Information About Floor Performance

Perceptions of unacceptable dynamic floor motion have challenged designers, contractors, and material suppliers for many years. Normal working loads, usually from the movement of occupants, sometimes result in floor motions considered annoying by other occupants. This can occur even on floors where structural design loads are extremely large compared to the forces generated by a person walking. Conforming to static deflection criteria, as dictated by building codes, does not eliminate this potential problem.

Weyerhaeuser has thoroughly investigated floor performance issues for floors framed with TJI® joist and structural composite lumber (SCL) products. The company reviewed theory and existing research, conducted additional laboratory experiments, and used extensive floor performance survey results to link research and theory to the perceptions of floor users.

Weyerhaeuser believes that the TJ-Pro™ Rating system (though currently limited to floors containing Trus Joist® TJI® products) is the most comprehensive indication of floor performance ever developed for wood-based assemblies. However, this does not mean there is a single floor rating above which everyone will be completely satisfied with a floor. Acceptable floor motions vary among individuals.

The general rule is that the higher the floor performance rating, the better. The discriminating user is advised to explore various system options to obtain the highest practical rating. With the TJ-Pro™ Rating system and its relative cost index, it is often possible to significantly increase the rating with little or no increase in assembly cost.

History and Background

Since the mid 1960s, Weyerhaeuser has been involved in evaluating floor performance. The company's TJI® joist, introduced in 1969, extended floor spans beyond those traditionally used in wood frame construction. Weyerhaeuser soon recognized that the usual code deflection limitation, L/360 under live load, did not necessarily result in satisfactory floors and began recommending live load deflection limits of L/480 for residential floors and L/600 for commercial floors. The improved deflection criteria resulted in more satisfactory floors and provided a reasonable starting point for floor designs today.

As the business grew rapidly through the 1970s, additional field experience revealed that some occupants still had floor performance complaints despite the stiffer static deflection criteria. This was a strong indicator that static deflection criteria alone would not guarantee an acceptable floor system. In the late 1970s, Weyerhaeuser held preliminary discussions with various universities about developing a research program to define floor assembly design criteria based on dynamics. Concurrently, a review of literature on the topic indicated that, despite a significant amount of research, there was no consensus about the dynamic property acceptance criteria for floors.

Through the 1980s, as business continued to grow, the number of complaints about "bouncy floors" grew proportionally. There was also a steady increase in observations about likely causes and possible corrections. Although unacceptable floor movement became better defined, satisfactory solutions were not evident: complaints were not solely related to dynamic properties, but also to other senses and even social criteria. Unacceptable dynamic performance is often perceived visually when a chandelier swings or a tall cabinet sways. A noise, such as a squeak emanating from a floor system, can also trigger perceptions of unacceptable dynamic response.

Even the history and the economic status of the observer were found to be important. For example, someone moving from a small slab-on-grade floor system to their first framed floor or a buyer spending large amounts of money on a home might often be more sensitive to floor performance. Motion perceptions on commercial floors, particularly those with large open areas, are thought to affect the value of the business. Although research continued through the decade, clear acceptance criteria still had not been defined.

In 1991, Weyerhaeuser formed a committee made up of engineers, marketers, and line managers to formally study floor performance. The objective was to find a rating system for design that adequately accounted for dynamic response for floor assemblies under normal working loads (in this context, working load means movement of occupants).

The project included a review of existing literature and laboratory research to investigate and confirm dynamic response properties. The committee conducted field investigations of typical assemblies and a comprehensive subjective survey of field floors to investigate the relative "feel" of these typical floors.

The survey considered the following floor assembly components:

- Joist stiffness and spacing.
- Joist span.
- Continuous member or single span.
- Deck stiffness.
- Composite action between joist and deck.
- Effects of ceilings and bridging.
- Effects of transverse partitions.
- Whether supports for joists were walls (considered rigid) or beams of some defined stiffness.

The research committee reached its objective in late 1995, and the project formed the basis for the TJ-Pro™ Rating system, which is now part of Weyerhaeuser structural frame software, ForteWEB® and Javelin®.

