Impact of plywood underlayment direction

By Frank Woeste and Peter Nielsen

Beginning in 2007, the *TCA Handbook for Ceramic Tile Installation* listed in bold print the following requirement for two-layer wood sheathing installation methods:

- **face grain of plywood shall run perpendicular to joists for maximum stiffness.**

Should the tile contractor or other interested parties be concerned whether or not the plywood underlayment runs perpendicular to the joists? Just how important is it anyway? Many times we're given directives (for example, when following a method in the Tile Council of North America's *TCA Handbook For Ceramic Tile Installation*), but if we're not given the "why," it's difficult to know how much importance to assign the directive. You may be thinking "A directive is a directive," so what's to discuss?

But what if the tile contractor shows up at the jobsite and the plywood underlayment has already been installed by another trade—parallel to the joists. Calling "time out" and having the underlayment removed and re-installed is no small endeavor. It can throw the job off schedule *and* it can be costly. In this scenario, the tile contractor needs to know how much importance to assign the directive: *run the plywood underlayment perpendicular to the joists*.

The purpose of this article is to discuss the aforementioned questions and to emphasize the importance of the directive to *run the plywood underlayment perpendicular to the joists*, so that good decisions can be made in the planning process and in the field. We will also clarify the meaning of "stiffness" in the context of a ceramic tile installation. The questions will be addressed in the context of one two-layer system—F149-07 (joists 24-inches on center., 23/32-inch tongue-and-groove subfloor, 19/32-inch underlayment).

Subfloor direction

In general, framing contractors know that the "strength axis" or 8-foot dimension of the subfloor panels must run perpendicular to the joists. Even though the *TCA Handbook* does not specifically state that the strength axis of the subfloor panels shall run perpendicular to the joists, it remains a residential building code requirement (IRC, 2006). The *2007 TCA Handbook* (and later) requires floor framing systems to be code-compliant as stated under the *Requirements* for each wood floor sheathing method. Tile contractors should be aware of the possibility that some subfloor panels may be installed incorrectly, with the strength axis running parallel to the joists. The impact of improper subfloor installation on ceramic tile performance could be severe, as the "stiffness" of an incorrectly installed 23/32-inch subfloor may be only one-fourth to one-fifth of a correctly installed code-conforming panel. (Panel stiffness data are discussed in more detail in the next section.)

Plywood underlayment direction

Knowing that the subfloor must be installed with the strength axis perpendicular to the joists for code compliance is important. But the tile contractor must also understand the importance of running the plywood underlayment perpendicular to the joists if he or she is to maximize potential for a successful installation. In fact, engineering science for the two-underlayment orientations reveals that both the subfloor and underlayment should run perpendicular to the joists (without exception).

Stiffness defined

"Stiffness" is a general technical term that quantifies the extent of a specific type of deformation due to a specific applied load. In the context of plywood/oriented strand board (OSB) installation, the type of stiffness of interest is "panel bending stiffness," referred to as EI. EI of a wood panel is a measure of how much it will rotate from applied gravity loads such as dead and live loads. It is also used to calculate deflection of a panel between joists.

The first five rows of a two-page table, Table 4A, from the *2008 APA Panel Design Specification* (www.apawood.org), which contain EI design data for rated panels, are shown below:

RATED PANELS DESIGN CAPACITIES

Span Rating	Stress Parallel to Strength Axis				Stress Perpendicular to Strength Axis			
	Plywood				Plywood			
	3-ply	4-ply	5-ply	OSB	3-ply	4-ply	5-ply	OSB
PANEL BENDING STIFFNESS, EI (lb-in.²/ft of panel width)								
24/0	66,000	66,000	66,000	60,000	3,600	7,900	11,000	11,000
24/16	86,000	86,000	86,000	78,000	5,200	11,500	16,000	16,000
32/16	125,000	125,000	125,000	115,000	8,100	18,000	25,000	25,000
40/20	250,000	250,000	250,000	225,000	~~18,000~~	39,500	56,000	56,000
48/24	440,000	440,000	440,000	~~400,000~~	29,500	65,000	91,500	91,500

Review of additional tables in the 2008 PDS revealed that the most common span-rated panels for F149-07 having a specified 23/32-inch subfloor and 19/32-inch underlayment would correspond to a 48/24-inch subfloor and 40/20-inch underlayment, respectively. Assuming the underlayment is four-ply and the subfloor is five-ply, the EI data can be used to examine the effect on wood sheathing stiffness from installing the 40/20-inch underlayment either perpendicular or parallel to the joists.

