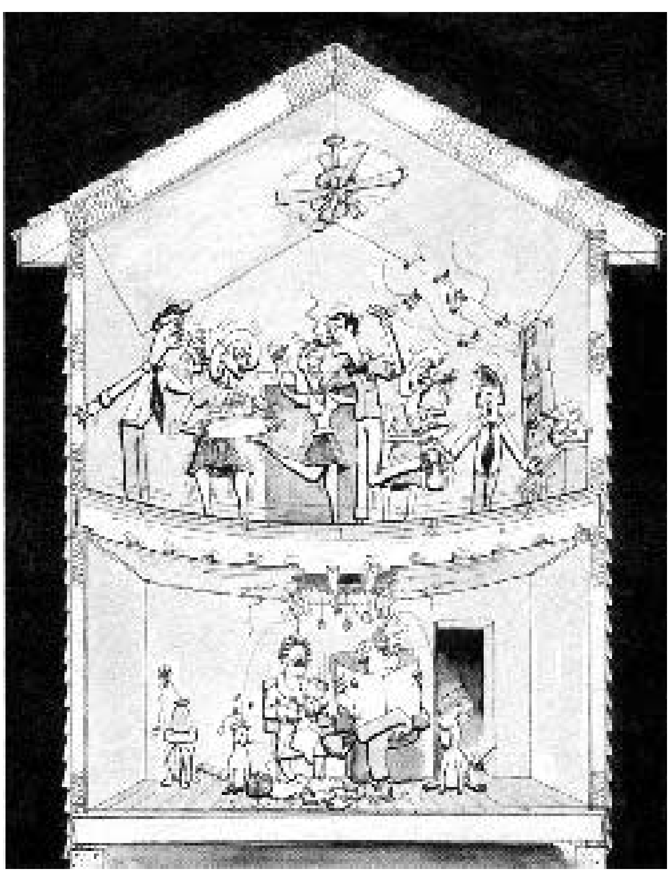
Taking the *Bounce* Out of Floors and Beams

by Harris Hyman

Modest oversizing of joists and beams will minimize deflection and maximize customer satisfaction



Half joking, people often ask of the architect or structural engineer, "Will the building fall down?" Well, when considering light-frame buildings, I can confidently answer, No! Such buildings almost never fall down. But they often have problems with sagging beams or floors: They don't break, but they might bend too much. This bending is called *deflection*.

A common example is an overly bouncy floor. You walk across this floor, and the dishes on the table rattle. The candles flicker and the TV changes channel. You really never will fall through the floor, but you might think that you will. Most important, you just don't feel good in this room.

Deflection Defects

Deflection becomes a real problem when the building is so deformed that it is not useful. For example, the gym roof on one New England school was a little too soft. When the snow piled up, the roof sagged a little — just enough to keep the great folding doors that divided the boys and girls from operating. After the first snow the gym was either divided or open, and stayed that way till the January thaw. Then the snow froze again until mid-March.

A passive solar building in New Hampshire had a sunroom with sloping south glazing on a low knee wall. The roof was a little too soft, and a good winter storm loaded it up, pressed it down, and pushed on the sloping windows. The wall bulged out, and the glazing panels twisted enough for the seals to break. By the time the snow had melted, most of the bulge had receded from the wall, but the double glazing had filled with condensate.

In another building, a contractor had failed to set sufficient fastenings into the major truss supporting the ridge in a fairly expensive and exotic Maine residence. The ridge sagged a little and pushed the rafters down and the walls out. Half a mil worth of new house took on a real Downeast seedy look.

Valley rafters are another problem area. They carry exceptionally heavy loads when, in a winter storm, snow collects in the valley. This rafter is usually a single stick, and it carries the weight of a group of jack rafters nailed into it. Consequently, valleys often sag and do funny things to interior finishes and to the inside corners to which they run.

Aspects of Deflection

There are four problems that can be caused by too much deflection. The designer should take into account: non-functionality of the building (the gym roof); the tendency to cause related damage (the greenhouse); unsightliness (sagging valleys or ridges); and human discomfort (bouncy floors).

Non-functional buildings. The first of the deflection problems is relatively straightforward to solve, but it requires a thorough look at a building's forces, not just the vertical bearing strength. The designer must assess all the possible ways the building can move out of the perfect square that is laid out on the drawings. This tactic requires some design sense.

For the most part building dysfunction is limited to a few special situations. For example, I might be asked to design a room for a sensitive test device in a scientific lab where any bounce in the floor would cause the test device to malfunction.

