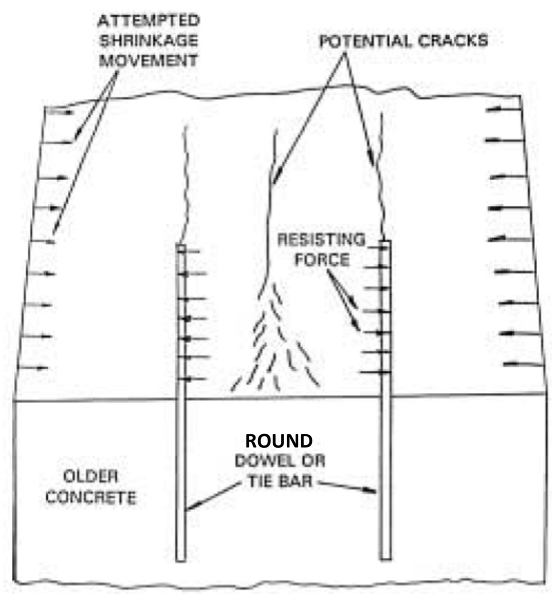
Square Dowel Design Requirements

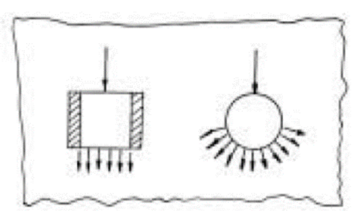
The value of square dowels to control differential deflections and transfer load across construction joints while minimizing stresses has been recognized for over 20 years (Concrete Construction 1999, Concrete Construction 2000). As noted by Ward Malisch of the American Society of Concrete Contractors (ASCC), "traditional round dowels may cause slab cracking by restraining movement along doweled longitudinal joints when workers place large floor slabs in long, alternating strips, with infill strips placed later" (Concrete Construction 2000).

As illustrated in ACI 2001 for <u>round dowels</u> in the figure to the right:

1) the first concrete placement (bottom half, labeled as older concrete) includes round dowels or tie bars; the concrete then shrinks such that these two dowels move closer to each other.
2) the second placement (top half) is placed later, with the dowels anchored into the older concrete protruding into the fresh placement.
3) the concrete in the second placement wants to shrink and move the two dowels closer together while the first placement will resist this or possibly even want to expand and move the two dowels apart.
4) this difference in movement across the construction joint can cause cracks as shown because the dowels resist the movement.



PNA's square dowel solution allows for joint activation and free horizontal movement of the concrete without restraint via a compressible foam adjacent to the sides of the dowel that is reliably secured in place by a Square Dowel Clip™. The image to the right, also from ACI 2001, illustrates the gap formed on the vertical faces of the installed square dowel as well as the change in the load response in a square dowel versus a round dowel. This and several other benefits of square dowels over rounds dowels for construction joints are noted in ACI 2001:



> "Although they have the same shear strength as round bars of equal weight, square bars provide more resistance to bending, so they provide more resistance to edge and corner curling for the same amount of steel.
>
> When square bars are substituted for round bars, the bars can be spaced further apart for the same steel weight and fewer dowels need to be installed. This is because a square bar has more cross-sectional area than a round bar of the same nominal size, Alternatively, load transfer

strength based on bar capacity will be greater if a direct substitution of square bars is made for round bars of the same nominal size without decreasing the number of bars.

Another advantage of square bars is related to the direction of forces radiating off the bar. The effect of load transfer in round bars induces tensile splitting stresses within the slab or pavement. This splitting stress is eliminated with square bars. Both bar shapes induce similar downward shear stresses in the concrete."

Design Recommendations

Dowel size recommendations are equivalent for round and square dowels; for example, if a 1" round dowel bar was to specified for a project then a 1" square dowel is recommended. The table below, based on ACI 2010 and ACI 2017 provides recommendations for square dowel size, length, and Square Dowel Clip™ length. Details on the necessary embedment multiplier and embedment length for a given dowel size are included in the Required Dowel Length section of this whitepaper. The Square Dowel Clip™ Length is sized such that any dowel that is installed within the specified tolerance will always have a clip length greater than the exposed half of an installed dowel.

Typical Slab Thickness Range, in.	Square Dowel Size, in.	Dowel Length, in.	Square Dowel Clip™ Length, in.	Embedment Multiplier	Embedment, in.
≤ 6	½	9	5.0	8.0	4.0
5 to 6	¾	10	5.5	6.0	4.5
6 to 8	1	13	7.0	6.0	6.0
≥ 8	1-¼	15	8.0	5.6	7.0

Embedment = Dowel Size x Embedment Multiplier
Dowel Length = 2 x Embedment + 1" Construction Tolerance
Square Dowel Clip™ Length = Embedment + 1" Construction Tolerance

When comparing a square dowel and round dowel with equal width (e.g., square dowel width = round dowel diameter), the square dowel has 27% more cross sectional area of steel and a 70% higher resistance to bending (e.g., moment of inertia). The recommended square dowel spacing in the table to the right for a given round dowel design spacing is based on confirmation of same or better performance of the square dowel alternate by designing for joint differential deflection, dowel flexural stress, dowel shear stress, concrete bearing stress, and concrete shear cone capacity using PNA's industry-leading comprehensive dowel design framework. Effectively, square dowels can be spaced 2 in. further apart than round dowels for 12-15 in. spacing and 3 in. further apart for 16-18 in. spacing.

