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DEFLECTION - ARE CURRENT STANDARDS FOR CERAMIC & STONE TILE FLOORS REALISTIC ?

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Ask anyone in the ceramic and stone tile industry what they think is the most common installation phrase, and chances are they will probably recite some version of the following:

"The maximum allowable deflection of a floor structure or substrate to receive a ceramic tile installation is 1/360 of the span."

Chances are even better that those same persons have only a vague idea, at best, of what the phrase really means, no less how to assess or measure deflection. Whether they are an architect, tile contractor, tile product manufacturer or building owner, that person most likely assumes that someone other than themselves are responsible for verifying deflection characteristics of a floor structure to insure a successful tile installation. Even worse, those persons that are technically savvy enough to understand the technical concepts of deflection rely on unrealistic methods and obsolete industry standards to assess deflection requirements.

This article will explore the concept of deflection using wood floor structures as a case study. Wood floor structures are generally the most problematic when it comes to the nature and extent of their flexibility. However, the concepts are generally the same for all types of floor structures.

DEFLECTION CONCEPTS

So, what does the term “deflection” mean ? Deflection is defined as the deformation that accompanies bending of a floor structure when exposed to the weight of people, equipment, and the weight of the structure itself; we are principally concerned with its maximum value, which occurs at the center of the span of the floor structure or the structures’ individual components.

Some degree of deflection occurs in all floor structures. But when designing the structure to accept rigid finishes such as relatively thin ceramic tile or stone tile, it is critical to confirm that deflection does not exceed prescribed limits. Some level of deflection exists in all structures exposed to loads. Besides the psychological discomfort of a “bouncy” feeling that excessive deflection produces, excessive deflection can cause problems ranging from minor cracking to complete delamination of tile floors, while still remaining well within safety margins against any catastrophic structural failure.

INDUSTRY STANDARD

The maximum allowable limit for the deflection of construction assemblies which support rigid building materials and finishes (ceramic tile, plaster , etc.) is generally accepted in the construction industry to be 1/360 of the span of the structure, under prescribed loads. For example, a floor structure with a 15 foot (4500 mm) span could have a maximum allowable deflection calculated as follows:

1/360 x 15 ' x 12 " = 0.5 in (12.5 mm)

(Note: it is convenient, but not necessary to convert span in “feet” to “inches” to arrive at a meaningful deflection figure).

More often overlooked than the span of the floor joists, though, is the span of the plywood subfloor spanning between wood joists. To most persons surprise, the plywood span is also subject to the same deflection criteria (Note: joist spacing is typically 16 in [406 mm], with clear span of 14.5 in [368 mm]) :

1/360 x 14.5" = 0.04 in (1 mm)

Applying the same deflection standard to the plywood span between joists results in an unbelievable maximum allowable deflection of 0.04 inches, or almost less than 1 mm !! Granted, this is a technical oversimplification, as the dynamics of load distribution change over small areas (especially with a rigid tile distributing the load over a small area) and are not directly proportional to distribution over longer spans. Nonetheless, the example illustrates that no matter how “stiff” the floor joists and beams, the stiffness of the plywood spanning joists may be inadequate to meet industry standards. In many cases, it is the span of the plywood sub-floor that is the limiting factor, and is often not stiff enough to meet the 1/360 deflection limitation. Tile industry standards currently require 2 layers of 5/8 in. (15 mm) thick plywood in applications where tile is directly adhered to the plywood subfloor.

But how does the architect, contractor or building owner know whether the design of a wood floor system meets this criteria for maximum allowable deflection? The “rule of thumb” formula, 1/360 of the span, only tells you the maximum allowable deflection or movement of the floor from a level position . How do they calculate the “actual” deflection of an “as built” floor structure to compare with the design values for maximum” allowable” deflection?

Well, in most cases, no one does any calculations or measuring in the field. Typically a chart called a span table is referenced. Span tables are a convenient short cut with a wide margin of safety which tell you the maximum span for a structural wood member of a given size (depth & width) , wood species, spacing, and the proposed live and dead loading (weight of people, furniture, and floor assembly) prescribed by building codes. But convenience has its price; span tables do not take into consideration a myriad of variables, the effect of which are grossly underestimated.

Let’s look at a case study of using span tables to assess deflection. Take for example, a common 2"x10" (50 x 250mm) wood floor joist, spaced 16 in. (400mm) on center, with a combined loading of 40 lb/ft^2 (195kg/m^2) live /10 lb /ft^2 (48 kg/m^2) dead load (weight of people ,equipment, and floor structure).

Consultation of span tables indicate that this typical joist can have a maximum span of between 14'- 6" (4420mm) and 17'-4" (5280mm), and meet the 1/360 maximum deflection criteria, depending on the species of wood specified.