Most likely, contractors will recognize the potential for this type of problem and hire an engineer to puzzle it out.

Related damage. The designer must also take a thorough look at the whole building to determine whether deflection in one part might cause damage to some other part. Most related damage from deflection is wreaked upon windows and doors, and analysis of those local areas is usually easy for the designer to handle.

The more difficult problems involve instability, where a part of the building moving out of place upsets an entire building. An example of an instability failure involves a post pushed out of place and a subsequent load bringing a porch down. Fortunately, this kind of problem is rare on light frame buildings.

Unsightliness and discomfort. The last two types of deflection failure are important to residential buildings but are extremely difficult to assess. It's perfectly clear when a building suffers dysfunction and damage. But what is unsightliness? What is discomfort? Deformations that can be detected by the eye alone might be called "unsightly," but we all have different eyes, and even a good eye needs a visual reference. On a sloping site, you can walk uphill and sight down a bulge in the eaves line that would never be noticeable from level ground.

Discomfort is even more difficult to gauge. A well-built floor feels good and solid; but how much bounce is tolerable? We do know that a couple of inches of hop is bad; but what about $^3/_8$ inch? Research into comfort is limited. Since health and safety are not affected, this does not have a particularly high priority. No one is injured by bouncy floors; they just make life a little less pleasant.

Designing for Deflection

Despite the obvious and pervasive nature of the problem, we have only one useful standard for designing against deflection. Several model codes limit the allowable deflection of a span to $l/180$ of the overall span (or 1-inch deflection in a 15-foot span) for roofs over unplastered ceil-

Table 1. Floor Joist Spans

50 Pounds Per Square Foot Total Load

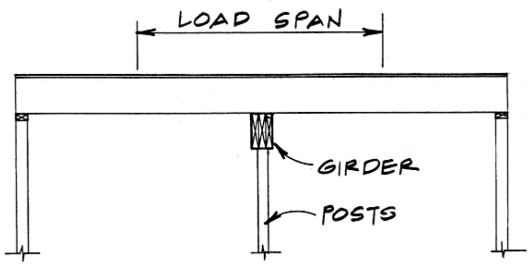
	Doug. Fir	Hem-Fir	S. Y. Pine	S-P-F
2x12 12" o.c.				
stress	24'-8"	22'-0"	25'-1"	20'-6"
deflection	20'-7"	19'-4"	20'-4"	18'-10"
2x12 16" o.c.				
stress	21'-5"	19'-0"	21'-9"	17'-9"
deflection	18'-9"	17'-7"	18'-4"	17'-2"
2x10 12" o.c.				
stress	20'-4"	18'-1"	20'-8"	16'-10"
deflection	16'-11"	15'-11"	16'-7"	15'-6"
2x10 16" o.c.				
stress	17'-7"	15'-8"	17'-10"	14'-7"
deflection	15'-5"	14'-5"	15'-1"	14'-1"
2x8 12" o.c.				
stress	15'-11"	14'-2"	16'-2"	13'-2"
deflection	13'-3"	12'-5"	13'-0"	12'-2"
2x8 16" o.c.				
stress	13'-9"	12'-3"	14'-0"	11'-5"
deflection	12'-1"	11'-4"	11'-10"	11'-0"

100 Pounds Per Square Foot Total Load

	Doug. Fir	Hem-Fir	S. Y. Pine	S-P-F
2x12 12" o.c.				
stress	17'-5"	15'-6"	17'-9"	14'-6"
deflection	16'-4"	15'-4"	16'-0"	15'-0"
2x12 16" o.c.				
stress	15'-1"	13'-5"	15'-4"	12'-6"
deflection	14'-10"	13'-11"	14'-7"	13'-7"
2x10 12" o.c.				
stress	14'-4"	12'-9"	14'-7"	11'-11"
deflection	13'-5"	12'-7"	13'-2"	12'-4"
2x10 16" o.c.				
stress	12'-5"	11'-1"	12'-8"	10'-4"
deflection	12'-3"	11'-5"	12'-0"	11'-2"
2x8 12" o.c.				
stress	11'-3"	10'-0"	11'-5"	9'-4"
deflection	10'-6"	9'-10"	10'-4"	9'-8"
2x8 16" o.c.				
stress	9'-9"	8'-8"	9'-11"	8'-1"
deflection	9'-7"	9'-0"	9'-5"	8'-9"