Underlayment perpendicular or parallel to joists

Referring to the table, underlayment perpendicular to joists corresponds to the left side of the table labeled *Stress Parallel to Strength Axis*. Note that all the EI data on the left side of the table is much larger than the EI data on the right side. For the case of underlayment parallel to the joists, the EI data on the right side applies. If we neglect composite action between the two layers of F149-07, the combined EI from the left side of the table is 440,000 plus 250,000 psi, or 690,000 psi (away from panel end joints[1]). On the other hand, if the underlayment is rotated 90 degrees, the combined EI is 479,500 psi (440,000 plus 39,500). Based on the assumptions, the first case has a **44** percent (690,000/479,500=1.44) greater bending stiffness than the second case.

Practical value of increased bending stiffness

The physical impact of increased bending stiffness of the wood sheathing on a tile assembly requires a mechanical explanation. As demonstrated below, increased stiffness between the joists and -- more importantly over the joists -- is valuable since it will reduce curvature of the sheathing under in-service gravity loads.

The relationship between bending stiffness of wood sheathing and the amount of curvature in the sheathing produced by gravity loads is demonstrated in Figure 1, which depicts two cases. The sheathing is loaded by a fixed amount of dead plus live load, causing the sheathing to bend over the indicated joist. In one case, the sheathing is represented by an arc of a circle that has a radius of r. In the second case, the sheathing is represented by an arc of a circle that has a radius of 1.44r (a larger circle).

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[1] To mitigate the negative effects of panel end joints, the reader is referred to: www.tile-assn.com/tileletter/pdfs/Underlayment-Nielsen-Woeste-0604.pdf

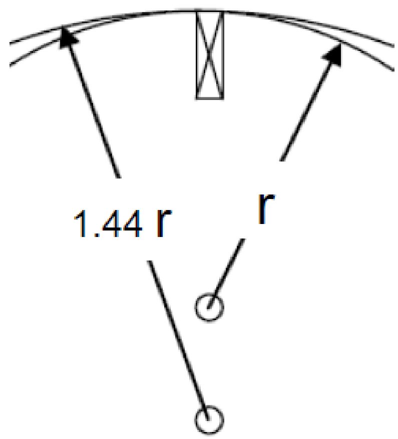

Figure 1. The two arcs of circles are shown representing the bend of floor sheathing from gravity loads. The gravity loading is assumed to be equal for both cases; however, the stiffness varies by 44 percent. The curvature is exaggerated for illustration purposes.

For a fixed amount of a bending-type load at the centerline of the joist represented by M, a simple linear relationship between radius of curvature, r, and EI of the floor sheathing is given by r = EI/M.
In Figure 1, the arc with a smaller radius of r corresponds to the case where the underlayment strength axis is *parallel* to the joists (EI=479,500 psi). The arc with a larger radius of 1.44 r corresponds to the case where the underlayment strength axis is *perpendicular* to the joists (EI=690,000 psi). Given that a brittle material will be bonded to the underlayment in each case, the case having the larger radius of curvature (1.44r) is clearly more favorable to a ceramic tile installation.
It is interesting to note that the deflection of the subfloor and underlayment panels in Figure 1, *relative* to the top of the joist, is zero (no deflection) even though the panels are clearly bent over the joists as represented by two radii, r and 1.44r. This example shows that "curvature" as represented by r in the equation above and drawn for the two cases in Figure 1 is not the same as "deflection."

Summary
We have reviewed the bending stiffness data for common span-rated wood sheathing panels and demonstrated how bending stiffness of two-layer wood sheathing systems can be maximized by installing both the subfloor "strength axis" and underlayment "strength axis" perpendicular to the joists.
Achieving maximum bending stiffness from both wood sheathing layers will "maximize the radius of curvature" or "minimize the bending action" of the wood sheathing/ tile assembly from gravity loads for the service life of the installation. We believe that, if a tile contractor understands the important role of the underlayment positioning as presented in this article, he'll have the confidence to call "time out" should the situation arise.

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