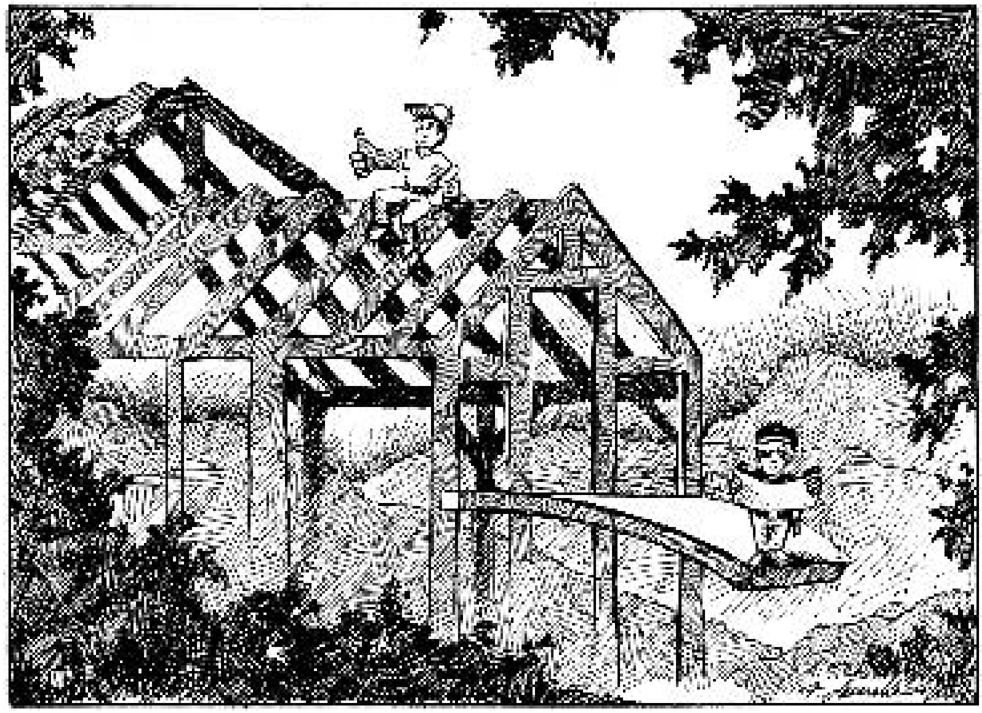
Secrets of Structural Engineering

by Harris Hyman

For most light construction, rules of thumb are good enough

I like to think I am a mature adult and that criticism just washes off, but I thought for months about a letter published last summer in The Journal (see: "Too Many Specialists" 6/88, p. 5). In it, a reader suggested that since everyone with a decent education can handle algebra, a few formulas might be more useful than the rules of thumb I presented for designing cantilever decks. I apologize for oversimplifying; here is my confession.



How We Calculate

We structural engineers don't really know quite what we are doing. We try to make buildings safe and sound, but we have our limitations. Let's look at a floor system. In a light frame building, it is an array of joists, often placed on top of a girder. The builder asks three questions of the structural engineer: What size should the joists be? How far apart should they be spaced? How big should the girder be? Simple enough for the engineer.

Here's how to calculate it: First look up the "design load," which is the expected weight on the floor. For a living room, Architectural Graphic Standards (John Wiley & sons) gives a typical oad of 40 pounds per square foot.

The beam formula can be used to figure out a number of dimensions. The formula is:

$$S = \frac{(Wd/144)\ (18L^2)}{f}$$

Here is what each variable represents. W is the standard load (pounds per square foot), and d is the spacing between the joists (expressed in inches). L is the length of the joists (expressed in feet), and f is the "design bending stress) (expressed in psi). S is the beam section modulus, a measure of the strength of the joist. You look this up in a table to find the corresponding joist size.

Let's try the formula. We already looked up W in Architectural Graphic Standards; it is 40 psf. The joists are usually spaced 16 inches on-center, so that is the value of d. The joists are to span 14 feet, so that is the value of L. The design-bending stress depends on the material, and the table in Architectural Graphic Standards gives 1,200 pounds per square inch for construction-grade spruce, so that is the value for f.

Plug the numbers into the formula:

$$S = \frac{(40x16\ /\ 44)\ x\ (18x14^2)}{1{,}200}$$

and we find that S – 13.07.

For a 2x8, we know S = 13.14. So, 2x8s, 16 inches center to center, can be used here with a little (.07) to spare. (Evaluating the girder is a similar process, with a slightly different formula.)

Okay, we've played engineer and carefully run through the formula. A computer can also do this for you and display it with screen graphics and many decimal places, but what do we rally know?

Let's look at a small room, say 12x15 feet. If you want a design load of 40 pounds per square foot, this gives a total load of 7,200 pounds. That's an incredible amount of baggage, equivalent to 40 people, or two yards of concrete, or my Chevy pickup with a tire-crunching overload. Designing for 40 psf seems very cautious. Yet, 40 psf is actually a much lighter load than is used for residential structures. More common are 50 and 60 psf, and I generally use 100 psf for living rooms.

