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"Serviceability of Wood Framed Floor Systems in Residential Construction" by S. B. Taylor & H. B. Manbeck

BACKGROUND

Over the last 30 years, engineered materials have revolutionized wood framed floor systems. Solid sawn floor joists with plank tongue and groove sheathing have been replaced in many instances with I-joists or open web joists sheathed with plywood or OSB. Engineered joists are typically stiffer, stronger and more consistent than their solid sawn counterparts. These attributes are achieved by efficiently orienting wood fiber in the direction necessary to resist applied stresses. Engineered wood products have a lower variation of material properties and are dimensionally more stable than solid sawn materials. In addition, engineered joists can be manufactured in depths and spans greater than a nominal 2x12 joist. Engineered joists can be designed to run the entire length of a typical residential structure over multiple spans and at wider spacings. The residential construction industry has captured these attributes to the advantage of the homeowner by providing designs that use less wood fiber but are nevertheless more open and economical that ever before.

One consequence of applying open architecture and larger spans to residential design is that traditional deflection limits no longer address all serviceability concerns. The present day homeowner typically has high expectations of how the floor system will perform. They not only want the floor system to be squeak-free, but they make judgments on how they want the floor system to feel given the habits and patterns of their families. In addition, the floor system (joists, sheathing, rim board and underlayment design) must be compatible with stiff floor toppings such as ceramic and stone tile as well as light and regular weight concrete. And finally, the long-term deflection (creep) behavior of long span floor systems is important when given the above demanding design conditions.

The most effective technique for avoiding floor performance problems is a disciplined design. As floor system components become more sophisticated, so do floor system design tools. In anticipating difficult situations such as long spans in open rooms, stiff toppings and elevated relative humidity, temperature and sustained load levels there are a few design tools and some rules of thumb to keep in mind.

WOOD FRAMED FLOOR SYSTEM DYNAMIC PERFORMANCE

The objective of any good floor performance design is to keep static deflection low while keeping joist frequency and system damping high. Floor system span is the single most influential factor of static and dynamic floor performance. Span significantly influences both joist deflection and frequency. Designers are usually looking for solutions for a given span defined by the architectural layout of the structure. Clearly the most cost effective way to decrease joist deflection and increase joist frequency for a given span is to increase joist depth. Other techniques include increasing joist stiffness and decreasing joist spacing.

Damping is extremely difficult to quantify due to the complexity of a three dimensional joist system. At the present time there are no repeatable techniques for predicting damping, or the ability of a joist system to dissipate vibration. Nevertheless one of the most effective ways to increase damping in a typical residential floor system is to add a layer of sheet rock or other heavy stiff panel product directly to the bottom of the floor. This helps stiffen the joists and adds a component of friction shared by all joists and thus helps to increase the rate at which the floor system dissipates vibration.

Simple rules of thumb such as keeping the joist span to depth ratio below L/20 (in.) and the frequency above approximately 15 Hz. are good “back of the envelope” guidelines but are not comprehensive. Open, large aspect ratio floor plans and under-designed sheathing on wide joist spacings are the root of many dynamic floor system problems that cannot be solved by simply considering longitudinal joist performance. For the best results, it is a good idea to consult with component manufacturers.

