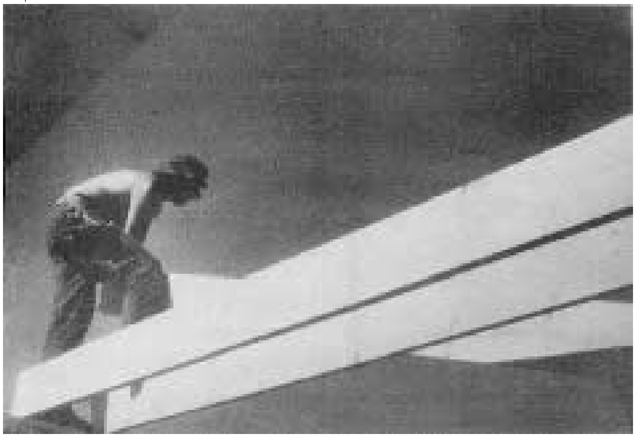


DEFEATING DEFLECTION

Avoid bouncy floors and cracked plaster by choosing the right joists, floor trusses, and plywood I-beams.

by Paul Hanke

Most residential and many light-commercial floors are built using wood-frame construction. This usually consists of joists with a plywood subfloor, but occasionally long-span parallel-chord trusses substitute for joists. Prefab plywood I-beams are starting to appear as an alternative to both. Sometimes heavy plank-and-beam construction is used.

Such floors are rarely designed using engineering formulas. Instead, builders use seat-of-the-pants guidelines or span tables (after which, the plumbers come along and make Swiss cheese out of everything). Yet this can produce squeaky or bouncy floors, which are a frequent source of callbacks. In this article you'll learn how to design a proper wood floor without recourse to an engineer.

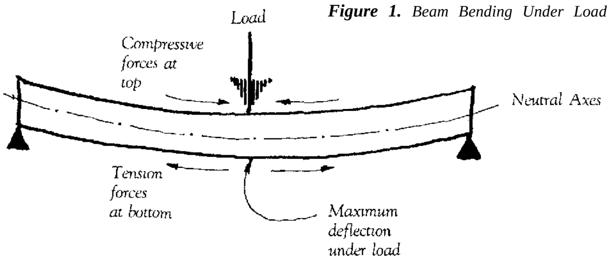
How Floors Behave

It is first necessary to know how floors behave. A typical joist, resting on a mudsill at one end and supported by a girder at the other, behaves like a simple beam. If you apply a load in the center, the joist will bend (or *deflect)* into a slight curve (see Figure 1). In this condition, the piece of lumber is like a curve in the road; the lower side of the curve stretches and becomes longer, and the upper side is squeezed into a shorter radius. This means that the wood fibers on the bottom are pulled into tension by the load, and the fibers at the top are squeezed together in compression. Hence, the very top and bottom of the joist are at maximum stress. Along the center is a line called the neutral axis where tensile and compressive forces are zero.

Loads

Joists are spaced fairly close together and covered with plywood sheathing, which distributes any applied load over several joists. Therefore, we generally treat floor loads as *uniformly distributed* as opposed to *concentrated*, as shown in Figure 1. (Concentrated loads. however, can be significant factors in the design of plank-and-beam floors.)

