

Recommendations for Standardized Dowel Load Transfer Systems for Jointed Concrete Roadway Pavements

Dowel Load Transfer



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Guide to Dowel Load Transfer Systems for Jointed Concrete Roadway Pavements

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The National Concrete Consortium (NCC) is a national forum for concrete pavement research and technology transfer initiatives. NCC is supported through the Technology Transfer Concrete Consortium (FHWA Pooled Fund TPF-5(159)).

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Introduction

Round steel dowels are the devices most commonly used for transferring loads across transverse joints in concrete highway pavements. In new pavement construction, dowels are often installed in pre-assembled wire basket assemblies that are intended to support and hold dowels in the desired positions during paving operations (Figure 1).

State highway agency requirements for dowel baskets vary widely. The adoption of a standard set of dowel basket designs will reduce manufacturer set-up and production costs and will allow manufacturers to more easily maintain a larger inventory of fewer varieties of assembled dowel baskets, resulting in lower costs and fewer production delays.

This tech brief summarizes recommendations for standardization of dowel load transfer system design and basket assemblies. Details concerning the fac-

tors considered and the supporting design theories can be found in the *Guide to Dowel Load Transfer Systems for Jointed Concrete Pavements*.

Dowel load transfer system design: current practice

Round steel dowels have, in recent years, become a standard component of the design of jointed concrete pavements in the United States. Dowel length and spacing are generally 18 in. and 12 in., respectively, though a few agencies have adopted shorter dowels and some pavements have been constructed with dowels concentrated only in the wheel paths.

The diameters of round steel dowels have historically (since about the 1950s) been 1/8 the slab thickness, but recent trends have been toward larger dowels to decrease dowel-concrete bearing stresses and joint faulting. There has also been increased interest in the use of elliptical and flat plate dowels to reduce bearing stresses and provide a more efficient dowel cross-section.

Recommendations

Dowel bar material

Structural and behavioral considerations favor the continued use of metallic dowels that have engineering properties similar to those that have been in use for nearly 100 years—carbon steel conforming to AASHTO M227 Grade 70-80 (ASTM A 615 Grade 40 or 60). This includes the use of solid stainless steel dowels, appropriately designed



Figure 1. Typical dowel basket assembly

hollow stainless steel dowels, stainless-clad and stainless-sleeved dowels, zinc-clad dowels and microcomposite steel dowels when long-term durability (corrosion) considerations dictate their use. Depending upon the environmental and design conditions present, plain carbon steel and microcomposite steel dowels may not offer sufficient corrosion resistance without the use of an epoxy coating or other effective barrier to prevent corrosion.

Glass fiber reinforced polymer (GFRP) and fiber reinforced polymer (FRP) dowels do not corrode, but have engineering properties that are significantly different from those of metallic dowels (e.g., Young's modulus about 80 percent lower than that of carbon steel). Field studies and laboratory tests have shown that the use of GFRP or FRP dowels of comparable size and spacing to standard metallic dowel load transfer systems often results in higher joint deflections, lower initial load transfer efficiency and more rapid loss of load transfer efficiency under repeated loads. Significant increases in dowel diameter or reductions in dowel spacing may address these problems, but these approaches may cause other problems (e.g., slab cracking or delamination along the plane of the dowels at the joint). In addition, the long-term (>20 years) performance of pavements constructed using FRP/GFRP dowels has not yet been established. Therefore, the routine use of GFRP and FRP dowels should be approached with caution.

Dowel bar diameter

Dowel bar diameter is an integral part of the design of the rigid pavement structural system and should be determined as a part of the overall pavement design/evaluation process because it directly affects key measures of pavement performance (e.g., pumping, fault-

ing, ride quality, etc.). Dowel diameter should not be selected independently of pavement design, or even as a simple function of pavement thickness.

Required dowel diameter should be determined through a rigorous design process that considers design load magnitude and placement, dowel spacing, dowel stiffness, and the relationships between these parameters and projected pavement distress and performance (e.g., faulting and ride quality). Therefore, no recommendation concerning the selection of a specific dowel diameter is provided here. However, it is recommended that the manufacturers of all types of round dowels be encouraged to produce products with standard finished diameters that can easily be used in standardized dowel baskets, for which recommendations are provided later in this document. It is also recommended that round dowels be produced in 1/4 in. diameter increments.