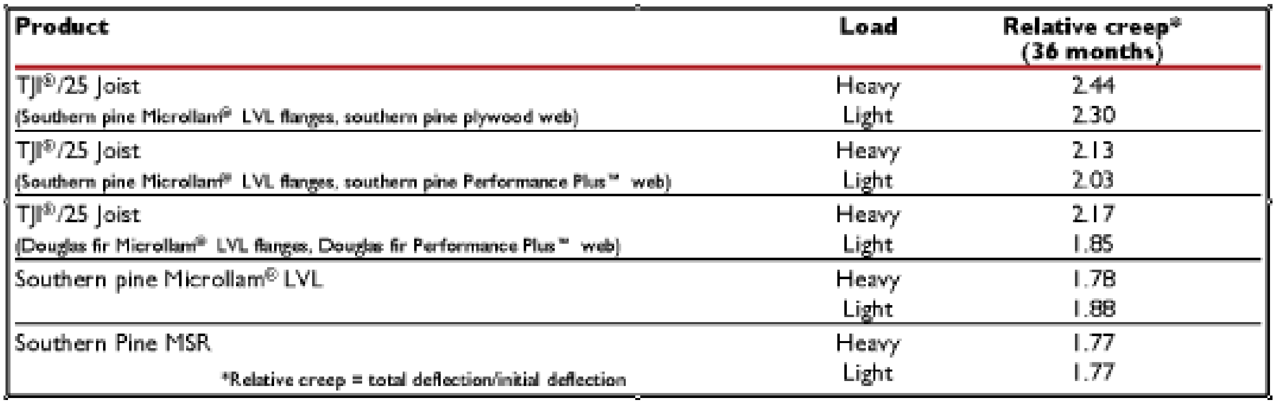
FLOOR SYSTEM COMPATIBILITY WITH STIFF TOPPINGS

New materials and architectural designs have introduced durable and attractive floor finishes for use over wood framed floor systems. When designing with ceramic and stone tile as well as light and regular weight concrete it is recommended that the designer consider floor system differential deflection and the additional dead load of the topping material.

Differential deflection can occur when a significant live load is applied to the mid-span of a floor joist located next to a joist that is supported by a beam, wall or column with much higher stiffness. The differential deflection from the loaded joist to the stiffer section of floor can induce a flexural stress in the topping and cause it to crack. Good design would recommend closer joist spacing or doubling-up joists in the transition area to even out the system deflection. The engineered wood products industry and the floor topping manufacturers must work together to define deflection and framing criteria to address this situation.

Stiff toppings can be applied in thicknesses ranging from ¼" for thin tile to 4" for concrete slabs embedded with hydronic heating systems. The weight of the topping should be added to the dead load of the floor system with no enhancement or composite action factor to the sheathing/joist stiffness when calculating floor system deflection and frequency. It has been shown that if a composite action factor is used to calculate an enhanced topping/sheathing/joist stiffness resulting in a longer design span, the additional topping mass on the extended span can cause measurable and perceptible vibration under footfall (Taylor and Hua, 2000).

CREEP OF WOOD FLOOR JOISTS



Product	Load	Relative creep* (36 months)
TJI®/25 Joist	Heavy	2.44
(Southern pine Microllam® LVL flanges, southern pine plywood web)	Light	2.30
TJI®/25 Joist	Heavy	2.13
(Southern pine Microllam® LVL flanges, southern pine Performance Plus™ web)	Light	2.03
TJI®/25 Joist	Heavy	2.17
(Douglas fir Microllam® LVL flanges, Douglas fir Performance Plus™ web)	Light	1.85
Southern pine Microllam® LVL	Heavy	1.78
	Light	1.88
Southern Pine MSR	Heavy	1.77
	Light	1.77

*Relative creep = total deflection/initial deflection

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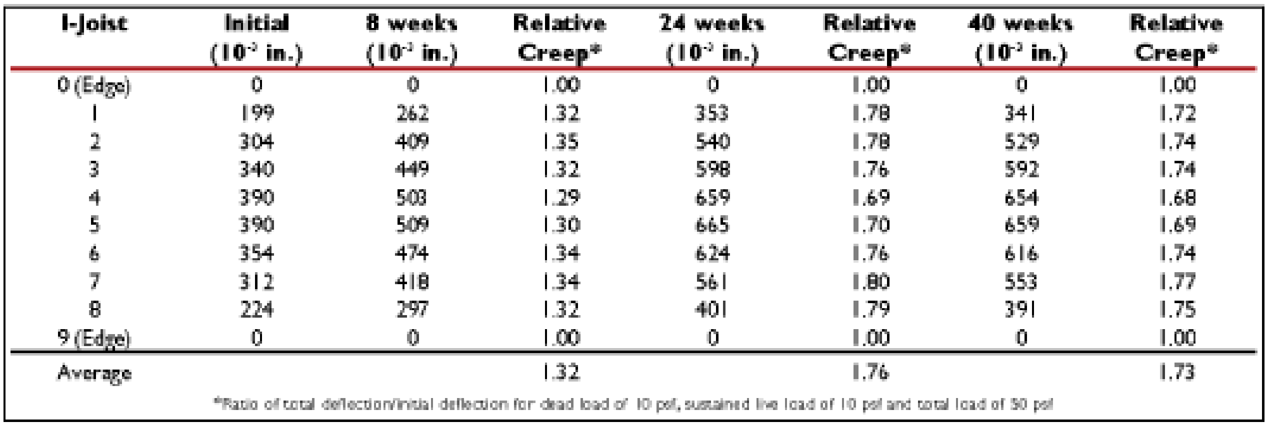
TABLE 1. SUMMARY OF RELATIVE CREEP DATA
FOR WOOD I-JOISTS AND RECTANGULAR SECTIONS (SHARP(1996))