Figure 1. *Beam Bending Under Load*



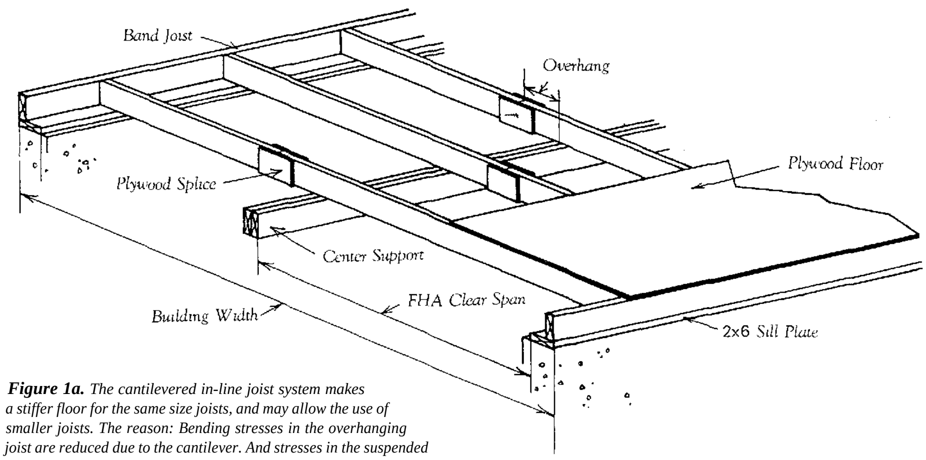


Figure 1a. *The cantilevered in-line joist system makes a stiffer floor for the same size joists, and may allow the use of smaller joists. The reason: Bending stresses in the overhanging joist are reduced due to the cantilever. And stresses in the suspended joist are reduced due to the shorter span.*

Loads are divided into two basic types—live and dead. Dead loads are composed of the weight of the building materials themselves and anything permanently attached to the building. Live loads include people, furniture, snow, and other forces that come and go.

Residential live loads for floors range from 40 pounds per square foot (psf) for most rooms, to 30 psf in bedrooms and attics, to 20 psf in attics that have limited storage capacity and no possibility of future rooms. Dead loads, including joists, subflooring, and the ceiling below, are typically assumed to be about 10 psf, so a combined total load for a living-room floor is 50 psf (40+10). Commercial floors, garages, barns, or stables may need to be designed for total loads of 100 psf or more.

Design for Safety and Deflection

A properly built floor must be both strong enough not to break, and stiff enough not to deflect too much under load. But it must also be resilient enough that it won't permanently deform when it deflects. Normally we don't have to worry about a joist or floor beam breaking under load, unless there is a serious defect such as a big knot in the tensile side or improperly cut holes.

In most cases the limiting factor is the amount of deflection permitted for a given span and load. If a floor deflects too much, the occupants may consider it unacceptably springy, or nails may start to pop and squeaks will develop. Excessive deflection can also cause a plaster or drywall ceiling to crack below, which is equally undesirable. This is why joists are normally sized to limit deflection. How far a given piece of lumber will deflect depends on (a) the species and stress grade of the wood, (b) the span, (c) the spacing between members, and (d) the applied load.

Stress-graded lumber, such as No. 2 spruce, is visually rated, based on the species and the number and kind of knots, splits, checks, and other defects found in an individual piece. For design purposes, we are concerned primarily with (a) fiber stress in bending (f_b), which rates a wood's ability to resist tensile and compressive forces, (b) the modulus of elasticity (E), which is used to calculate stiffness, and (c) shear strength.

We want to keep deflection within acceptable limits for two reasons: to limit springiness in the floor, and to keep plaster from cracking below. To reduce springiness, we want to limit deflection at mid-span under live load only to the length of the span in inches (l/360). For a 15-foot span, this means $(15\times12)/360=1/2$ inch maximum allowable deflection. To keep the plaster from cracking downstairs, the limit is l/240, using the heavier combination of live *and* dead load.

However, as Harris Hyman has pointed out in these pages, you can build a higher-quality floor at little extra expense by sizing the joists to keep deflection less than *l*/480. For a given span and load, you can do this either by going to a larger joist size or by using closer spacing.

For example, going from 2x10s to 2x12s for a 24x40-foot house costs an extra $120 for framing at 40¢ per board foot. And since stiffness increases with the square of the depth of a joist (that is, doubling the depth makes the piece four times stiffer), you can buy a noticeable increase in quality pretty cheaply.

Other Ways to Increase Spans or Stiffness

In addition to using deeper joists, there are several other ways to increase the span or stiffness of a piece of lumber.

One approach is to use closer spacing. Typical joist spacing is 16 or 24 inches o.c., but 12, 13.7, and 19.2 inches o.c. are also *modular* spacings, in that they add up to 8 feet. Another

