Q Can deflection of a low-slope roof cause ponding? How can this be avoided?

A *Frank Woeste, P.E., professor emeritus at Virginia Tech, responds:* Historically, structural designers and builders have assumed that a design slope of 1/4 inch per foot (1:48) is sufficient to prevent ponding action, thinking that the installed roofing system will maintain at least a 1:48 slope in-service as required by some roof covering systems. However, in many cases and for different reasons, ponding on limited areas of low-slope roofs is common. That's due to roof deflection, which over time can cause water to collect in some areas of a roof where the design slope for drainage is not adequate, and in fact changes from a "positive" drainage slope to a "negative" slope **(1)**.

A study case. To demonstrate how a 2018 IRC/IBC-compliant design can result in roof ponding, I modeled a 20-foot roof span with a design slope of 1/4 inch per foot framed with 2x10s (No. 2 grade, KD19, modulus of elasticity of 1.5 million psi) at 16 inches on-center. Loading was 20 psf live load and 20 psf dead load, with a ceiling attached to the joists, and live-load deflection of less than L/240 (L is the span).

As shown on the vertical axis of the graph on the following page, the 1/4-inch-per-foot design slope results in the left bearing being 5 inches above the right bearing. The span of 240 inches is depicted along the horizontal axis of the graph. The straight black line represents the slope (1:48) of the 2x10s prior to any type of loading. This slope matches the "design slope," which is normally communicated to the joist or truss designer by the construction drawings or a specification.

Depicted by the orange curve, the Design Total Deflection was calculated based on 20-psf live load plus 20-psf dead load, for total load of 40 psf. The range of the vertical axis is minus 1 inch to plus 5 inches. If any part of the joist deflection curve goes below zero (or minus in the graph), pooling or ponding is the natural outcome during a rain event.

For the study case and 40-psf total load, the slope of the framing provides "positive drainage" along the entire span. However, when the roof experiences design loads, the actual roof slope is greater than a 1/4 inch per foot on the left bearing and less than 1/4 inch per foot on the right bearing location. This graphic demonstration shows that the "design slope" communicated on drawings or specifications is different from the "actual slope" of a constructed roof assembly that experiences in-service loads.

The Design Total Deflection plus Creep Deflection is depicted by the red curve to represent the potential total deflection in-service. The deflection values were calculated by adding the estimated in-service creep deflection to the Design Total Deflection values. Note that for the span between about 160 and 240 inches, the red deflection curve collects water, having a negative slope from the right bearing for about 4 feet.

The term "creep" requires some explanation. A good example of creep is the familiar sag of a heavily loaded book shelf after several years in-service. By definition, creep deflection is the additional deflection of a structural element over time. The amount of creep deflection in wood is largely dependent on the initial moisture content of the lumber and stress level due to sustained loads, typically dead loads. The extent of yearly moisture content cycles, driven by seasonal weather changes (heating verses cooling conditions), also contributes to creep deflection.

For design purposes, a "creep factor" is defined as the deflection of a member in-service divided by the initial deflection due to the applied dead load. For solid-sawn lumber, a creep factor of 1.5 is recommended by the National Design Specification (NDS) for Wood Construction for dry lumber (KD19 or SDRY)—meaning moisture content (MC) of less than 19% at time of manufacture. For lumber

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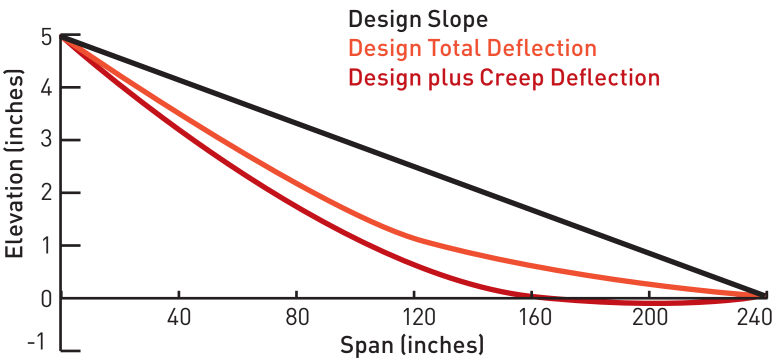
As shown on this exterior deck over habitable space, inadequate drainage caused by the deflection of a low-slope roof can lead to ponding.

Photos by Scott D. Coffman/courtesy Construction Science and Engineering with an MC greater than 19%, a creep factor of 2.0 is recommended.

Limited long-term testing of engineered components revealed a creep factor above 2.0. Given the uncertainty of the initial and in-service MC cycles of the lumber as well as actual stress levels in-service, I believe a factor of 2.0 is a reasonable creep factor to use for assessing the ponding potential of low-slope roof framing. The Design plus Creep Deflection curve (red) was based on a creep factor of 2.0, meaning the initial dead load deflection was doubled.

Steps to address ponding potential. A first thought of a builder or contractor might be to ask the component supplier or design professional to address the low-slope ponding issue. This may not be the best option, however, as the supplier or designer may default to building-code deflection ratios in the IRC or IBC, which do not include consideration of potential in-service ponding behavior. For example, Table 1604.3 in the 2018 IBC lists deflection limits for roof members, such as L/120, L/180, L/240, and L/360, for different combinations of live load, snow or wind, and dead plus live load. As in many cases, the footnotes to the table are extremely important (but often neglected); footnote "e" for roof members reads:

"The preceding deflections do not ensure against ponding. Roofs that do not have sufficient slope or camber to ensure adequate drainage shall be investigated for ponding. See Chapter 8 of ASCE 7."



Modeling predicts that design loads plus creep deflection will cause 2x10 joists with a 1/4-inch slope per foot over 20 feet to have a negative slope within the last 4 feet of the lower bearing point (graph, above).

Roof deflection caused by the weight of mechanical equipment that wasn't accounted for in the original design can lead to ponding.

A more reliable approach for builders, contractors, and design professionals to address the potential for roof ponding is to specify a 3/8-inch- or 1/2-inch-per-foot roof slope in lieu of the commonly used 1/4-inch-per-foot specification. For the study case discussed previously, a 3/8-inch-per-foot roof slope provided a positive drainage slope for the entire span.

In addition to the design slope specification, it is critically important for builders, contractors, and design professionals to include the position and footprint of the HVAC equipment on the roof in the construction plans, including the weight of each unit **(2)**. Being that some component suppliers may not use an ample "creep factor" in their deflection analysis, an alternative might be for the specifier to artificially increase the weight of the HVAC units by a selected creep factor, at least 1.5 or 2.0, and to specify the larger HVAC weight on the plans. This approach would reduce the in-service stress level for the impacted framing, thus automatically reducing the amount of expected creep deflection in-service. A point to remember is that it's the "sustained load," or dead load, that drives creep deflection.

Another concern is the actual MC of joists or wood truss lumber at the time of construction. Roof framing lumber, as well as FRT lumber when used, should be well dried to guard against increased creep deflection during the drying period before reaching the equilibrium MC. Well-dried KD19 lumber should have an average MC of about 15% with a maximum of 19%. The industry standard for "dry lumber" is less than 19%; it does not specify an average MC that is relevant to the concern for creep deflection.

A good resource for design professionals interested in addressing creep deflection by in-depth structural design methods is "Low-slope Roofs," a comprehensive article by Scott Coffman and Thomas Williamson in the March 2019 issue of *Civil+Structural Engineer* (csengineermag.com/low-slope-roofs/).