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Guidelines for Tile Installation in Engineered Wood Framing Assemblies

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Engineered wood structural framing systems are now used in approximately 50 % of new home construction in the U.S. Since the introduction of engineered wood products in 1970, there has been considerable controversy in the tile industry over technical considerations and limitations for installing tile over engineered wood products (primarily I-Joists and OSB subfloor) used in structural framing, sub-floor sheathing, and underlayments While engineered wood products have highly predictable performance characteristics, the considerations for use in structural framing systems are much different than conventional sawn dimension lumber.

The primary issues are the longer span and spacing capabilities of engineered wood I-Joists, as well as the effects of moisture absorption on engineered wood products. Increased joist span and spacing result in a greater amount of floor movement, which in turn can cause or contribute to cracking and adhesion failure of rigid tile floor finishes. The tendency to absorb moisture can change the characteristics and reduce the strength of engineered wood products, causing additional problems, or further aggravating the effects of increased movement.

Engineered Wood Product Terminology

The term engineered wood (EW) products encompass a wide variety of product types. EW products are manufactured by bonding wood strands, veneers, lumber or other forms of wood fiber to produce larger composite units with specific structural performance characteristics. These wood products may be used as individual structural components, or be further engineered as a component in different types of composite structural products.

There are four general categories of engineered wood products:

- Structural panels - also known as the subfloor in wood floor construction, this category includes plywood, oriented strand board (OSB) and other composite subfloor panels such as COM-PLY (OSB core with plywood veneer-type surface)

- I-Joists - typically composite assemblies composed of laminated lumber (LVL) flanges and oriented strand board (OSB) webs

- Structural composite lumber - primarily laminated veneer lumber (LVL) which can be used as beams, joists, or the flanges of I-Joists

- Glue laminated timber - also known as glulam, and primarily used in commercial construction

Technical Background

Increased I-Joist Span

The capabilities of engineered wood extend floor structural spans of the I- joists well beyond those traditionally available in sawn dimension lumber frame construction. As a result, the traditional minimum criteria for deflection of L/360 under live loads as required by code often does not produce satisfactory results with tile finishes.

While the longer spans of I-Joists can result in a greater amount of floor motion, it is not the increased spans and overall deflection that typically cause tile cracking and failure. The problems appear to be caused more so by increased torsion, twisting and vibration of the subfloor assembly as a result of the increased load capacity, lighter weight and longer spans of I-Joists. At the same deflection rate of conventional dimension lumber framing, the longer I-Joist spans actually result in a smaller radius of curvature under identical tile module sizes, therefore inducing less shear and flexural stress on the tile at the longer spans. So while increasing stiffness of I-Joists is important, it is only one of several considerations for successful tile installations.
I-Joists are often designed using either predetermined span tables or computer programs which may utilize dead load criteria that is not representative of the actual weight of modern tile floor assemblies. This is critical for those tile installations incorporating thick mortar beds, heavy dimension stone slabs, or underlayment products, which can significantly increase the deflection of the I-Joist under full design loads even though the

I-Joist would remain structurally safe. Sound engineering practice would also require consideration of certain fixed concentrated loads of equipment or fixtures if they exceed the typical 40 psf uniform load prescribed by code (a kitchen island with a stone slab counter weighing no more than 1,600 pounds and evenly distributed is within prescribed design load boundaries, while a 1,600 pound piano supported on three narrow legs is not).

Increased Joist Spacing and Deflection of Subfloor Panels

The spacing of I-Joists is one of three variables that must be balanced to satisfy the basic requirements of an engineered wood structure. The span and depth (size) of the I-Joists are the other variables.   Increasing the spacing is typically the prime consideration, as there is a tangible labor and material saving by eliminating one or two joists per 96 inch length of subfloor panel. In reality, decreasing the joist depth, or increasing joist span while maintaining traditional joist spacing of 16 inches on center may have equal, but less tangible benefits.

The issue with joist spacing is the effect of increased joist spacing on the stiffness and resulting deflection of the subfloor and underlayment between the joists under loading. Conventional dimension lumber joists are typically spaced either on 16 or 12 inch centers as a result of the more limited structural capacity of sawn lumber at average spans compared to EW I-Joists. I-Joists introduced and popularized the concept of 19.2 and 24 inch centered floor joist spacing, primarily as a result of the increased structural load capacity of these products. The 19.2 and 24 inch spacings correlate with the modular length (96 inches) of subfloor panels, thus maximizing economy and performance by eliminating one or two joists per 96 inch length of plywood.