Figure 2. Notches and Holes

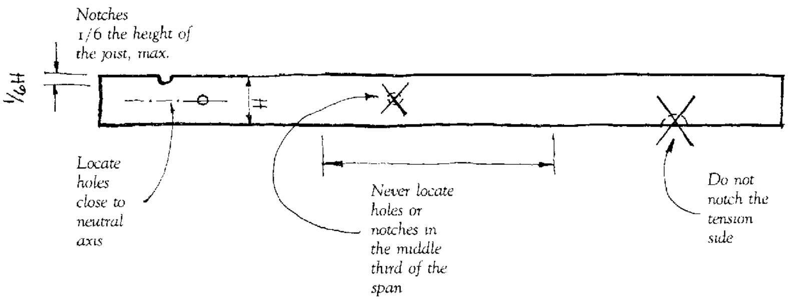
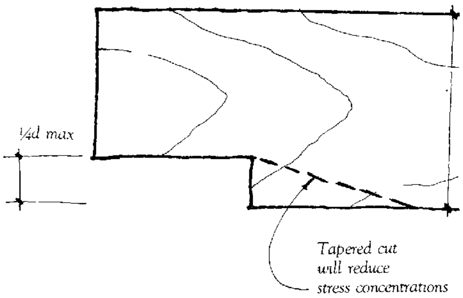


Figure 3. End Notches



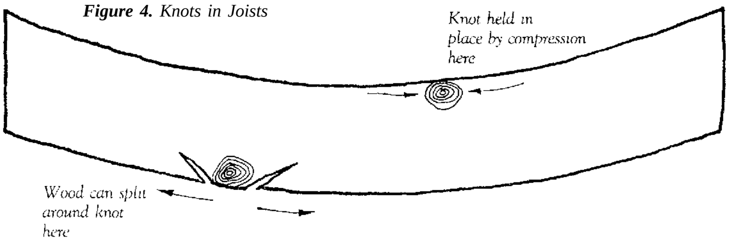


Figure 4. Knots in Joists

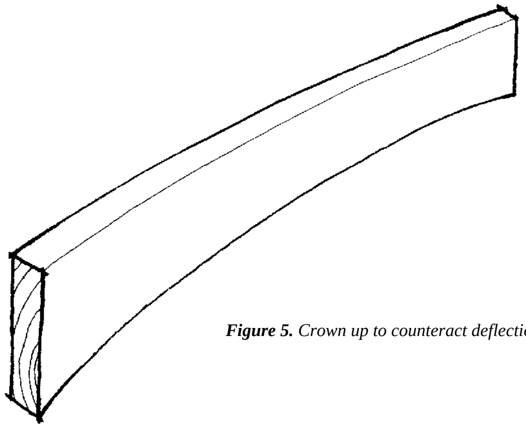


Figure 5. Crown up to counteract deflection

approach is to simply choose a higher grade of lumber. Bear in mind, however, that if you order all No. 1 stock, you are still likely to receive a mix of No. 1s and No. 2s from many lumberyards, which may not meet the required span/performance specification.

A third alternative is to use the *cantilever principle.* When a piece of wood is canted over a support point, the resulting deflection on that side tends to straighten out the normal bending on the opposite side. The so-called cantilevered in-line joist system (Figure la) uses this principle to either increase span capability or allow the use of smaller stock. A good leaflet on the subject is included in the list at the end of the article.

Glue nailing the plywood subfloor to the joists is another useful technique. It makes the subfloor and joists act as one piece, which, in turn, stiffens the joist by providing T-beam action. This eliminates nail popping and squeaking, and in some cases allows the use of smaller joists. Span tables for glue-nailed plywood floors are included in the OVE manual listed at the end.

Another little-used technique for stiffening joists is to place the joist over two supports. (Both the OVE booklet and NFPA *Span Tables* listed below include data on two-span floor joists.) This technique, however, is used mostly for stiffening 2x6 T&G decking in plank-and-beam floor construction.

Sizing Joists

A rule of thumb for nominal 2x joists, 16 inches o.c, is that the maximum allowable span (in feet) will be approximately 1 1/2 times the depth of the joist (in inches). For instance, 2x10s installed 16 inches o.c. will safely span about 15 feet (1-1/2×10). For 24-inch spacing, you should probably go up one size for the same grade of lumber. Refer to the span tables listed at the end of this article for closer analysis, or consult *Wood Structural Design Data.*

Other Hints and Tips

Joists can be seriously weakened—sometimes to the point of failure—by carelessly cutting notches and holes. To be absolutely safe, pipes and ducts should always be run between or under joists. It is preferable to support joists on top of the central girder rather than hang them—from the point of view of the mechanical trades. In the real world, of course, sub-trades often cut joists to run pipes, wires, and ductwork.