A Look at the Lumber

Now let's look at construction-grade spruce. I have run controlled tests on lumberyard spruce, bending 2x4s to destruction. I've found that if you cull out the garbage – stuff with big knots, half bark, nicks, chips, warps, or twists – the wood will take a stress of 6,000 psi to 9,000 psi. that's a bit stronger than the standard 1,200 psi design stress it's rated at.

So actual wood strengths can be much higher than their standard rating. Combine this with the fact that we tend to be very cautious with the psf design loads, and on the whole a building can be about 20 times stronger than it really needs to be. As engineers, we've carefully followed standard, well-accepted, by-the-book formulas to create over-built, expensive monsters. This is prudent, but is it the best approach?

We rely on experience and, occasionally, experiment. Our experience tells us that 40 psf and 1,200 psi work out pretty well, and that structures that hedge on these numbers seem a little weak.

Dynamic Loading

This engineering analysis has assumed two things: One, that 40 psf is a realistic living room loading, and Two, that buildings fail most often when the floor falls in. But let's take a closer look.

How is a floor really loaded? Numbers like 40, 60, or even a 100 pounds evenly distributed on each and every square foot fit conveniently in a formula, but it does not describe the real world. In my living room, there are a few pieces of furniture, a 400-pound wood stove, and a lot of raucous kids running around. People come over to visit and stand around and sometimes dance. Does this seem like 40 pounds on each and every square foot?

Really, the floor has a dynamic loading, with a variety of changing impacts. This dynamic loading can be analyzed, but this takes a complex and costly process. On a $50,000,000 bridge, we structural types actually do this sort of thing, but for a living room? Bouncing is the real living room load, and 40 psf is simply convenient as shown by experience. It gives a pretty good low-cost working tool.

Buildings Rarely Fall Down

More important is the idea people have that buildings fall down. In general, they don't. Wood frame buildings almost never fall down. I once did an insurance investigation on a house that actually used 2x8s to span 15 feet in the living room. When I dropped my 220 pounds into the sofa, coffee splashed out of the cup on the adjacent table, crockery rattled on the kitchen shelves, and a small tidal wave roared through the goldfish bowl. The house drove the owners crazy. But, when asked, the builder produced engineering calculations that showed adequate strength, so why was anyone worrying? Well, it didn't feel good.

After a blizzard of letters from the homeowners' lawyers, the contractor made some adjustments. The owners lost some space to allow for columns and girders. They learned to live with a slightly soft living room, and the contractor ate the cost of the remedial construction.

A more careful design would have been a lot cheaper and more satisfying.

It should have examined whether the building was stiff enough to do the job. These calculations are based on rules-of-thumb. Engineering is a little more sophisticated than a good guess, but it is well tempered by a lot of practical tests over many years.

When to Innovate

For most work, experience and rules-of-thumb will do, but when the spans become larger and the framing costs become significant, it might be time to become inventive. While it may not be profitable to use an innovative framing system on a small house, some experimentation could be worthwhile for 100 feet of clear span in a mall or small auditorium. It could also be a disaster, like the Hartford Civic Center, the Tacoma Narrows Bridge, or the Crown Center Skywalk.

Structural experiments are processes that look at the extra capacity you need and adjust the material or the span to your requirements. When do you experiment? When there are significant gains to be made. It's a little silly to weaken the living room floor to save $75 on a $150,000 house, but it's equally silly to refuse to consider new methods for a large open space.

I'll suggest two sources for getting an insight into structure. Simplified Engineering for Architects and Builders is the standard reference book that explains how to do basic structural calculation, and Why things Don't Fall Down explains how to think about structures. The two books are a good match that combine insight with nuts-and-bolts.

Simplified Engineering (John Wiley & Sons) was written 50 years ago as a course text, and it has been used by more than half the architects in the country as a basic reference. James Ambrose updated Harry Parker's original edition. Its sixth edition is a thorough treatment of most aspects of ordinary structural work. The best thing about it is you don't need calculus, as you do for most structural texts.

With basic high school algebra, most designers can use the book. Simplified Engineering works out lots of examples and includes discussions on how and when to apply formulas. It covers wood, steel, and reinforced concrete.

Why Things Don't Fall Down, (Pelican Books) by Dr. J.E. Gordon, is a wonderful companion piece. It requires a minimal knowledge of algebra, but it offers a thorough understanding of structure. It is also an excellent history book, tracing the development of our modern thinking about structure. Moreover, it is an excellent anatomy book, dealing with the skeleton and structure of a living creature. I reread it every couple of years and find some new insights.

These two books belong together. Without Gordon, Ambrose seems to grind numbers without understanding, and Gordon without Ambrose makes us effete critics who can't really put it together.

After all of this you might be asking, So, how big should the joists be? The old rule of thumb still works: Divide the span by 2 and add 2. For example, a 12-foot span divided by 2 is 6, plus 2 is 8; so use 2x8s. Call your neighborhood engineer when the spans exceed 20 feet. ■

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