Note: *All calculations were based upon design values for No. 2 Grade, 5 inches and wider. The deflection calculations assume a limit of l/360. This table illustrates the author's point that joists designed to limit deflection are usually of adequate size to meet the stress (bending strength) criteria.*

Table 2. Maximum Post Spacing for 100 psf Floor Loads



Load Span	*Girders*		
	Double 2x12	Triple 2x12	Quad 2x12
30'	4'-9"	5'-5"	6'-0"
24'	5'-2"	5'-11"	6'-6"
20'	5'-6"	6'-3"	6'-10"
16'	5'-11"	6'-9"	7'-5"
12'	6'-6"	7'-5"	8'-2"
10'	6'-11"	7'-11"	8'-9"

Note: *This table shows maximum post spacings for common girder sizes, where total floor loads are figured at 100 pounds per square foot. The author uses the 100 psf value in designing girder systems for residential public spaces. If girders are built of 2x10s, reduce the post spacing in the chart by 20%.*

ings; l/240 for floors over unplastered ceilings; and l/360 for floors over plastered ceilings. This is based on an old design standard that suggests the plaster ceiling under the span will crack with any additional sag, and that the primary safety concern is falling chunks of plaster. Even though we don't use plaster ceilings much anymore, this criterion is still used and actually will give a reasonably comfortable floor design.

The best approach, I feel, is to calculate the deflection as well as the strength of a building. It's a little more work, but it's likely to produce a little better building — one that will (almost) never fall down.

The basic reason why buildings don't fall down is that a safety multiplier is applied to materials. Good clean spruce has a true bending strength of about 6,000 to 9,000 psi, but we normally use a design value of only 1,200 psi. This safety factor of about 5 covers the variation in the natural strength of spruce trees and quality of the wood. By comparison, steel has a safety factor of only 1.6 because it is much more regular in strength and quality.

There is no safety multiplier applied to the modulus of elasticity (E), which is a measure of the stiffness of wood of a particular species and grade. Deflection is computed with realistic values for the properties of wood of a given species and grade. Designing for deflection typically makes a conservative building design, because if a building is strong enough to resist bending, it is not likely to break.

Sizing Joists

With only instinct to justify it, I do use one design check for bounciness on floors: Will a load of 500 pounds distributed over four joists produce a deflection of more than 1/2 inch? The 500 pounds approximates a large man taking a strong step. A half inch just feels reasonable. In general, joists designed for deflection are covered for strength against failure and will usually meet the code requirements.

I also design the floors for living rooms, kitchens, and other public spaces in a house for 100 psf total load rather than the 40 psf live load required by some codes (see Table 1, previous page). This is a little overdesigned, but the added expense is relatively small, and it gives a house a good feeling. There is no need for this strength in bedrooms or bathrooms, unless the owners have some unusual proclivities.

Sizing Girders

The builder should also give some serious attention to the girder systems that hold up the joists. Carpenters and builders often *underdesign* girders. The typical triple 2x12 girder *looks* like a lot of wood, and certainly *feels* like a lot of wood. But it may not be enough if the span between posts is too long.

Let's take a typical situation — a 24x24-foot garage with a triple 2x12 girder down the center on a single post. This supports the floor joists for the apartment above. Depending on the species used, this may be a little light for a 40 psf floor load. It is very light for the 100 psf I suggest for residential public spaces. A second column wouldn't cost much and would stiffen the place a whole lot. For the post spacing I would use for 100 psf loads, see Table 2.

You don't usually have to worry about deflection in sizing girders. As it turns out, when a girder is designed to carry a load, it is almost always okay in deflection.

Creep

Creep occurs when, over time, deflection causes beams to be permanently deformed. But it just doesn't happen much. Constant loads that are very close to the design limits are necessary to produce creep. To limit deflection over time, the *Wood Handbook*, by the U.S. Forest Product Lab, Madison, Wisc., recommends designing for about one-half the deflection ordinarily permitted for longtime deflection. The *Wood Handbook* is a good reference on the structural properties of wood.

A Soft Problem

You've noticed that I've used a variety of "soft" terms in discussing deflection: "instinct," "tolerable," "reasonably comfortable," etc. Well, the problem of deflection *is* soft, because it is often a question of judgment. Guidance by code is limited and in a single dimension, the vertical, while buildings actually move in four dimensions. Like most messy technical solutions to messy real-world problems, design for deflection really demands art and good sense in addition to number crunching. Good luck. ■

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