If this is the case, the depth of a notch for a pipe (Figure 2) should be limited to one-sixth of the joist depth, and notches should *never* be located in the middle third of the span. This is true also for holes, which should be located along the neutral axis halfway up the joist. In addition, never cut into the bottom, tensile side of a joist.

Similarly, notches at the ends of beams or joists, which are typically found in mortised timber-frame construction, increase and concentrate shear stresses. These should be limited to a maximum of one-quarter of the beam depth (Figure 3). A tapered detail causes less stress concentration than a square corner does. Open-web trusses obviously eliminate the problem, but they are subject to their own constraints, as we shall see.

Like notches, splits or deep checks near the end of a joist can encourage shear failure. Such pieces should be discarded or shortened to cut off the defect.

Knots in the bottom side of a beam are just like cuts, in that the wood can split in tension around the knot. For this reason, knots of any size should always be placed on the upper, compression edge—where they will forever be squeezed tightly in place (Figure 4). This requirement sometimes conflicts with the rule that joists should always be installed with the crown up. The crown-up rule attempts to counteract normal downward deflection with the built-in *camber* (arch) of a bowed stick (Figure 5). If a significant knot occurs opposite the crown side, I would discard the piece or use it in a noncritical location, such as over the foundation wall.

A notch in a joist should be limited to one-sixth the joist depth, and should never be located in the middle third of the span.

Shear

As mentioned earlier, lumber can fail due to horizontal shear forces, which tend to split the wood along the grain. The following analogy shows how this happens. If you take a pack of playing cards, support it at the ends and press down in the middle, the deck will bend (Figure 6). As it does, the cards slide by each other. This is exactly what happens along the longitudinal fibers in wood.

A typical stress grade for shear resistance might be as low as 65 psi for weaker species, while the stronger ones may have a psi of 75 or 80. For a built-up member such as a triple 2x10, you can safely assume the higher figures, since it is unlikely that a split would spread laterally from one piece to another. Shear rarely governs the lumber size in repetitive joists, but must be considered when you use single members such as beams.

Is Cross Bridging Necessary?

One final factor to consider is lateral stability. Loaded joists that are set on edge can conceivably buckle (like a tall, thin column) or tip sideways. It is generally accepted today that joists with a height/width ratio of up to 6:1 (e.g., 2x12s) do not need cross bridging or solid blocking to prevent buckling, and that such devices do virtually nothing to dampen vibrations. Labor time is increased, and plumbers often knock the blocks out, anyway.

The only use I can see for bridging is to keep joists from toppling over like dominoes if you do something foolish—like dump a huge stack of plywood in the middle of a floor and leave for the day (see *NEB,* June 1985, page 9). In the case of green lumber, blocking is essential to resist warping and twisting as the lumber dries.

Trusses to the Rescue?

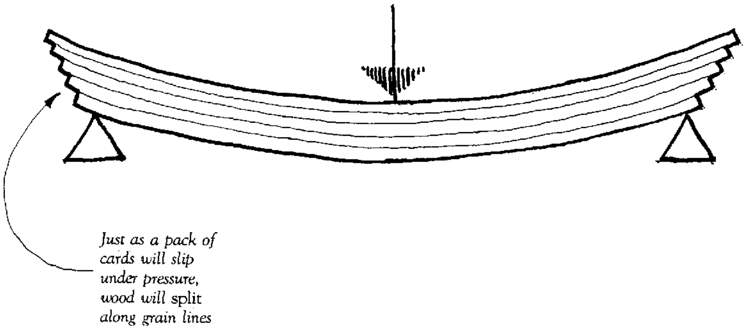
Trusses are magical devices that can span long distances with no interior support. They are very efficient in that they use little material to do a big job. They are also lightweight and easy to handle, although they require some care. The cost is higher than for solid lumber, but I'm told that this is offset in many cases by labor savings and by eliminating the central carrying beam.

Some time ago I ran across a fellow who wanted a boxing ring in his cellar; posts were therefore unacceptable. Clear-span, parallel-chord floor trusses were his salvation. A more typical use would be for a woodworking shop in the basement.

Trusses can be either top-chord- or bottom-chord-bearing (Figure 7). Open webs are paradise for plumbers and electricians. The spacing is typically 16 or 24 inches o.c., and the depths range up to 24 inches for very wide spans. The trusses are pre-engineered for your particular application, and are widely available through lumberyards.