Basic Dynamic Properties and Assembly Component Effects

The following are simple fundamental dynamic properties and their relative effects:

Frequency: Most people agree that low frequencies, particularly in the range of 8 Hz or less, are uncomfortable. Most of the TJI® floors investigated in the survey, which consisted of joists and decks only, have a natural (first) frequency from 10 to 20 Hz. Some researchers found higher-order frequencies (second or third) to be important.

Amplitude: In general, large movements are more noticeable regardless of frequency. Amplitude increases with span.

Damping: If the wave motion caused by a moving load decays rapidly, the movement is less noticeable regardless of frequency and amplitude. Damping increases with the addition of a ceiling and with a solid partition transverse to the joists. Adding mass reduces damping. Typical dynamic wave motions and damping related to mass are shown in Figure 1 below.

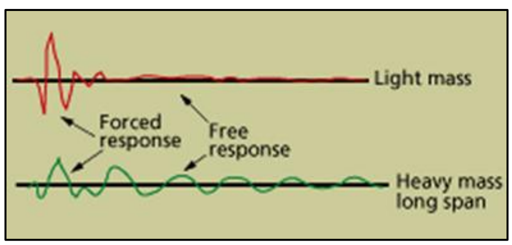


Figure 1: Dynamic wave motion and damping.

The addition of a poured topping on the deck increases the transverse stiffness of the floor, which is a positive effect. The added mass, however, decreases damping. An appropriate method of accounting for these contradictory effects is still being investigated (see Poured Toppings).

Other Components: Acceleration and velocity are sometimes used as variables in floor performance evaluations.

The following notes discuss the relative effects of various floor assembly components:

- **Assembly Stiffness:** This is an assembly parameter often related to the dynamic properties of the system. This stiffness is represented by the deflection obtained from a concentrated load placed at the center of the assembly. On a relative basis, this measure includes the combined stiffness of the major components of the assembly and shows their interaction. Increasing assembly stiffness has a positive effect.
- **Basic Stiffness:** This is a combination of joist depth and span. Greater basic stiffness increases frequency and assembly stiffness. For a given span, increasing the joist depth results in the greatest increase in basic stiffness.
- **Joist Spacing and Deck Stiffness:** Reduced joist spacing, or increased deck thickness, generally improves the performance of a floor by increasing assembly stiffness.

- **Composite Action:** This is a measure of how the deck component of the assembly interacts with the joist to effectively increase basic stiffness. Increasing deck stiffness, or the use of construction adhesives, increases composite action for short-term dynamic loads.
- **Continuity:** Joists that are continuous over several supports generally enhance floor performance. Care must be taken if such joists continue into an adjoining occupancy as these members can transmit vibration and sound through the floor assembly.
- **Ceilings:** A directly applied (not suspended) gypsum ceiling improves floor performance. Assembly stiffness and damping are slightly increased.
- **Bridging/Blocking:** (See next section).
- **Beams:** When joists are supported on beams there is a small increase in deflection under normal working loads, which slightly reduces the rating. Beams designed for relatively large tributary floor areas have less effect.

Additional Contributing Factors: Full-height framed partitions that are transverse to the joist and away from supports have the effect of damping vibrations, which improves floor performance. However, such partitions must be solidly connected to the floor assembly.

Materials and Construction: The use of quality materials and careful attention to details can increase the rating by several points. At present, there is insufficient data to measure this effect; however, it is beneficial to ensure that:

- All fasteners hit the joist members.
- All supports are solid and level.
- Hangers, when used, are carefully installed in accordance with manufacturer's instructions.

Remember that a floor assembly deflects even under light working loads. Bridging of 1x _ that splits during installation and duct work that rubs against joists can produce noise that may reduce the perceived quality of the floor.

Floor Performance Enhancements and Field Fixes

The most effective and economical technique for ensuring good floor performance is the identification of the proper depth, series, and spacing for the floor joist during the design phase. A deeper, stiffer joist is the most economical solution for increasing floor performance for a given span. Bridging/blocking, strapping, ceilings, and extra flanges are considered to be floor performance enhancements and field fixes — not span extenders.

