Performance Risks of a Double-Tapered Plate Dowel

The single-taper of a PNA PD^3 plate dowel® has been engineered to maximize load transfer performance while accommodating realistic construction tolerances. Double-tapered plate dowel systems for sawcut contraction joints cannot accomplish such optimization for the reasons discussed herein.

Of concern is the significant loss of capacity of a double-taper plate dowel when factoring for construction tolerances and how a crack propagates through a concrete slab's thickness. This article focuses specifically on the impact that misalignment of a single- or double-tapered plate dowel basket and/or the sawcut joint over the basket plus variation in crack angle can have on the capacity and performance of the joint.

Background on PNA's PD^3 Plate Dowel®

As evidence of its value, it is worth noting that the PD^3 plate dowel® system was used with great success in more than one billion square feet of concrete floor slabs in more than 15 countries worldwide within its first ten years of use (Parkes, 2007). Its specification and use has only expanded with time, most recently with guidance in ACI 330.2R-17, *Guide for the Design and Construction of Concrete Site Paving for Industrial and Trucking Facilities*, which supports its use on exterior pavement.

Owners and engineers originally specified the PD^3 Basket® into slab-on-ground applications to facilitate construction by laser screeds because of the recognition of the ability of the PD^3 plate dowel® to allow for horizontal misalignment (e.g., rotation) of the dowels, and thus the basket holding the dowels in place, without causing additional restraint stress in the concrete. This allowance for misalignment in construction ultimately reduced the risk of slab cracking (ACI, 2010); this and other benefits of the PD^3 Basket® system are discussed in more detail in PNA's memo titled *The Value of PD^3 Plate Dowels®*.

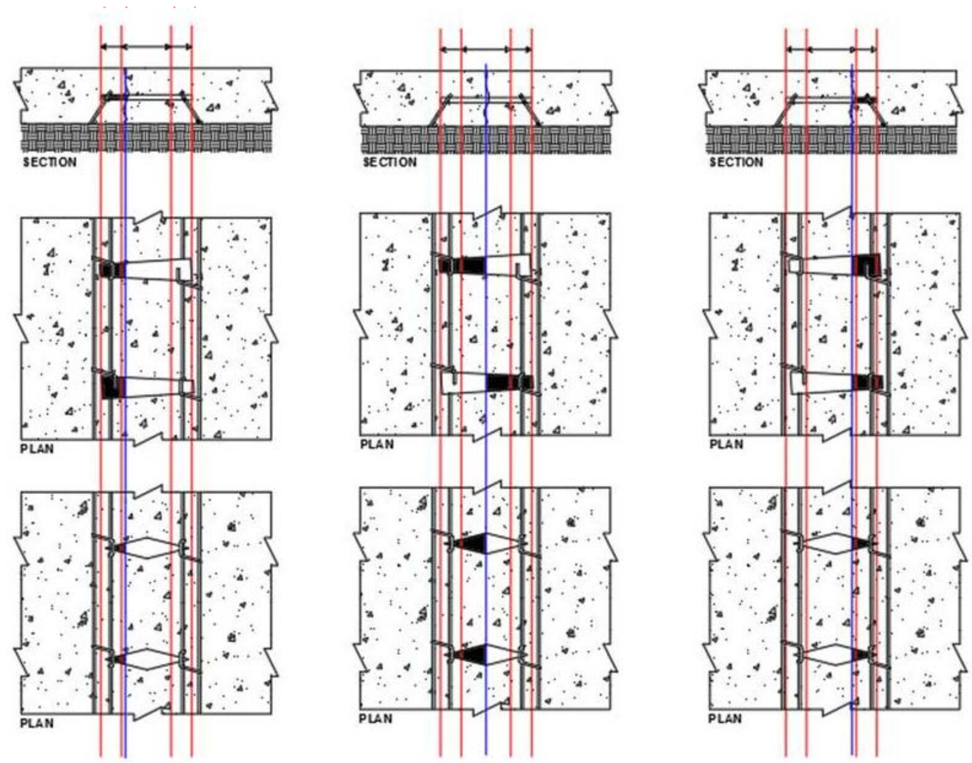
How a Dowel's Taper Impacts Cross Sectional and Bearing Area