A considerable amount of work has been done to address questions and concerns about long-term performance of wood floor joist materials. In 1996 Sharp and Craig reported that the creep rupture performance of two commercially available structural composite lumber products were consistent with the long-term load behavior of structural lumber in bending. In addition, Table 1 is a summary of research comparing the creep behavior of wood I-joists and machine stress rated lumber (MSR) for heavy and light load levels (Sharp, 1996). Relative creep results suggest that for single member analysis the relative creep of all members is above the NDS recommended factor of 1.50. Results also suggest that measured relative creep was lower for solid rectangular sections than for wood I-joist sections when subjected to the wide swings of temperature and relative humidity. In an effort to determine how these results relate to floor system design, subsequent creep testing has focused on full floor systems.

CREEP OF WOOD FRAMED FLOOR SYSTEMS

A recent Penn State University study measured the creep response of an I-Joist/OSB floor system subjected to a sustained uniformly distributed load of 20 psf (dead load of ten psf and a sustained live load of ten psf) for a period of 40 weeks. Temperature and humidity were maintained in a manner similar to a non-air conditioned residential building during the test period.



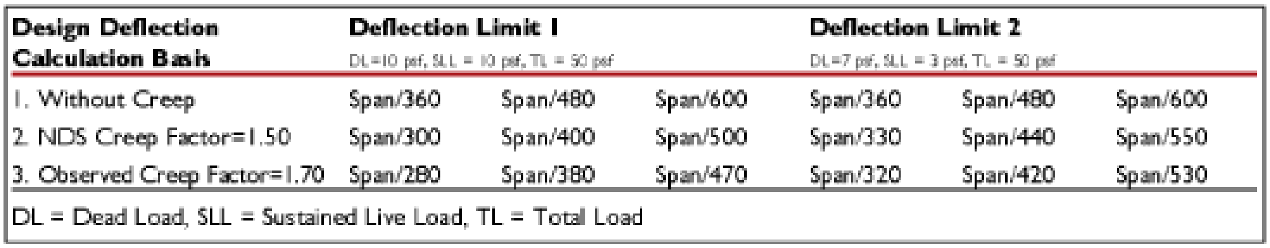
I-Joist	Initial (10^{-3} in.)	8 weeks (10^{-3} in.)	Relative Creep*	24 weeks (10^{-3} in.)	Relative Creep*	40 weeks (10^{-3} in.)	Relative Creep*
0 (Edge)	0	0	1.00	0	1.00	0	1.00
1	199	262	1.32	353	1.78	341	1.72
2	304	409	1.35	540	1.78	529	1.74
3	340	449	1.32	598	1.76	592	1.74
4	390	503	1.29	659	1.69	654	1.68
5	390	509	1.30	665	1.70	659	1.69
6	354	474	1.34	624	1.76	616	1.74
7	312	418	1.34	561	1.80	553	1.77
8	224	297	1.32	401	1.79	391	1.75
9 (Edge)	0	0	1.00	0	1.00	0	1.00
Average			1.32		1.76		1.73

*Ratio of total deflection/initial deflection for dead load of 10 psf, sustained live load of 10 psf and total load of 50 psf

CLICK ON IMAGE FOR LARGER VIEW
TABLE 2: SUMMARY OF TOTAL MID-SPAN DEFLECTION AND
RELATIVE CREEP FOR FULL-SCALE WOOD I-JOIST FLOOR SYSTEM (WISNIEWSKI AND MANBECK, 2000

The mid-span deflections and relative creep values for each joist in the floor system after eight, 24 and 40 weeks of sustained loading are given in Table 2. Relative creep was nearly constant across joists at each time interval. Continued observation of the floor response resulted in a 66 week average relative creep of 1.70. Relative creep nearly stabilized at approximately 1.70 after 24 weeks of loading. Interestingly, the observed floor system's relative creep after 24 weeks is less than or approximately equal to the relative creep reported by Sharp for several bare I-joists. The observed relative creep of the I-Joist floor after the deflections stabilized after 24 weeks was higher than the 1.50 creep factor suggested in the National Design Specification for Wood Construction (AFPA, 1997) and higher than the relative creep of 1.12 reported by Fridley, et al (1997) for a solid sawn joist/plywood floor system. The three test floors in the study by Fridley were constructed of No. 2 southern pine 2x8 joists with nailed 23/32 inch southern pine Sturd-I-Floor tongue and grooved plywood under similar sustained loads.