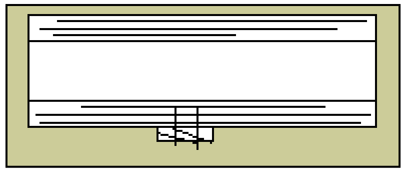
According to the results from the research measuring the static, dynamic, and subjective performance of floor systems, the enhancements listed above can, when properly installed, improve floor performance by reducing point load deflection. However, if such enhancements are used to expand the span of a given floor system, they can significantly reduce dynamic floor performance. Therefore, span extensions based on the increased number of effective joists from enhancements are not recommended. The TJ-Pro™ Rating system accounts for this behavior.

Bridging/Blocking and Strapping

Enhanced TJ-Pro™ Rating for bridging/blocking and strapping are allowed for approved systems installed at 8′ on-center or less. Bridging/blocking and strapping should be continuous from wall to wall (or support beam) and evenly spaced along the floor span. When interruptions from HVAC equipment and/or changes in joist depth occur, the proper detail should be applied. The list below includes installation details and material specifications for each of these systems.

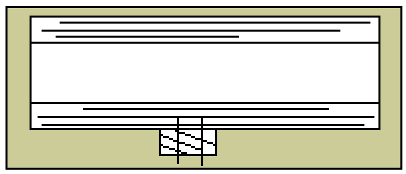
TJI® blocking is currently the only approved blocking system for use in TJI® joist floor systems. Reference *Trus Joist® TJI® Joist Specifier's Guide* (TJ-4000) for recommended TJI® blocking installation. Trus Joist® SCL can also be used as a blocking material following proper nailing and installation method. The TJ-Pro™ Rating system will be the only approved method of describing floor system performance.

1x4 Strapping



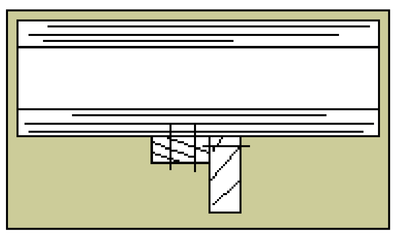
Spacing: maximum 8′ on-center between rows
Material: sawn lumber
Connection: two (2) 2″ long screws at each joist (nails may cause squeak and damage to joist flanges)

2x4 Strapping



Spacing: maximum 8′ on-center between rows
Material: 1.3E TimberStrand® LSL or No. 2 (or better) sawn lumber
Connection: two (2) 2½″ long screws at each joist (nails may cause squeak and damage to joist flanges)

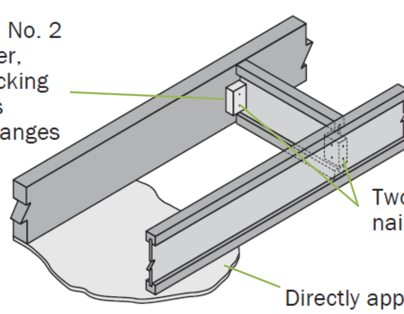
Strong Back



(2x4 or deeper vertical flange connected to a 2x4 flat strap)

Spacing: maximum 8′ on-center between rows
Material: 1.3E TimberStrand® LSL or No. 2 (or better) sawn lumber
Connection: two (2) 2½″ long screws at each joist (nails may cause squeak and damage to joist flanges); 8d (0.113″ x 2½″) nails at 12″ on-center for connection of vertical flange to flat strap

TJI® Blocking with End Blocks



Spacing: maximum 8′ on-center between rows
Material: specified in illustration above
Connection: specified in illustration above

Poured Toppings

Poured toppings are used to significantly increase the fire and sound ratings of single and multi-family floor systems. The addition of lightweight or normal weight toppings (¾″ to 3″ thickness) can affect floor performance. Weyerhaeuser conducted research measuring the static, dynamic, and subjective performance of floor systems with poured toppings.

Research results show that poured toppings reduce the point load deflection of floor systems by increasing the load sharing between joists. However, poured toppings can significantly reduce the dynamic performance of long span floor systems. The TJ-Pro™ Rating system accounts for this behavior. Span extensions based on the composite action of the topping to sheathing connection are not recommended. Weyerhaeuser recommends accounting for the additional mass of topping by including the topping weight in the uniform dead load calculations.