A joint's differential deflection under loading increases with a smaller dowel cross-sectional area across a joint; this is why larger dowels are necessary for heavier loads. If the bearing surface area becomes too small, there then also exists the risk of concrete bearing stresses being greater than the strength of the concrete, causing failure of the concrete around the dowel and resulting in measurable dowel looseness and increased differential deflection. Thus, joint deflections increase with either a smaller cross-sectional area across the joint or with a smaller plan area (e.g., when looking down from the surface) of dowel.

Typical construction tolerances for dowel bars in concrete flatwork range from ± 2 in. (50 mm) to ± 4 in. (100 mm). At offsets of the joint face from the dowel center in this range, the double-tapered plate dowel always has significnatly less area through which to transfer load in shear from slab-to-slab, resulting in larger joint deflections. To visualize this, consider Figure 1, which shows an ideal (cenetered) sawcut location and crack propagation in 1b and offsets to the left and right of center in 1a and 1c, respectively – the black colored areas illustrate minimum embedment area for each dowel, which indicates the side of the dowel used for design purposes.

PNA PD3 Single-Tapered Dowel

Double-Tapered Dowel



(a) (b) (c)

Figure 1. Illustration of the impact of joint face offset because of construction tolerances with sawcut location and crack progation through half the slab thickness to the left of center (a), on-center (b), and right of center (c) relative to the mid-point of the dowel's length.

Consider a ½ in. (12.5 mm) thick PNA PD3 single-tapered plate that is 2.5 in. (64 mm) wide at its midpoint and with a 4° taper on each side versus a ½ in. (12.5 mm) thick double-tapered plate that is 3 in. (75 mm) wide at its midpoint and with a 14° taper on each side, as depicted in Figure 1. As shown in Figure 2, the 3 in. (75 mm) wide double-tapered plate has a larger area at its center than the PD3 single-taper because it is the same thickness but wider at its mid-point. At an offset of 1.35 in. (34 mm) towards the PD3's narrow side a point of equalibrium is reached, where the two dowels have equal width and thus equal area; past this point the double-tapered plate quickly loses area realtive to the PD3. Moving towards the wide side of the PD3, the breakeven point is even closer to the middle of the dowels, at an offset of just 0.75 in. (19 mm), past which the PD3 area increases while the double-tapered plate quickly decreases. In fact, in the typically specificed construction tolerance window of ± 2 to 4 in. (50 to 100 mm), the double-tapered plate has anywhere from 10% to 67% less cross sectional area through which to transfer load from slab-to-slab than does the single-tapered dowel.