Some cautions, though. There is usually a minimum order. And you have to

Figure 6. Horizontal shear



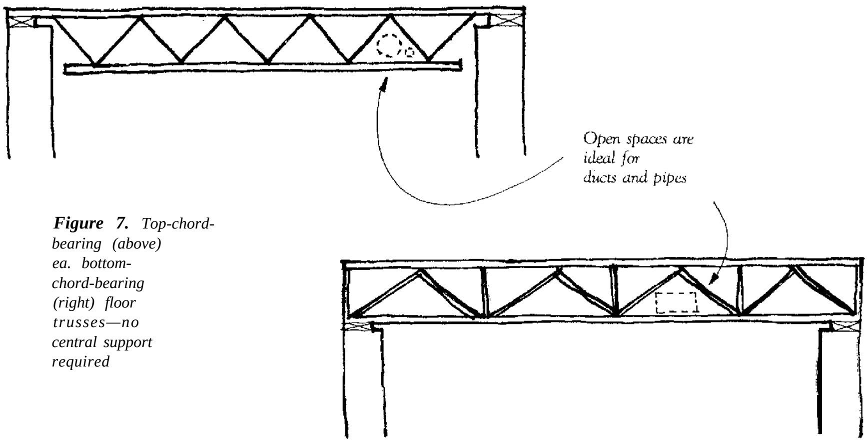


***Figure 7.** Top-chord-bearing (above) ea. bottom-chord-bearing (right) floor trusses—no central support required*

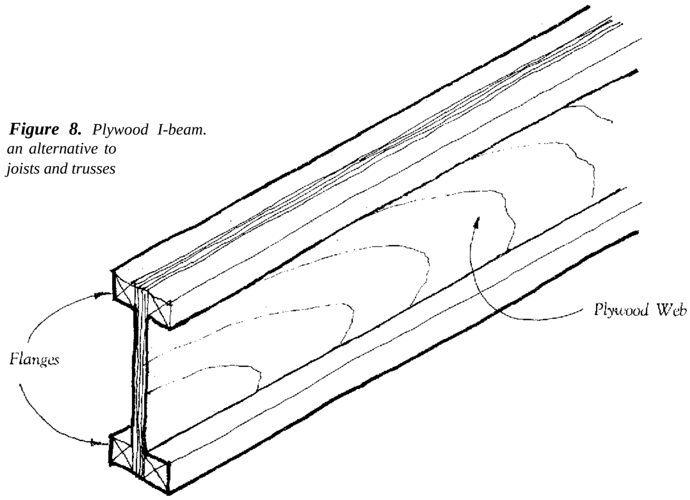


***Figure 8.** Plywood I-beam. an alternative to joists and trusses*

be sure the delivery truck can negotiate onto your site, since these babies are up to 30 feet long. Also, because the trusses have no mid-span support, twice as much load is transferred to the outer bearing walls as in joist construction. For this reason, header sizes need to be increased over openings in the walls. And, finally, trusses must be handled on edge, never flat, or they may break.

The Contender: Prefab Plywood I-Beams

A close relative of floor trusses is the prefabricated plywood I-beam (Figure 8). I-beams are designed to use wood efficiently, putting the bulk of material at the top and bottom edges, called flanges, where the greatest tensile and compressive forces exist. The plywood web between them can be very thin since it acts merely to connect the flanges along the neutral axis.

Manufacturers such as Trus Joist produce pre-engineered I-beams in 60-foot lengths and various depths. They are shipped to distributors, cut to length, and sold. Like trusses, these prefab I-beams must always be handled on edge.

I am told that this new breed of material has captured 60 percent of the framing market west of the Rockies. According to one manufacturer, I-beams offer no savings for the cheapest house or for a single custom house, but production builders might realize a savings of 20 percent or more compared to conventional joist construction.

Any of the above products—joists, trusses, or plywood I-beams—can provide a suitable floor-framing system. The question is one of proper design, detailing, handling, economics, and convenience. ■

Paul Hanke is an architectural designer, teacher, writer, and sometime builder in Warren, Vt.

FURTHER READING

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Simplified Engineering for Architects and Builders, by Harry Parker and James Ambrose. John Wiley and Sons. New York. 1984. Hardcore technical analysis. (Reviewed 4/85.)

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