Each specific design should consider the long-term performance of poured toppings. Weyerhaeuser considers toppings a separate component and considers it the responsibility of the topping manufacturer to warrant topping materials and their performance. The following recommendations guard against field problems and enhance long-term systems performance:

- Shear transfer studs (double headed nails) and/or bonding agents applied to clean dry sheathing before pouring can enhance the connection between the poured topping and the floor sheathing.
- Pouring toppings during conditions optimal for curing can increase the performance of the bond between the poured topping and floor sheathing.
- Protecting the floor against impact loads and excessive moisture during cure and service can increase the effective life of the topping.
- The curling of poured toppings at corners and edges can be minimized with good construction practices such as assuring uniform curing rates and edge tie downs.
- Good construction practices should be followed to avoid performance problems when using radiant heating systems in poured toppings on wood framed floor systems. Heating system manufacturers should be consulted to address heating and cooling cycles, installation details and proper topping section to use in combination with heating coils.
- Professional engineers and topping manufacturers should be consulted to address any unusual environmental and service conditions.

Research

As part of the project, dynamic research was conducted on a variety of floor assemblies. User perception research was conducted internally, as briefly discussed in the next section. Weyerhaeuser personnel and various consultants have conducted additional research at universities and on field floor assemblies.

The study included a worldwide literature search on the subject of floor performance. Although much of this international research was not specific to wood-based assemblies, it was helpful in understanding the scope of the floor performance issue. The research team studied approximately 100 documents, including content and references contained in the following list:

- Dolan JD, Li X, Woeste FE. Effect of imposed load on solid-sawn wood-joist floor vibrations. Forest Products Journal 1995 Jan; 45(1).
- Galambos TV. Vibration of steel joist-concrete slab floors. Technical Digest 1988; (5) Steel Joist Institute.
- Murray, TM. Building floor vibrations. Engineering Journal/American Institute of Steel Construction 1991 third quarter.
- Ohlsson, SV. Ten years of floor vibration research - a review of aspects and some results. Proceedings of the National Research Council of Canada Symposium/Workshop on Serviceability of Buildings. 1988 May 16-18; (1): 435-50
- Onysko, DM. Deflection serviceability criteria for residential floors. Project no. 43-10C-204, 1988. Forintek Canada Corp.

- Smith, I, Chui Ying Hei. Design of lightweight wooden floors to avoid human discomfort. Canadian Journal of Civil Engineering 1988; (15):254-62.

Researchers have proposed a considerable number and variety of dynamic floor performance criteria. Although general consensus has not been reached, Weyerhaeuser believes that many approaches have merit. In the Trus Joist® TJI® project, the committee did not find a single criterion that correlated to the field surveys. Therefore, Weyerhaeuser developed the TJ-Pro™ Rating system, which provides better correlation to the research.

There is a worldwide trend toward building code adoption of minimum performance criteria for floors. For wood construction, the most noted are the *National Building Code of Canada*, which contains criteria based on D.M. Onysko's work for sawn lumber, and Euro-Code (EC) 5, which is being adopted by the EC and contains criteria based upon Sven Ohlsson's work. Criteria similar to that used for sawn lumber have been proposed for engineered wood products in Canada and are currently being reviewed.

While the adoption of minimum criteria by codes is valuable, such criteria may not be appropriate in all cases. Weyerhaeuser investigations led to the conclusion that a design tool was needed to permit the selection of performance appropriate to any application. Weyerhaeuser uses the TJ-Pro™ Rating system as a floor performance tool.

Surveys

The subjective data used in the floor performance project came from surveys conducted on approximately 1000 floors over a period of several years. The floor assemblies used in the survey included residential and commercial floors as well as a wide range of Trus Joist® products from the shallowest and smallest flanged TJI® joists to the deepest and largest flanged TJI® products.

Analysis and Ratings

Weyerhaeuser's data analysis procedure required input of all the assembly parameters and the subjective ratings of the observers into a computer application devised for that purpose. Researchers calculated a wide variety of assembly parameters, both static and dynamic, and correlated the results to the subjective ratings from the surveys. The best correlation obtained was an R^2 of 0.5. The correlation produced a regression equation that predicts a floor assembly rating on a scale comparable to that of the survey ratings. This predicted rating is not limited to the integer values in the survey but is continuous from a range near 0 to about 6, with the lower values representing the best floors. This rating system was thought to be confusing, so an arithmetic conversion was applied to yield a rating system in which higher values represent better floors. The final rating ranges from 25 to 65.