As a result of the increased deflection of the subfloor at increased joist spacing, there is an significant increase in the subfloor radius of curvature under loading, which in turn can induce excessive flexural and shear stress on an a tile adhered and laminated to the subfloor. This is even more critical with today's larger 12 x 12 inch and greater tile modules, as some of the stress induced by the increased movement can be absorbed by the softer and more frequent grout joints of smaller tile module installations across the same increased joist spacing. Similarly, while I-Joists can support localized concentrated loads within the prescribed deflection criteria, the typical subfloor panel thickness used with I-Joists are not sufficiently stiff enough to support concentrated loads without excessive deflection beyond tile's capability.

Therefore, the stiffness or deflection rate of the subfloor panel is more critical than the span and deflection of the I-Joists. It is recommended to provide a subfloor panel by itself, or a subfloor panel in combination with an underlayment panel, that has a greater stiffness or maximum deflection that is less than that of the span of the I-Joists. While a tile installation bonded directly to the subfloor which utilizes a more flexible adhesive or a bonded flexible interlayer / membrane will minimize the shear stress induced by increased deflection, the tile remains susceptible to cracking if the loads exceed the tile flexural bending or breaking strength. A non-bonded tile installation that has the capability of distributing concentrating loads to the joists (full mortar bed), is much less susceptible to distress as long as the I-Joists are designed using realistic dead loads of the non-bonded mortar bed system.

Differential Deflection

EW I-Joists located adjacent and parallel to an end wall or internal load bearing wall have significantly different deflection rates than those located over the continuous support of the rim joist or bearing wall. This differential deflection, especially at longer I-Joist spans, can result in significant torsion and twisting due to the significant difference in movement over relatively short distances adjacent to the perimeter or internal support. Therefore it is necessary to compensate with framing details (outriggers, decreasing I-Joist spacing) as recommended by typical EW manufacturer guidelines to eliminate the stress induced on tile.

Effects of Moisture on Engineered Wood Products

Exposure to moisture can affect the physical performance of engineered wood products. EW products, including plywood, generally have an equilibrium moisture content (MC) which is lower than conventional sawn dimension lumber. EW products are manufactured to a MC of 6 - 8%, while sawn lumber is kiln dried to 15 - 19% MC. The net effect is that engineered wood will gain moisture in most environments, while the moisture content of conventional sawn lumber will likely decrease in service. The primary disadvantage of engineered wood when exposed to moisture, though, is that EW absorbs water more rapidly than conventional lumber, so that the duration of moisture exposure and the resulting rapidity / exaggeration of moisture effects due to longer spans are much more critical than with conventional sawn lumber. The are many new products on the market today which recognize this characteristic and utilize new glue resins and edge sealing techniques which reduce problems that could result from prolonged moisture exposure.

Increased moisture content generally results in decreased strength of EW products. Temporary high moisture typically creates problems with stiffness, but drying to normal equilibrium moisture content usually returns the wood to full strength. However, repeated wetting-drying cycles will eventually produce permanent strength loss and deformation. Raising the moisture content of EW from normal equilibrium (11-12%) to fiber saturation of about 30% from prolonged moisture exposure can decrease stiffness of EW by 25% (fiber saturation being the point at which there are no further dimensional or structural changes in wood).

Similarly, long term elevated moisture content (>15%) can have a significant effect on wood creep. Wood creep is similar to that of concrete, where dead load deflection (weight of floor assembly and other non-load bearing materials) can increase over time. Under normal conditions, creep in wood is predictable to an extent as approximately 50 % of initial deflection. Under elevated MC, deflection due to creep can triple. This means that if concentrated loads are applied while EW remains damp, the result can be significantly greater deflection under loads or permanent deformation of the floor levelness.

As the structural properties of I-Joists are based on dry-use design values, even more precaution must be exercised in continuous high moisture environments such as indoor swimming pools, or environments with large cyclic moisture changes such as bathrooms or exposed EW framing above damp basements. Moisture content of EW I-Joists should be checked and stable before installation of tile finishes.