Round Dowel Spacing, in.	Equivalent Square Dowel Spacing, in.
12	14
13	15
14	16
15	17
16	19
17	20
18	21

Required Dowel Length

Historically, dowel bar length for dowels used in construction joints and dowel bar retrofits (DBR) was the same as that for sawcut contraction joints to simplify supply of dowels; this is the case for ACI 2006, where slab-on-ground design made no distinction between dowel length for contraction vs. construction joints. Efforts in the 2010s to optimize design to reduce steel material use and costs, and for sustainability, resulted in modern guidance wherein dowels in construction joints are shorter because of the greatly reduced tolerances versus a sawcut contraction joint. When a dowel is installed in a sawcut contraction joint, the contractor aims to saw the joint over its mid-length, but dowels are 3+ in. longer than mechanically necessary to account for variance in crack location at the depth of the dowel versus what is drawn on a plan detail. When a dowel is installed in a construction joint or as a DBR, the vertical face of the resultant joint is well-known.

Appendix A from CP Tech 2011 provides more insight on evolution of dowel length consideration. As detailed, the required embedment multiplier (e.g., depth of embedment of the dowel on one side of the joint as a multiple of dowel diameter) need be about 5 to 8, depending on the dowel size, to achieve the intended mechanical load transfer and long-term stability of the joint. While this requirement was considered in the original standardization of round dowel lengths to 18 in. for sawcut contraction joints for highway use, it only recently has been considered more directly for construction joints.

In practice, efforts such as CP Tech 2011 resulted in modern guidance as:

- ACI 2010 for slab-on-ground design wherein round and square dowels need be 10, 13, and 15 in. in length for ¾, 1, and 1-¼ in. round or square dowels, respectively.
- ACPA 2011 wherein dowels for DBR for road and highway pavements need only be 15 in. in length to reduce their length by 3 in. from the typically specified 18 in. length.
- ACI 2017 for industrial and trucking facility pavement design wherein ¾, 1, and 1-¼ in. round or square dowels have the same length recommendations as ACI 2010.

PNA's guidance on square dowel length is in-alignment with ACI 2010 and 2017, with the addition of a ½ in. square dowel that is 9 in. in length and with the table in the Design Recommendations section of this whitepaper elaborating on the specific details of these recommendations.

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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ACI 2017, “Guide for the Design and Construction of Concrete Site Paving for Industrial and Trucking Facilities,” American Concrete Institute, 330.2R-17.

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Concrete Construction 1999, “Square Dowels Control Slab Curling,” Ernest K. Schrader.

Concrete Construction 2000, “Move Over Round Dowels,” Ward Malisch.

CP Tech 2011, “Guide to Dowel Load Transfer for Jointed Concrete Roadway Pavements,” Dr. Mark Snyder, Concrete Pavement Technology Center.

Appendix A. Excerpt from Concrete Pavement Technology Center 2011, "Guide to Dowel Load Transfer for Jointed Concrete Roadway Pavements"

Today's dowel bar length practices have evolved from practices in the late 1920s that typically featured the use of 3/4 in. dowels measuring 3 ft in length and spaced 18 to 36 in. apart. By the late 1930s, 24 in. dowel lengths were more common, and the benefits of using larger diameters and closer spacings were beginning to be recognized.

The analytical roots of pavement dowel design are found in the work of Timoshenko and Lessels (1925), who developed the original analysis of dowel bars embedded in concrete by considering the dowel as having semi-infinite length. In 1938, Friberg showed that the effect of cutting the dowel at the second point of contraflexure (typically less than 7 in. into the concrete for 1 in. dowels and less than 8.5 in. into the concrete for 1.25 in. dowels) resulted in a net change in the maximum bearing pressure at the face of the concrete of less than 0.25 percent. Based on this finding, he concluded that dowel lengths could be further reduced (to values less than 24 in.).

This work, along with the results of laboratory and field studies, including work begun at the Bureau of Public Roads in 1947, led the American Concrete Institute Committee 325 (Concrete Pavements) in 1956 to recommend the use of 18 in. long dowels spaced 12 in. apart—a practice that has been widely adopted and remains the most common practice today. These recommendations were given for steel dowels between 3/4 in. and 1.25 in. in diameter used in pavements with thicknesses between 6 and 10 in.

Based on the above, it can be noted that today's dowel lengths were originally selected to be long enough to ensure that the resulting bearing stresses at the joint face would be very close to values that would be obtained with dowels of semi-infinite length (i.e., the analysis originally performed by Timoshenko and Lessels in 1925). They do not seem to be based on the results of data that relate dowel embedment length to dowel performance, although such data have been available since at least 1958, when Teller and Cashell first published the results of the Bureau of Public Roads repeated shear load testing of full-scale pavement joints.