The comparisons in Table 3 illustrate the impact of creep on long-term floor structural performance. The entries in row one represent the code minimum (span/360), and two higher deflection limits (span/480 and span/600) without a creep adjustment factor using a total load of 50 psf. The adjusted deflection limits in row two were calculated using the sum of the short-term live load deflection plus 1.50 times the sustained live and dead load deflection. The adjusted deflection limits in row three were calculated using the sum of the short-term live load deflection plus 1.70 times the sustained live and dead load deflection. Deflection Limit One (columns 2–4) designates limits calculated for a dead plus sustained live load of 20 psf and a total load of 50 psf for span/360, span/480 and span/600 total load initial conditions. Deflection Limit Two (columns 5–8) designates limits calculated for the same initial conditions for a dead plus sustained live load of ten psf and a total load of 50 psf.



Design Deflection Calculation Basis	Deflection Limit 1 DL=10 psf, SLL = 10 psf, TL = 50 psf			Deflection Limit 2 DL=7 psf, SLL = 3 psf, TL = 50 psf		
1. Without Creep	Span/360	Span/480	Span/600	Span/360	Span/480	Span/600
2. NDS Creep Factor=1.50	Span/300	Span/400	Span/500	Span/330	Span/440	Span/550
3. Observed Creep Factor=1.70	Span/280	Span/380	Span/470	Span/320	Span/420	Span/530

DL = Dead Load, SLL = Sustained Live Load, TL = Total Load

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TABLE 3. COMPARISON OF SEVERAL DESIGN DEFLECTION LIMITS
WITH AND WITHOUT CREEP CONSIDERATIONS

Rows two and three in Table 3 indicate the decrease in the deflection limit actually achieved after the floor creeps under the total load. For an application with dead plus sustained live load of 20 psf and a design deflection limit of span/480 without considering creep, the actual deflection limit after considering creep is span/400 using the NDS specification for solid-sawn joists. Similarly, the actual deflection limit using the observed creep responses for I-Joist/OSB floor systems is span/380.

The relative creep values in Table 3 represent upper and lower practical limits on the impact of long-term loading on the total deflection of residential floor systems. These comparisons illustrate that, although the creep response of composite I-joist floor systems is greater than that of wood floors with solid sawn joists, the difference in total deflection is only in the three to seven percent range depending upon the level of the applied sustained load. The results also demonstrate that the total creep-induced deflection increase for typically loaded residential floors is in the order of ten percent. The majority of the wood I-joist manufacturers have recommended a deflection criteria of L/480 for years. The deflection limit comparison herein is one of the reasons for this recommendation.

FUTURE STUDIES

The wood I-Joist floor system creep response reported by Wisniewski and Manbeck is limited to observations on one floor. Also, they were unable to make one-to-one comparisons between the creep response of wood I-Joist floor systems and solid-sawn wood joist floor systems because the environmental conditions for their tests were not identical to those used in prior studies. Consequently, research is underway to measure and compare the creep response of four identical wood I-Joist floor systems to the creep response of two structurally equivalent solid-sawn wood floor systems under identical environmental conditions. The study is a joint venture between the Agricultural and Biological Engineering Department at Penn State University and Trus Joist, A Weyerhaeuser Business.

CONCLUSIONS

A proper design is the most effective way to achieve good static and dynamic floor performance. Designers can take advantage of the experience, recommendations and software tools offered by component manufacturers to assist in this difficult task. One area that still requires investigation is the development of design recommendations and installation details for floors with stiff toppings such as ceramic tile.

Testing appears to indicate that wood I-joists are slightly more susceptible to creep than dry solid sawn lumber. However, the common practice of disregarding creep design provisions has not resulted in widespread problems. Decades of observations and experience with conventional and I-joist floors reinforce the fact that creep related floor system problems are rare. In part this is because the applications are for dry use, the specified deflection limits are higher than code minimum and the actual sustained live loads are much less than specified. Creep is generally associated with system exposure to high moisture conditions under significant loading such as stacks of sheathing placed on wet floors during construction. The creep testing results and comparative deflection limit analysis presented herein demonstrate how the current practice of span/480 deflection criteria addresses creep behavior. For best results when designing for dynamic performance or if design conditions call for high loads or high moisture conditions, a design professional or component manufacturer should be consulted.

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