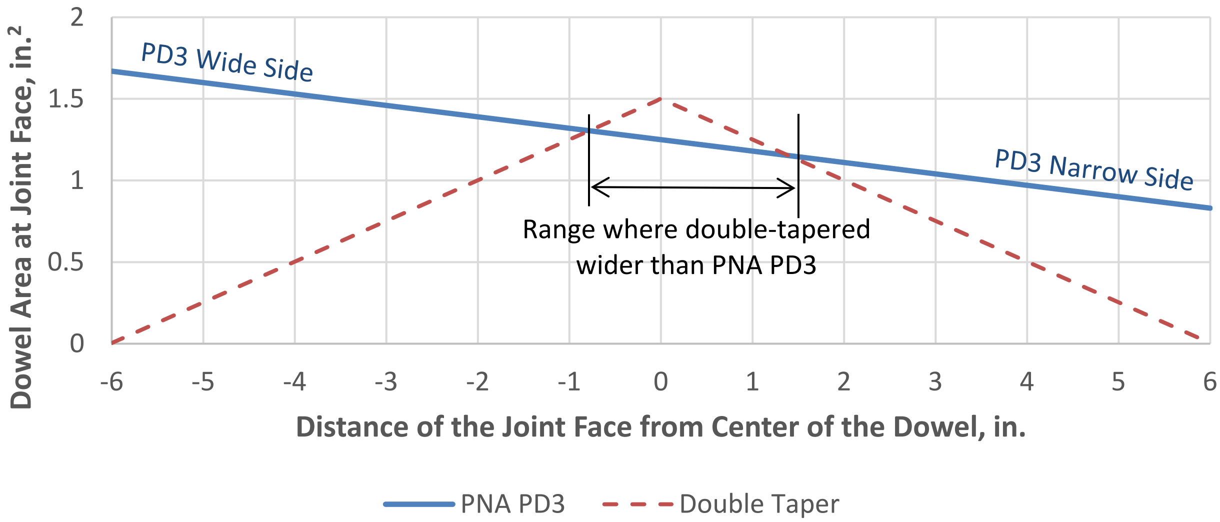


Figure 2. Cross-sectional area of a single dowel at the joint face at varying offsets of the joint face from the dowel's centerline.

The bearing area has an even more drastic comparison, as shown in Figure 3. The double-tapered plate never has more bearing area (e.g., surface area on the top of the dowel) than the PD3. In the ± 2 to 4 in. (50 to 100 mm) tolerance range, the double-tapered plate has anywhere from 48% to 84% less bearing surface area than the single-tapered dowel in the. This lesser bearing area of steel, and thus lesser volume of steel supplied in a double-tapered plate dowel, is precisely why a lower price might be offered by its manufacturer for the same o/c spacing as a PD3 but, as shown in the following section, the double-tapered plate dowel offers inferior performance at typical construction tolerances and thus is not a 1:1 comparable product to the PNA PD3 plate dowel®.

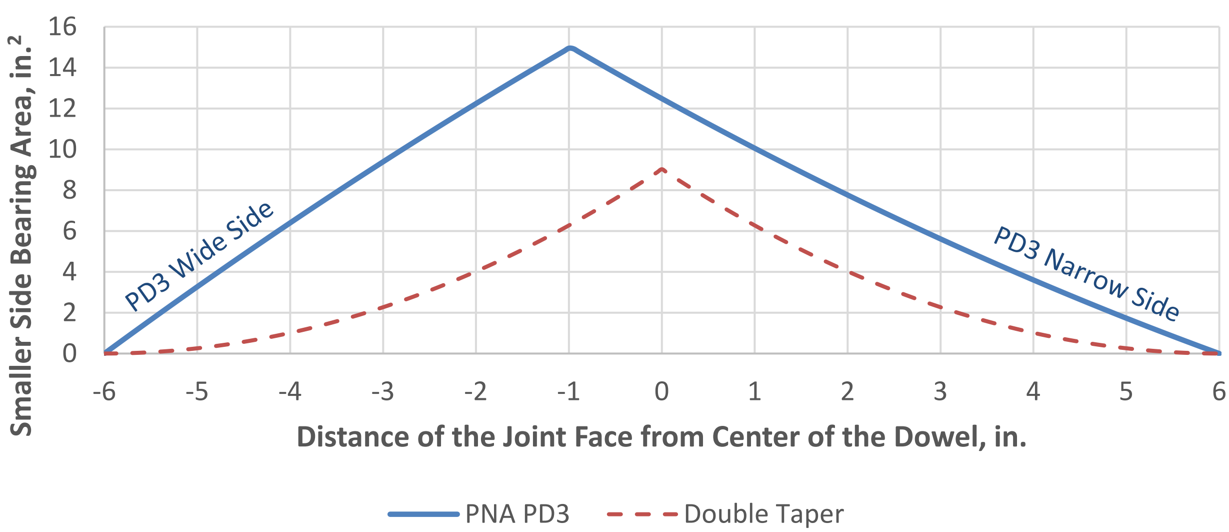


Figure 3. Bearing area of a single dowel at varying offsets of the joint face from the dowel's centerline.

Lower Cross Sectional and Bearing Area = Higher Stress and Deflection

To visually illustrate the differences in a proven engineering format, a finite element analysis (FEA) model was developed with the PD3 single-tapered plate dowel in both orientations and a double-tapered plate dowel. Figure 4 shows stress and deflection plots for a condition where the joint crack face is 2 in. (50 mm) offset at the depth of the dowels. Each dowel is of the dimensions provided earlier in this document, modeled in A36 steel, and has the same load applied to it. As shown, both the maximum stress and dowel deflection are nearly 2 times higher in the double tapered plate dowel.

