

Sizing Stiff Floor Girders

by Frank Woeste, P. E., and Dan Dolan, P.E.

We received a call recently from a homeowner who had a problem he wanted us to solve. He had just built a garage with living space above, and the upstairs floor was too bouncy. The odd thing was that the homeowner had specifically asked the building designer to ensure that the floor was very stiff, so the designer had specified floor joists (wood I-joists, in this case) with an $L/720$ live-load deflection limit. So why was the floor so springy?

The problem, as it turned out, was the midspan girder that the joists crossed. Although the girder had been sized correctly by “code” for strength and stiffness, its deflection limit was much greater than that of the joists. As a result, the whole floor system felt bouncy.

This is not an unusual condition. Professors at Virginia Tech, as well as a number of graduate students, have just completed five years of research on residential floor vibration. We analyzed more than 200 actual wood-frame (dimensional lumber, floor truss, and wood I-joist) floor systems. As a result of this research activity, homeowners and engineers frequently call us for help with residential floor vibration problems. We’ve found that most of the problem floors — floors with excessive vibration — are framed with joists running to a girder, and that the girders are typically too long between supports and therefore too flexible.

Bad Vibes

Traditionally, the stiffness of wood-frame floor systems has been controlled by limiting live load deflection to $L/360$ (where L is the joist span). But while this deflection limit may prevent plaster from cracking (the reason it was developed), it may not prevent annoy-

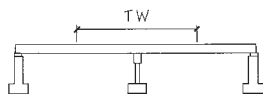
ing vibration of the floor, especially as the span gets longer.

All floors vibrate when someone walks across them; the question is whether you feel it or not. The perception of “excessive” vibration is subjective, so complaints by homeowners will vary. However, research done in the past suggests that most people are

sensitive to vibrations in the 8 to 10 Hertz range. (A Hertz is a measure of vibration frequency; one Hertz equals one cycle per second). This sensitivity is believed to be because the human organs have a natural frequency of 8 to 10 Hertz; floor vibration in the same range is therefore perceived to be uncomfortable.

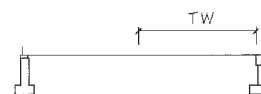
Sizing Built-Up 2x10 Girders ($L/600$ deflection, 40 psf live load, 10 psf dead load)

To use this chart, first figure out the tributary width (TW) that the girder must support (see illustrations). Then find the required F_b and E values for the 2x10 lumber. Note that the required values increase as girder span increases, but decrease when you upgrade from a three-ply to a four-ply girder. In the box below, right, these is a partial list of design values from some commonly available species and grades. Select a species and grade that meets or exceeds the required design values for your conditions.



Three-Ply 2x10 Girder

	TW (Feet)	Required F_b	Required E (million)
8-Footer Pier Spacing	10	650	0.78
	12	781	0.93
	14	911	1.09
	16	1041	1.24
	18	1171	1.4
	20	1301	1.55
9-Footer Pier Spacing	8	659	0.88
	10	823	1.11
	12	988	1.33
	14	1153	1.55
	16	1317	1.77
10-Footer Pier Spacing	6	610	0.91
	8	813	1.21
	10	1016	1.52
	12	1220	1.82



Four-Ply 2x10 Girder

	TW (Feet)	Required F_b	Required E (million)
8-Footer Pier Spacing	14	683	0.82
	16	780	0.93
	18	878	1.05
	20	976	1.16
	22	1073	1.28
	24	1171	1.4
9-Footer Pier Spacing	12	741	0.99
	14	864	1.16
	16	988	1.33
	18	1111	1.49
	20	1235	1.66
	22	1358	1.82
10-Footer Pier Spacing	8	610	0.91
	10	762	1.14
	12	915	1.36
	14	1067	1.60
	16	1220	1.82

Crunching the Numbers

Joist Vibration

For a simple-span joist supported by rigid supports, such as a foundation wall, the *fundamental frequency* can be calculated by

$$f = 1.57 \sqrt{\frac{386EI}{WL^3}}$$

where f is the calculated frequency (Hz); E is the modulus of elasticity of the lumber (psi); I is the moment of inertia of the lumber (in.⁴); W is the actual dead weight of the joist and floor material (lb.); and L is the clear span (in.).

Floor System Vibration

When floor joists are supported by a girder, the vibration frequency of the floor system can be calculated by

$$f_{\text{system}} = \sqrt{\frac{f_{\text{girder}}^2 + f_{\text{joist}}^2}{f_{\text{girder}}^2 + f_{\text{joist}}^2}}$$

Note that the floor system frequency is less than that of the component parts.

“unacceptable” floors had vibration rates below 11 Hertz.

Recommendations

It makes sense to try to build floor systems that have a *fundamental frequency* well above 10 Hertz. Based on our findings, a target frequency of 15 Hertz will result in an “acceptable” floor most of the time.

For simple joist spans running from foundation wall to foundation wall, the calculation is fairly straightforward (see “Crunching the Numbers,” above). For those who want to avoid the math, a simpler recommendation is to size floor joists for $L/480$ deflection instead of $L/360$. An easy way to do this is to take the allowable joist span from an $L/360$ span table and multiply by .91.

When the floor joists are supported by a girder, however, the calculations get a little more complicated. If you work through the formula for “system” frequency, you’ll see that the frequency for the floor system is less than that of the component parts — the joists and girder. For example, when both the joists and girder have a frequency of 15 Hertz, the frequency of the floor system is only 10.6 Hertz.

To avoid the complication of having to calculate the vibration frequency of every floor system, we recommend designing built-up wood girders for floor systems with a live load deflection limit of $L/600$, and limiting girder span to 10-feet for dimension-lumber girders.

The sizing chart, at far left, gives the required bending strength (F_b) and stiffness (modulus of elasticity, or E) for 2x10 lumber used in built-up girders for normal residential floor loads. In the box at left, the structural design values of several common wood species are given. These values were taken from the *National Design Specification Supplement*, 1993 edition, published by the American Forest & Paper Association (202/463-2700).



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The Research

Because of the subjective nature of the problem, we combined a subjective measure of floor vibration with a scientific measurement. One person would do a “heel drop” — that is, stand on his toes and drop at once on his heels. Another person standing a few feet away would assess the vibration pro-

duced as either “acceptable,” “marginal,” or “unacceptable.”

The researchers would then measure the floor’s actual vibration with an accelerometer. What we found was that floors judged to be “acceptable” generally vibrated at 15 Hertz or higher. The floors judged “marginal” tended to be in the 11- to 13-Hertz range, while the

Lumber Design Values*

Species	Grade	Fb (psi)	E (psi)
Douglas Fir–Larch	Select Structural	1450	1,900,000
	No. 1 & Better	1150	1,800,000
	No. 1	1000	1,700,000
	No. 2	875	1,600,000
Hem - Fir	Select Structural	1400	1,600,000
	No. 1 & Better	1050	1,500,000
	No. 1	950	1,500,000
	No. 2	850	1,300,000
Spruce-Pine-Fir (South)	Select Structural	1300	1,300,000
	No. 1	850	1,200,000
	No. 2	750	1,100,000
Southern Pine	Select Structural	2050	1,800,000
	No. 1	1300	1,700,000
	No. 2	1050	1,600,000

Source: NDS Supplement, 1991.

*Applicable adjustment factors have already been included in the “Required F_b ” in the sizing chart on page 60. When selecting a lumber species, use Base Design Values without any adjustments.