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Understanding floor performance in wood-based construction

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As the science of floor performance has continued to evolve, the increased awareness by professionals in the building industry has created a common thirst for knowledge on the subject. This paper is written to increase your understanding of floor performance and discuss some of the complexities involved. There are also recommendations included to help you avoid poor performing floors.

We start with vibration.

People are sensitive to vibration. An example of human sensitivity to vibration is seasickness. The condition of motion sickness is caused by a person's sensitivity to the low frequency vibration of waves. When it comes to floors, people can be annoyed by a floor's vibration and it may affect their ability to focus on work. If an occupant is sitting at a desk and every time someone walks by, the desk rattles, well that's a real distraction. Noticeable floor vibration can also give occupants a perception regarding the quality or safety of a building.

People's sensitivity to vibration is related to their activity. If they are sitting or lying down they will sense vibration much more than if they are walking or otherwise active. If a person is running or doing rhythmic activities such as aerobics, they won't be as sensitive to a floor's vibration. Next to occupant activity, magnitude and duration of the vibration has the biggest impact when it comes to human sensitivity.

The term "floor performance" measures the acceptability of a floor's vibration. The vibration is due to the impact of footsteps and is governed by the floor's natural frequency of vibration and movement under load. The goal of measuring floor performance is to limit movement and vibrations to acceptable levels, based on human sensitivity.

First of all, a floor must be designed to meet code requirements, including strength and stiffness, as well as possible sound and fire resistance criteria. For commercial structures, architects typically design for fire and sound, and engineers design for strength and stiffness requirements. In addition to code requirements, using quality products and installation components are important. Floor vibration is another factor that contributes to a floors performance. While Canada includes floor vibration in its residential building code, the United States has no minimum requirement for floors based on vibration.

Furthermore, who should be responsible for floor performance? Should it be the architect, the engineer, or a combination of both? What is clear is that architects, engineers and builders share a common goal in providing good floor performance and avoiding client complaints.

What components affect vibration?

Every floor system has its own built-in natural frequency of vibration. There are many factors that contribute to a floor's vibration characteristics, including:

- Joist span
- Joist stiffness
- Subfloor thickness/stiffness
- Composite action between joists and subfloor based on connections
- Composite action between concrete topping and the subfloor and joist
- Floor damping and assumed damping ratios
- Floor mass and effective weight assumptions
- Blocking, with or without straps
- Strong-back bridging stiffness and connections
- Partition walls and adequate connections to the floor
- Floor occupancy use
- Floor openness
- Ceiling attachments and stiffness
- Stiffness of joist support beams
- Joist continuity
- Proper installation of components

Subfloor thickness.

Subfloor panels are a critical component when it comes to load sharing and floor vibration characteristics. But there is a subfloor consideration that vibration calculations don't take into account: deflection of the panel between the joists. A common example of this is when $\frac{3}{4}$ " panels are used over joists spaced at 24" on center. While this application is fairly common and meets code requirements, many occupants don't like the deflection of the panel they feel when they step between the joists. To avoid this issue, many designers will use $\frac{7}{8}$ " thick panels when joist spacing is 24" on center, or $1 \frac{1}{8}$ " thick panels when joist spacing is 32" on center. Other components, such as carpet and pad or a concrete topping, may eliminate the need for thicker subfloor, based on deflection between the joists. The point being that vibration control must be checked separately from these common subfloor thickness guidelines.

Floor performance basics.

- Stiffer floors perform better than less stiff floors in all cases. Using deeper joists is the best way to create a stiffer floor.
- Stiffer subfloors will help share the load among joists improving performance. After joist depth, this is often the best way to increase performance.
- Gluing and nailing the subfloor to the joists helps stiffen the floor and avoid squeaks. Always specify a glued and nailed floor.
- Concrete topping generally helps with short spans but can hurt long span floors by lowering the natural frequency of the floor.

- Damping effects of partitions, furniture and people, will improve a floor's performance.
- Blocking should typically be avoided as a method to increase floor performance, since there is a higher potential for squeaks, as well as increased labor costs. If blocking is used, it should be rigidly attached.
- When designing floors with separate occupants, don't continue a joist from one occupant space to an adjacent occupant space. For example, from one apartment to the next. People may not mind when they create their own vibrations but will likely be annoyed by someone else's.
- Proper installation of components is required to achieve floor performance goals.
- Design software such as RedSpec™ with the FloorChoice™ rating system can be used to predict a floor's performance.

Should all floors have the same performance level?

Occupancy use may determine the design of a floor with regard to vibration control. Following are some examples:

Offices and Public Buildings: Floor performance should be highly considered to avoid occupants' complaints from floor vibration, as well as avoiding the perception that the building is weak or unsafe. A minimum FloorChoice™ floor performance rating of 4 is recommended, though the design should take into account any client wishes for a stiffer floor.

Single-Family Housing or Condominiums: An owner typically has pride in their home and wants to avoid a poorly designed floor. However, cost is often an issue. A high-end home may require more stringent design criteria compared to a starter home, based on the owner's finances and preferences. In addition, consideration may be given to individual rooms. For example, a bedroom area which will have limited traffic is not as critical as a kitchen area or family room with high use. Main living areas and large rooms are more apt to have open areas where users are walking at a rhythmic gait, while small rooms or rooms filled with furniture, will prevent that same walking pattern.

