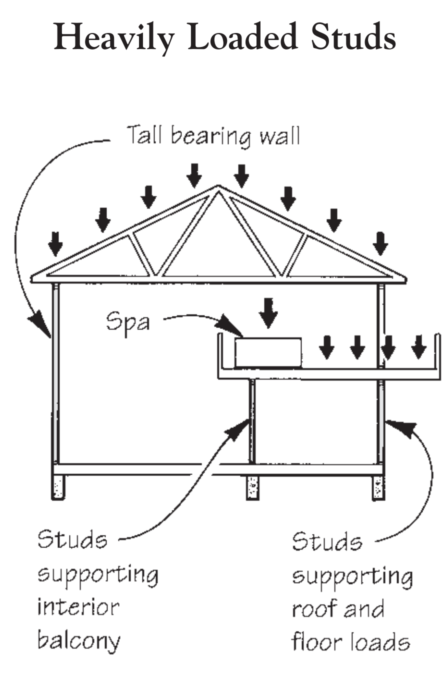


Figure 4. *This building section illustrates three areas where you might need to check for stud buckling: tall bearing walls, exterior walls carrying unusually high combined loads, and unsheathed interior bearing walls carrying heavy loads.*

the post's stronger dimension — the $3^1/_2$-inch dimension. Since the insulating sheathing should not be given structural credit, the post should be looked at in its weaker direction, too — the 3-inch dimension. Without running through all the numbers again, the allowable stress, evaluating the post in its weaker direction, is 50.6 psi — only about 16.6% of the actual maximum compressive stress.

What's the Best Fix?

We've already seen above that the $3^1/_2$-inch dimension of a 2x4 post is too weak for such a tall post. The builder could have framed that end wall with 2x6s. Using the previous four-step procedure, the reduced allowable stress for a 2x6 post is approximately 206 psi (x = 0.29, C_p = 0.17. If you check this number, remember that the *NDS* F_c value for a 2x6 — 1,210 psi — is slightly less than the F_c for a 2x4, because the size factor increase gets smaller as the lumber gets wider.) The actual compressive stress on the top of a double 2x6 post is

$$f_c = \frac{3{,}200 \text{ lb.}}{(3 \text{ in. x } 5.5 \text{ in.})} = 194 \text{ psi}$$

This is less than the reduced allowable stress, so it's okay. Remember, too, that with nonstructural sheathing, the builder should also add horizontal blocking at midspan all the way out to the corner of the room. The blocking cuts the effective length of the post in half, and brings the slenderness ratio down to 32 — well below the 50 maximum.

Other Places to Check

In addition to structural posts, you may need to check studs in tall bearing walls, as well as bearing walls that carry unusually high loads. Figure 4 gives some examples of places to check for stud buckling. Keep in mind that interior finishes like drywall and $^1/_4$-inch paneling don't offer much restraint against sideways buckling, so heavily loaded interior bearing walls may need blocking or structural sheathing.

Temporary bracing. A couple of years ago I was called in to design a floor heating system for a stone house that was being gutted and retrofit with a new roof. Since a new slab was to be poured, the carpenter had left out all the interior walls and temporarily supported the massive new roof framing with a few long 2x6s spiked together as columns under the long LVL ridge beam.

Construction slowed as the weather got colder, and then we were hit with one of the worst winters of the century in this area. Several feet of snow piled up on that roof and eventually took its toll as the temporary posts buckled and the roof collapsed. Fortunately no one was hurt; the last I heard, the contractor's liability insurance was about to take a hit.

Would the roof have collapsed under normal circumstances? Probably not. But it demonstrates the kind of temporary conditions to watch out for. Anytime, for example, that you're having a pallet of plywood or roof shingles lifted up to the top of an unsheathed structure, watch out. Such a concentrated load can cause a wall to bow. ■

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