OSB subfloor panels respond to water vapor much like plywood subfloors. However, exposure to liquid water can result in rapid and large thickness swell in some products which can be greater than 10-15 %, and less than half of that increase in thickness will recover on drying. The large thickness swell is due to rebound from densification which is released upon exposure to water.

Direct adhesion of tile to OSB has traditionally been prohibited by the tile industry. This is due to the above described swelling during or after installation, as well as the recovery upon drying, both of which have been proven to adversely affect tile adhesion. Even when an appropriate underlayment is utilized over OSB prior to installation of tile, there may be risk of increased deflection or other movement from wetting-drying cycles. When used as the web material in an I-Joist, the swelling of OSB from prolonged water exposure can result in decreased stiffness, due to relaxation of the compressed strands of wood.

Summary of Technical Recommendations

I-JOIST DESIGN & CONSTRUCTION GUIDELINES

- EW products must be properly stored (covered, off the ground) in accordance with manufacturers instructions to prevent excessive moisture absorption. Avoid concentrated loading of EW framing after installation if exposed to prolonged periods of rain prior to enclosure of the building envelope.

- I-Joist design and selection must be based on realistic uniform dead loads (weight of materials) for a tile installation (especially if a thick mortar bed installation is proposed), and anticipated concentrated loads whenever possible.

- The maximum deflection of an I-Joist under tiled areas should be no greater than L/480 under live loads, and not the code required minimum of L/360. Additional stiffness is optional to provide a greater safety factor, especially with fragile tile or thin natural stone tile with lower flexural strength; limiting deflection to L/960 will provide maximum stiffness under most all common conditions, while still allowing economical spans common to residential construction with all I-Joist depths. The Marble Institute of America recommends maximum deflection of L/720 under live loads for natural stone tile installations.

- If tile is to be installed in limited areas only (kitchen, bath, foyer), an increase in stiffness for the entire residence may not be necessary or economically feasible. It is more practical to decrease I-joist spacing to 16 or 12 inches on center under those areas if possible. Otherwise, utilize solid blocking between joists to both support subfloor panel edges and stiffen the subfloor panel (plywood or OSB) either as a preventative or corrective measure.

- Follow manufacturer's required construction details for all floor framing conditions to insure specified performance of EW products (examples: solid blocking at mid-span support beams, load bearing web stiffeners, outriggers near perimeter support walls, or use of "wet" design values to provide added safety factor in continuously damp environments).

- Provide bracing for the bottom flange of exposed I-Joists (basements) with lateral wood bracing or metal bridging even if not required by the I-Joist manufacturer (required only for certain I-Joist depths/sizes) to protect from increased torsion and vibration common to I-Joists.

SUBFLOOR (Plywood, OSB or COM-PLY) DESIGN & CONSTRUCTION GUIDELINES

- The traditional and proven wood subfloor thickness for tile installations on joists spaced 16 inches is two layers of 5/8 (19/32)inch thick plywood. The deflection of this assembly over 16 inch joist spacing and code prescribed uniform loads is in the range of L/1000; the deflection under concentrated loads is approximately L/450, assuming average quality plywood (deflection may be reduced with the use of higher quality grades and wood species of plywood). The equivalent stiffness with 19.2 inch I-Joist spacing is achieved with a 3/4 (23/32) inch thick subfloor (plywood or structural equivalent OSB), with a 5/8 (19/32) inch thick plywood underlayment or a 3/4 (23/32) inch underlayment for 24 inch I-Joist spacing.

- Other generic or proprietary underlayments including thicker proprietary plywood products manufactured for tile assemblies, or mortar beds and cement backer boards which may be substituted for the reference 5/8 (19/32) or 3/4 (23/32) inch underlayment, as long as the substitution has been tested by tile industry organizations such as TCA, or can be demonstrated as the structural equivalent of the reference plywood underlayment. The minimum recommended thickness of subfloor panel over I-Joist framing is 3/4 (23/32) inch thick plywood or OSB; however, for 19.2 and 24 inch joist spacing, stiffer generic and proprietary 7/8 inch thick plywood subfloor panel products are available.

- Subfloor panels (plywood and COM-PLY) must be installed with the face grain perpendicular (long dimension across) I-Joists on 16 and 24 inch spacing to insure proper strength. Subfloor panels must be both glued and attached with minimum 6d ring shank nails or screw fasteners. A 1/8 inch space must be provided between subfloor panels at both panel end and edge joints.