What happens if you don’t know the physical characteristics of the species or grade of wood? A more common problem is that no one has any idea what species or grade of wood joists is specified. A review of the physical characteristics of different grades of wood reveal that certain common grades of wood framing lumber have 400% less strength than the highest quality structural grades. Similarly, what if the proposed dead load (weight of structure and finishes) does not fit the typical 10lb/ft^2 (48kg/m^2) or 15lb/ft^2 (973 kg/m^2) choices given in most span tables ? To prove this point, take as an example, a popular floor finish assembly consisting of 3/8 in. (10mm) thick granite tile, installed with a medium bed mortar over a ½" cement board underlayment. These materials will weigh about 15 lb/ft^2 (73 kg/m^2). Add to this the weight of a typical wood floor structure and gypsum board ceiling at 15 lb/ft^2 (73 Kg/m^2) for a total dead load of 30lb/ft^2 (146 kg/m^2) (a 100% increase over typical span table dead loads).

The above are just two of the many examples why the common practice of using a span table to analyze deflection of a tiled floor assembly is unacceptable. The span tables do not take into account the many variables that are critical to determine appropriate floor stiffness for a tile or stone installation.

CALCULATING DEFLECTION

Lets look at the formulas for determining actual deflection. The formula for a simple beam or joist carrying a uniform load is:

$$D = \frac{5}{384} \times \frac{W l^3}{E I}$$

The formula for deflection of a beam or joist carrying a single concentrated load at the center of the span is:

$$D = \frac{1}{48} \times \frac{P l^3}{E I}$$

D - Deflection (in or mm)
W - Uniform Load (lb or kg)
l- Span (in inches or mm)
E - Modulus of Elasticity (psi or MPa)
I - Moment of inertia (in^4 or mm^4)
P- Concentrated Load (lb or kg)

A condition that frequently occurs in construction consists of a combination of a uniformly distributed load and concentrated loads acting simultaneously. The deflection for each loading can be calculated separately with the above formulas and the deflection sum would be the total maximum deflection. This condition, by the way, is not addressed at all when using a span table to analyze deflection. A temporary concentrated load could be the sole contributing factor to a cracked tile or stone installation.

Let's calculate the actual deflection of the same model 2" x 10" (50 x 250mm) wood floor joist. This floor structure would have the following physical characteristics: 2 x 10 joist, spaced 16 in. o.c., with industry standard wood subfloor construction, the same 3/8" (10mm) granite tile installed over ½ " cement board ; total dead load of 30 lb/ft^2 ($146 kg/m^2$). Live loading is prescribed by the building code at 40 lb/ft^2 ($194\ kg / m^2$). The total live and dead load would be 70 lb/ft^2 ($334\ kg/m^2$). The total uniform load distributed along the length of the floor joist would be the 15' (4500mm) span times a factor of 1.33 to account for the 16 in. joist spacing for a total uniformly distributed load of 1,396 lbs. (633 kg). The moment of inertia for a 2 x 10 is taken from wood engineering data to be 104 in^4. The modulus of elasticity for a common grade of framing lumber (Hemlock - Fir #1 & 2) is 1.7×10^6 psi.

The calculation is performed as follows:

$$D = \frac{(5)\,(1,396)\,\,[(15)\,(12)]^3}{(384)\,(1,700,000)\,(104)} = 0.6 \text{ in}$$

You recall in the previous deflection calculation that this model joist had a maximum allowable deflection, based on the standard limit for a tile floor, of L/360, or 0.5 in (12.5mm) for a 15' (4500mm) span. The conclusion then, based on the weight of the above described tile floor finish assembly, is that actual deflection exceeds allowable deflection by 20 %, and therefore the design of the floor joist is not suitable to prevent excessive deflection of the tile installation. A change in any of the variables, such as a lower quality grade of wood lumber to, for example, Spruce, or a temporary concentrated load, could further increase actual floor deflection, and likely lead to cracking or delamination of the tile.

MARGIN OF SAFETY

As you can see, calculation and analysis of deflection is a complex science affected by many variables. While a detailed understanding of deflection is not necessary, it is important to have a knowledge of deflection concepts and terminology in order to request an investigation, and then make proper installation or troubleshooting recommendations. As demonstrated above, reliance on a chart or "rule of thumb" is no longer an acceptable approach to determine the deflection and resulting stiffness, of a subfloor structure. These short cut methods, combined with the plethora of new tile and stone methods and materials, and variations in constructions methods and quality, leave an uncomfortably small margin of safety for a problem-free installation.

As a result, it has become necessary to require building owners to enlist the services of a qualified architect or engineer to assess and calculate actual compliance with deflection criteria. When making installation recommendations, it is prudent to request verification of deflection, or to require a liability disclaimer.

FUTURE RESEARCH

Current standards and research into the effect of deflection on ceramic or stone tile floor finishes have not kept pace with rapid changes in construction industry technology. Very little has been done to study the effects of floor movement on large format ceramic tiles, fragile thin stone and thin-set installation products, or engineered wood products.

Industry organizations are currently conducting research which may result in the development of new standards for deflection of the wall and floor structures to receive rigid flooring finishes such as ceramic or thin stone tile. These standards will more accurately reflect current methods and materials used in the tile and stone industries.

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