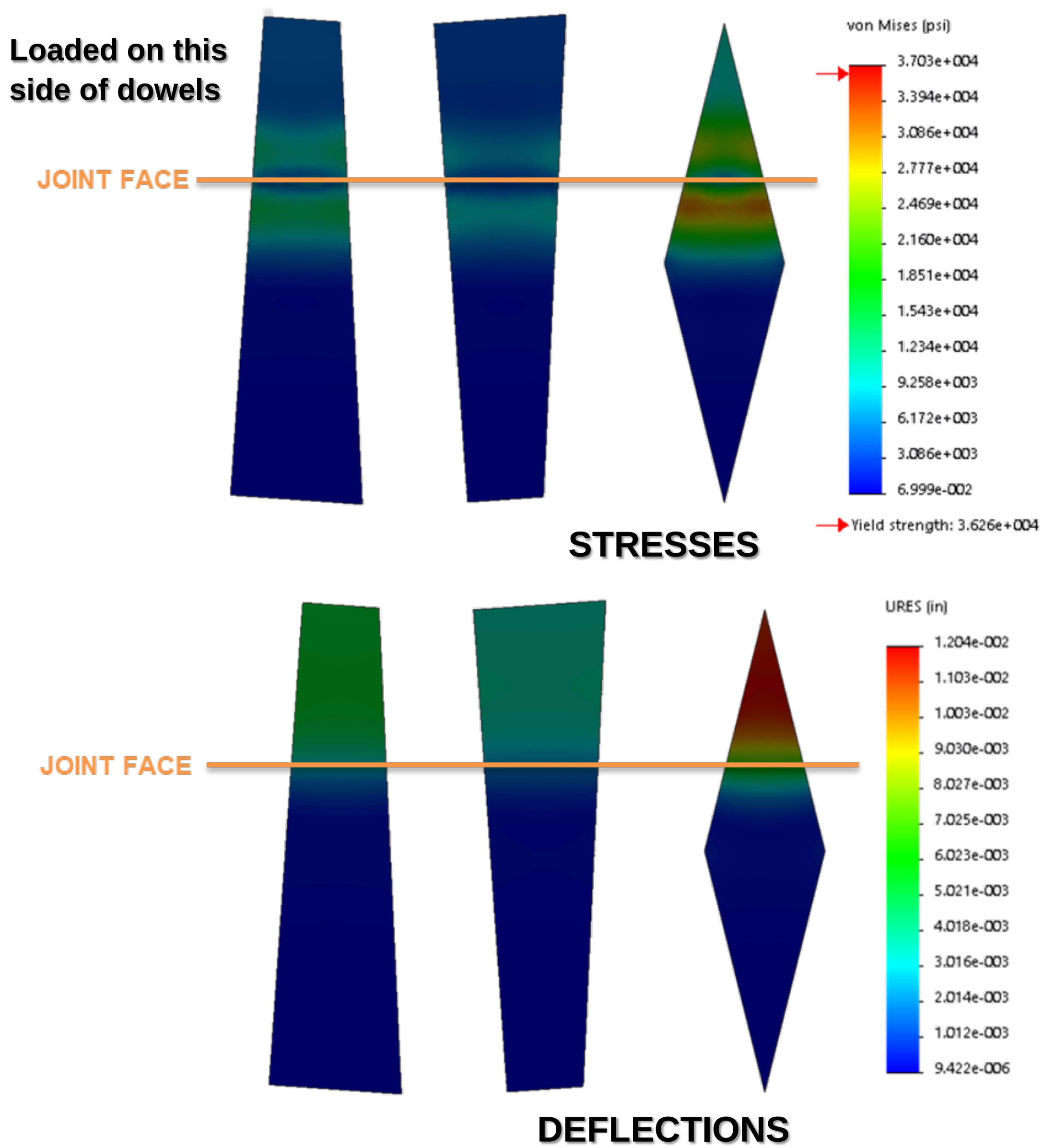


Figure 4. Finite element analysis result shows stresses (top) and deflections (bottom) on PD3 single-tapered plate dowels in either orientation (left and center) and a double-tapered dowel (right) under the same load at a 2 in. (50 mm) sawcut offset.