Based on the results of repeated load tests, Teller and Cashell (1959) determined that the length of dowel embedment required to develop maximum load transfer (both initially and after many hundreds of thousands of cycles of repetitive loading) for 3/4 in. dowels could be achieved with an embedment of about 8 dowel diameters (6 in.) while 1 in. and 1.25 in. dowels required only 6 diameters of embedment (6 in. and 7.5 in., respectively). Their test data suggest that even shorter embedment lengths (i.e., 4 dowel diameters or less) may still result in acceptable performance (bearing stresses and dowel looseness appear to increase only marginally and load transfer loss is less than 1 percent, as illustrated in Figures 2 and 3). As a point of interest, it was this same study that resulted in the recommendation that "dowel diameter in eighths of an inch should equal the slab depth in inches."

Khazanovich et al. (2009) performed a laboratory study of dowel misalignment conditions (including longitudinal translation, which results in reduced dowel embedment) and found that the shear capacities and relative displacements of 1.25 in. and 1.5 in. diameter steel dowels were probably acceptable, even when embedment was reduced to 4 in. or less. This study is described in the section about dowel alignment requirements.

Burnham (1999) evaluated the field performance and behavior (after 12 years of service) of several pavement joints on a Minnesota concrete pavement where the joints were not sawed at the proper locations, resulting in reduced embedment lengths. He concluded that "a minimum dowel bar embedment length of 64 mm (2.5 in.) is needed to prevent significant faulting and maintain reasonable load transfer efficiency across a joint."

Field experience and the analytical work and lab tests described above all seem to indicate that dowel embedment requirements could be reduced from current levels (resulting in dowel bars that are significantly shorter than 18 in.) and still have good pavement joint performance while reducing pavement construction costs. Any dowel bar length selected should reflect both embedment requirements and variability in dowel placement and joint location (which is usually lower in pavement repair and dowel bar retrofit applications (Figures 4 and 5) than in new construction and might justify the use of even shorter bars in repairs).

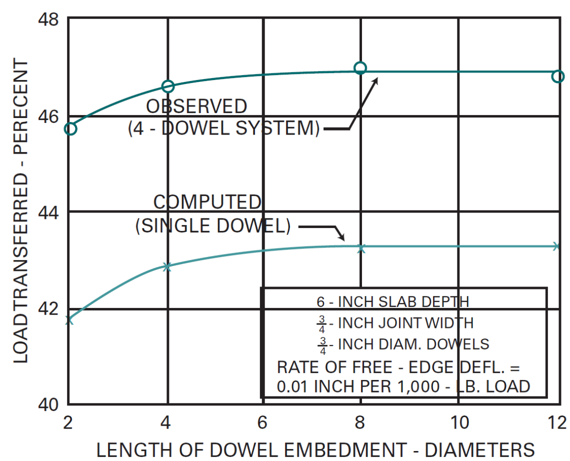

Figure 2. Load transfer versus dowel embedment (observed and computed), after Teller and Cashell (1959)

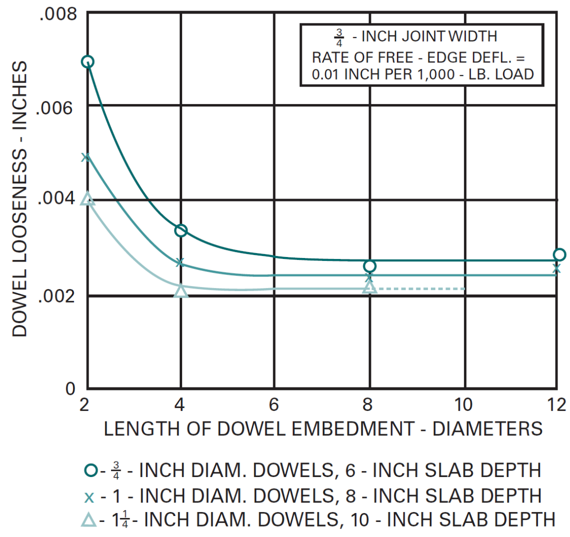

Figure 3. Effects of dowel embedment and diameter on dowel looseness after 600,000 repetitions of a 10,000 lb load (after Teller and Cashell 1959)

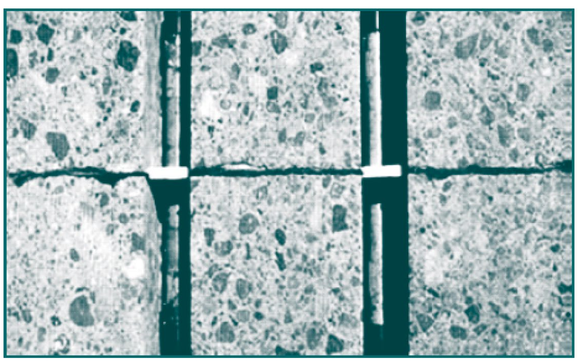

Figure 4. Photo of retrofit dowel bar assemblies, ready for repair material (photo credit: International Grooving and Grinding Association)

Figure 5. Photo of epoxy-coated dowel bars in full-depth concrete pavement repair (photo credit: www.pavement interactive.org)