Figure 2 represents the percentage of the population expected to perceive a floor as being good to excellent. Notice that as the rating increases past 40, the percentage of the population that judges the floor to be excellent rises sharply. However, even at high ratings, which may not always be economically practical, no more than 60% to 70% are expected to judge the floors as excellent. This seems to support our view of human nature since many of us have difficulty rating anything as excellent. On the lower side, note that the excellent rating begins to dramatically decrease at around 35 points, and the better rating drops sharply at about the same rating level. However, there is a relatively constant percentage (about 25%) that rate floors good across a range from 25 to about 40. This seems to indicate a degree of uncertainty on the part of many observers. As the rating drops below 25, the evaluation becomes quite unstable but still clearly indicates a region of unsatisfactory floors.

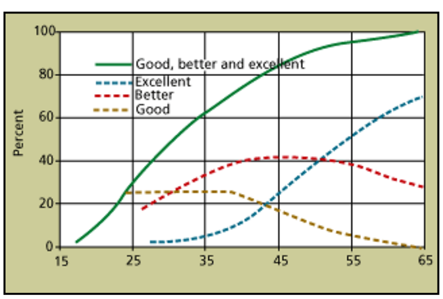


Figure 2: Percent population perceiving a floor to be good to excellent v. floor performance.

Figure 3 represents the percentage of the population that is expected to perceive a floor as being unacceptable. Notice that the upper line in Figure 3 is an inverse of the upper line in Figure 2. That is, the value of either of these lines is equal to 100 minus the value of the other line. Notice also that there is a flat portion in the unacceptable rating curve at about 25%. This indicates to us that a percentage of the population is either sensitive or tends to hold negative opinions. Even at quite high ratings, there is a small percentage of the population that can be expected to find floors unacceptable. Of course, it is possible that some of these negatives are due to unreported construction problems or errors in describing certain assemblies.

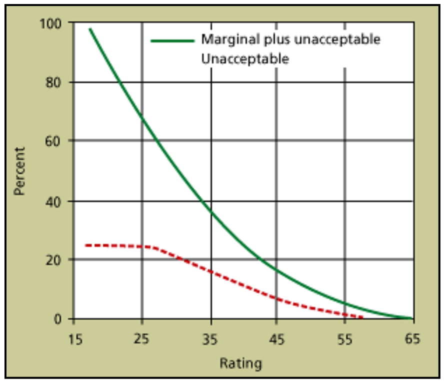


Figure 3: Percent population perceiving a floor to be unacceptable to excellent v. floor performance.

Selecting an Appropriate Rating

The TJ-Pro™ Rating system is intended for typically loaded floors (i.e., not for dance halls, weight rooms, etc.).

Floor performance is highly subjective and selecting an appropriate rating level cannot guarantee 100% satisfaction. However, the TJ-Pro™ Rating system enables the designer to select an approximate level of acceptability. The factors that go into this selection are not complicated: the designer knows the type of occupancy and activities and can estimate the number of people who will participate in these activities. For example:

- A large open area in a store should be judged differently than a residential bedroom. Many people will use the store and annoying floor motions could deter business.
- Different areas of a single-family dwelling could require different considerations. For example, a recreation room designed for entertaining might be considered separate from the den.
- Should rental apartment unit floors be considered from the same view point as those in expensive condominiums? That might depend on the size of the rental units, the expected rental income and perhaps even the part of town where the rentals will be located.

While it is desirable to obtain the highest possible rating for all floors, there are always economic considerations. The TJ-Pro™ Rating system gives designers a comparison cost value based on an input cost of decking and the volume of floor joists in the assembly. This is not an accurate cost per square foot, but it gives a reasonable relative number. Some experimentation with varying components of the assembly will give the designer a good feel for how to obtain the best value in the assembly, from both cost and performance rating standpoints. For example, depending on building details, it may cost very little to increase joist depth. In other cases, a smaller joist section at reduced spacing may be the best choice.

The TJ-Pro™ Rating system should not be interpreted as precise. Survey results indicate that sensitive individuals may detect a difference with a rating change as small as 3 to 5 points.

If you have any questions, please contact your Weyerhaeuser representative.