Dowel Capacity Comparison

A modern dowel design framework was utilized to predict joint differential deflection, dowel flexural stress, dowel shear stress, concrete bearing stress, and concrete shear cone capacity failure modes from zero offset to the typical maximum construction tolerance of ± 4 in. (100 mm) to facilitate a direct comparison of the load-carrying capacity of the single- and double-tapered plate dowels described above. The analysis included consideration for joint opening, the supporting k-value, dowel spacing and grouping action, etc. – the only variables changed in this comparison were the 2.5 in. (64 mm) width and the 4° taper on each side for the single-tapered plate dowel versus the 3 in. (75 mm) width and 14° taper on each side for the double-tapered plate dowel. Figure 6 shows results with the system's capacity shown as a percent realtive to the single-tapered plate with 0 in. (0 mm) of offset from the dowel's center.

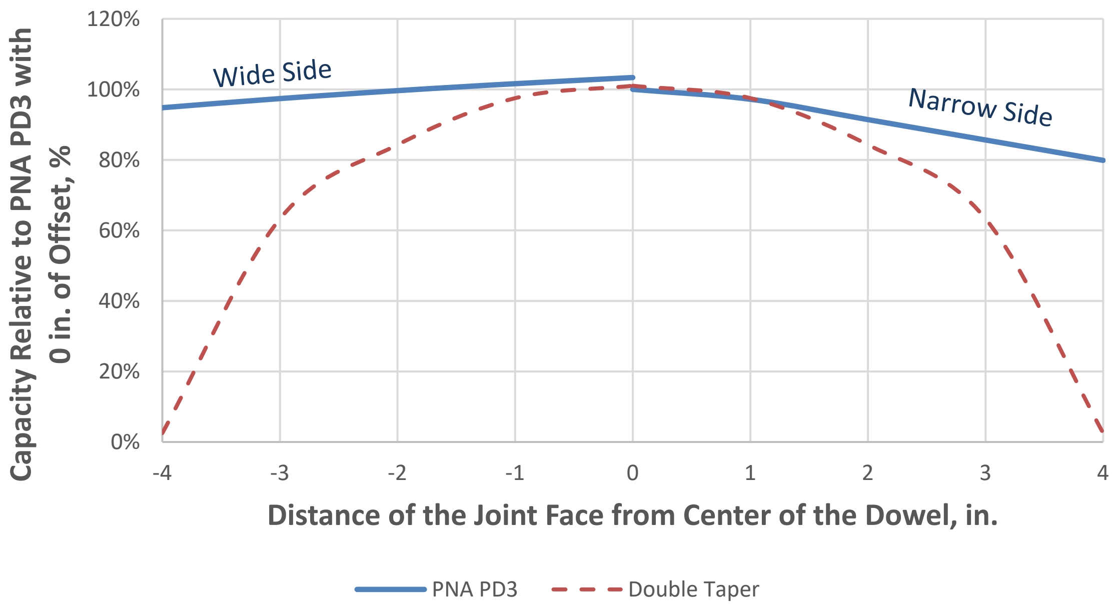


Figure 6. Relative dowel basket capacity at varying offsets of the joint face from the dowel's centerline.

As shown above, the 100% case for the PNA PD3 single-tapered plate dowel is on the narrowing side of the dowel; the widening side of the single-tapered plate has a slightly higher capacity at a 0 in. (0 mm) offset because of its increasing width. For the single-tapered plate basket, if the joint face offset is 4 in. (100 mm) towards the narrowing side, the capacity of the system is 80% of the ideal case and if the joint face offset is 4 in. (100 mm) towards the widening side, the capacity of the system is 95% of the ideal case.