Apartments or Low-Cost Housing: It's common to see floor performance take the back seat to cost for these applications. Often the owner is more concerned about limiting the cost of a building than providing a renter with a quality floor.

All Buildings: Even if a building is designed with a limited budget, it does not mean floor performance should be ignored. Often, a floor can be designed to avoid unwanted vibrations with relatively small added cost.

Do all floor joist manufacturers provide floor performance tools?

While some joist manufacturers provide a rule-of-thumb approach, most don't have tools to help predict floor performance.

Historically, many manufacturers have used "L/over" deflection values as a guide to design floors. While this approach is better than nothing, it is a poor predictor of a floor's vibration characteristics. For example, a short-span joist with a live load deflection of L/360 may provide a terrific floor, while a long-span joist can have a live load deflection of well under L/600 and still have poor vibration performance.

We are frequently asked whether the RedBuilt™ FloorChoice™ rating system and the Trus Joist rating system provide similar results. Our experience is—while the two systems have their differences—they do provide similar results for shorter to medium span floors, which tend to have higher frequencies of vibration, but as the joist span gets longer, the two methodologies provide widely differing results. RedBuilt’s methodology will typically provide lower ratings for long-span, low frequency floors which RedBuilt analyzes per AISC/CISC.

The RedBuilt approach.

Many assumptions must be made when determining a floor’s natural frequency. While RedSpec™ software only approximates actual conditions, it is arguably the best tool in the industry to estimate an engineered wood floor’s vibration characteristics. The FloorChoice™ ratings that it generates are also useful for comparing the floor performance of multiple systems, and it provides some assurance that design intent is satisfied. Because not all variables are taken into account when calculating a performance rating, ratings can be conservative in some instances, and liberal in others. RedBuilt does have the ability to analyze floors using variables not available in RedSpec™ software, at a customer’s request.



RedBuilt referenced the following methods, in combination with their experience, to create FloorChoice™, RedBuilt’s floor performance rating system:

- Point-load deflection method based on the Canadian Construction Materials Centre (CCMC) report “Development of Design Procedures for Vibration-Controlled Spans Using Engineered Wood Members”
- Acceleration at resonance based on the AISC/CISC design guide “Floor Vibrations Due to Human Activity”

Every design assumption made can affect floor performance ratings. The following two assumptions regarding concrete toppings and perpendicular partition walls significantly impact a floor rating:

1. If there is a good bond between a floor topping and the subfloor, not only does the floor system become stiffer in the direction the joist is running, but also in the transverse direction. This added stiffness in both directions can significantly help a floor’s performance. However, if debonding occurs between the topping and subfloor there will be no composite action. RedBuilt takes the more conservative approach and assumes no composite action between the topping and the remainder of the floor system. By request, RedBuilt can change this assumption, but such analysis must be done outside of RedSpec™ software.
2. Partition walls running perpendicular to floor joists can significantly improve floor performance due to damping and stiffening the floor in the transverse direction. For partition walls to help with load sharing, the connection

between the partition wall and floor must be sufficient to keep the joist from moving relative to the partition wall. The RedBuilt™ FloorChoice™ rating system does not include any allowance for partition walls. RedBuilt can change this assumption, by request, but such analysis must be done outside of RedSpec™ software.

Recommendations.

Floor vibration should be taken into account when designing floors. With floor design software, specifiers can predict a floor's vibration characteristics to help achieve the desired level of performance. Following is a suggested approach for those designing and specifying a floor system.

Discuss floor performance with your clients, and determine floor performance preferences early in the design phase of a project. Most building owners have not been exposed to—and don't have a good understanding of—floor performance. A guide to the RedBuilt™ FloorChoice™ rating system can be found under the "Reference" tab on the RedBuilt website. This guide will help facilitate discussion between designers and their clients. If the owner or developer agrees on floor performance criteria at the beginning of a project, they tend to be more satisfied with the end results, especially if they have chosen cost over performance.

Use RedSpec™ software or contact your local RedBuilt Technical Representative to do preliminary sizing for strength and vibration performance. A RedBuilt representative can provide cost comparisons between potential systems to determine the system that best meets the project requirements.



Make final floor design decisions and specify the desired RedBuilt product series, depths and spacing on the plans as well as the thickness of the subfloor material to be used. Always specify a glued and nailed subfloor which helps stiffen the floor.

Many designers want to keep their specifications open to allow alternate suppliers. For those folks, here are some recommendations: When allowing substitute products, require that the approximate floor joist stiffness, depth and spacing be maintained, as well as the subfloor thickness. This approach will help assure that the floor performance you designed for is at least approximately maintained. If components such as strong-back bridging are included in the design, maintain those requirements as well. In addition to floor performance, make sure any alternate suppliers include all the products and services required by your specifications, including strength design, allowable nail spacing, LVL flanges, any engineer sealing requirements, equivalent rim and beam substitutions, product or design warranties, etc.

Remove any "L/over" requirements from your specification unless you enforce the substitution per the paragraph above. I have encountered many projects where a designer specified a floor system to achieve a certain level of performance, only to

have an alternate joist supplier use a conflicting live load deflection limit shown in the specifications resulting in a floor that did not meet the designer's intent.

The science behind floor performance is available for you to use today. RedBuilt offers RedSpec™ sizing software with FloorChoice™ floor ratings. We also offer you the expertise of our Technical Sales Representatives to help you balance cost with performance to achieve the best system that meets your design goals.

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About the Authors:

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