While the double-tapered plate basket might have a comparable capacity in the ideal case of 0 in. (0 mm) offset, construction is never ideal. Even if baskets are staked, there's still variability in sawcut location and execution and, completely out of the contractor's control, the angle of the crack from the bottom of the sawcut to the depth of the dowel. Thus, a realistic construction tolerance is in the ± 2 to ± 4 in. (50 to 100 mm) range; in this range, a double-tapered plate dowel of the size suggested has significantly lowered capacity than the PD3 single-tapered plate dowel of the size suggested.

The Basket Configuration Increases the Single-Tapered Plate's Factor of Safety

The above considered an ideal case where the joint's sawcut was made perfectly straight along the basket's length, either at the dowel's mid-length or at some offset. The following four tolerances complicate alignment in the field:

a) Measuring the planned joint location and marking lines on the grade or vapor barrier to indicate where the dowel basket *should* be placed.

b) Installing baskets *as accurately as possible* to the marked lines, often simultaneously with concrete placement via truck dumping to avoid the need for pumping.

c) Transferring the *intended* joint location from the grade or formwork onto the slab surface to indicate where sawcuts *should be* located.

d) Sawcutting joints *as aligned as possible* along the intended location.

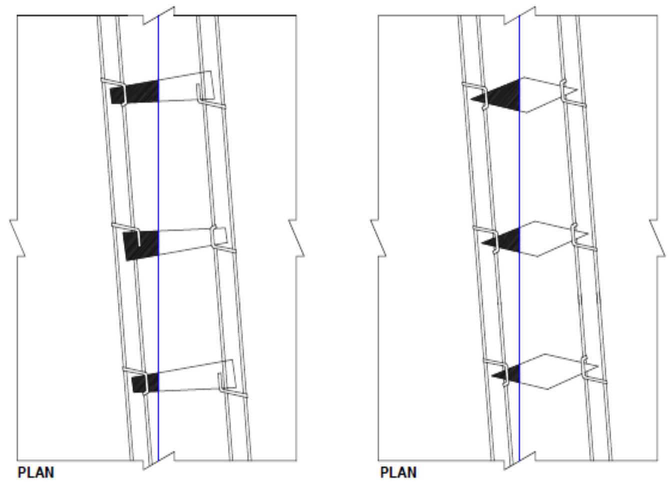


Figure 5. Illustration of dowel baskets skewed with respect to the sawcut and the value of single-tapered plate dowels in increasing their design factor of safety relative to double-tapered plate dowels because of their alternating orientation in the basket.

With any of these steps, the possible compounding errors along the dowel's length and of the parallelness of the final sawcut joint with respect to the length of dowel basket increases (Figure 5).

The previous sections illustrated the impact of sawcut offset on cross section and bearing area. A PD3® basket includes single-tapered plate dowels in alternating directions so that adjacent dowels will compensate for what one might lose in cross sectional and bearing area; that is to say, while a single dowel might be loaded on the narrowing side of the single-taper plate, the next dowel in the basket is being loaded on its widening side. Double-tapered plate dowels in a basket will always be loaded on an increasingly narrowing tip. Thus, the composite dowel group action achieved by a PD3® single-tapered plate dowel in a basket is greater than that of a double-tapered plate dowel, further enhancing the PNA PD3® basket safety factor relative to a double-tapered basket.

Comparable Design Requires Project-Specific Engineering

While pavement and slab engineers routinely relied on dowel design tables in documents such as those from ACI 330 and 360 in the past, such tables cannot provide project-specific optimization because they are intentionally conservative in an attempt to minimize the risk of performance problems in the field; in some cases, however, a typical design, as recommended in such documents, is insufficient for the loads that the dowel will receive, exposing the owner to unforeseen risk and costs. As such, the only manner through which comparable designs can be developed for optimization of a single-tapered plate dowel design is through project-specific engineering. PNA provides such dowel design optimization at no cost to owners, engineers, contractors, or anyone else involved in the process of ensuring the serviceability of concrete slabs and pavements.

For More Information

If you would like to request a complimentary project-specific dowel design for your next project or for more information on this or any other topic related to concrete flatwork:

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