The concepts described above also apply to the design of non-round dowel sections (e.g., elliptical, flat plate, and other shapes), although these products will probably require a different set of baskets (perhaps more difficult to standardize) than those used for round dowels.

Dowel bar length

The current typical dowel length of 18 in. was selected mainly to closely match theoretical analyses for a dowel of semi-infinite length. It results in a capacity that is typically many times higher than typical design and service loads. Full-scale tests, field studies and analytical work going back to the 1950s show that reduced round dowel embedment lengths (as little as 4 in. and sometimes less) will provide adequate structural performance while reducing pavement material costs.

Based on the body of available research work and experience cited previously, it is recommended that round metallic dowel systems be designed to provide a minimum of 4 in. of embedment on each side of the joint. Overall dowel bar length should be selected to provide the desired minimum dowel embedment on both sides of the joint, plus additional dowel length to account for variances in dowel placement across the joint. Sources of placement variance include tolerances in the marking and sawing of joints in new pavement construction, which could add several inches to the required overall dowel length. Less variation in dowel placement can be assumed for dowel bar retrofit and full-depth repair applications, where the location of the dowel within the joint can be easily controlled. In these applications, acceptable performance can be expected to result from the use of dowels that are significantly shorter than those used in current practice.

Dowel corrosion protection

Epoxy coating remains the least expensive, potentially effective alternative for corrosion protection of carbon steel dowels (and for additional protection of other metallic dowels). However, the durability of epoxy-coated dowels is reduced if epoxy defects develop during transport, construction, or service.

Epoxy coatings for dowel bars have typically used a flexible green material produced under AASHTO M254 or ASTM A775. Some agencies believe that epoxies produced under ASTM A934 (nonflexible products that are typically purple or grey in color and developed for use with prefabricated reinforcing) offer superior abrasion-resistance; however, these epoxies are required to meet the same abrasion requirements as ASTM A775 epoxies when tested using ASTM D4060. Epoxy coatings

used in other applications (e.g., for coating pipelines) have been developed with significantly greater abrasion and impact resistance, but also do not have the flexibility of the materials meeting AASHTO M254 (ASTM A775), a factor that probably isn't important for dowel applications. No specific recommendations concerning epoxy type are presented here, but designers are encouraged to recognize that different epoxy types with different abrasion resistances might provide different corrosion protection at a given coating thickness.

Any epoxy used for dowel bars must be applied uniformly and with sufficient thickness to provide the desired protection of the dowel. AASHTO M254 requires coating thicknesses to be 7 +/- 2 mils, as this was the thickness range required for epoxy-coated reinforcing bars when the specification was first developed. However, ASTM has, since that time, increased the allowable coating thickness (under ASTM A775) to a range of 7-16 mils for bars with diameters greater than 3/4 in, and many agencies require significantly thicker reinforcing bar coatings than those required by the current AASHTO M254 specification.

In consideration of the results of the above information, along with the results of a 2009 survey of state epoxy coating practices by the National Concrete Consortium, it is recom-

mended that the average dowel bar epoxy coating thickness be greater than 10 mils (with all individual thickness measurements greater than 8 mils). No maximum coating thickness is recommended because it is believed that manufacturer profit motives will prevent the use of excessive amounts of epoxy. It should be noted that the use of too much epoxy coating would, theoretically, produce a softer support layer surrounding the dowel, which would result in increased differential joint deflections; however this effect is believed to be minimal.

Additional corrosion protection is not necessary for dowels manufactured using only 316L stainless steel (solid or hollow dowels), FRP or GFRP, or carbon steel dowels with adequate thicknesses of stainless steel or zinc alloy cladding. Other metallic dowels may develop some corrosion under pavement joint exposure conditions; their performance potential could be improved with the use of good epoxy coatings.

Dowel basket height

Table 1 presents recommendations for standard dowel basket heights (from base to center of dowel bar) for any given dowel diameter. The largest dowel diameters listed exceed those commonly used for metallic highway pavement dowels, but might be appropriate for some FRP or GFRP replacements of common highway dowels.

The basket height for each dowel diameter has been selected to result in placement of the dowel exactly at mid-depth for slab thicknesses at the lower end of each thickness range and placement slightly below mid-depth for slab thicknesses at the upper end of each thickness range. The table reflects a preference for reduced cover on the bottom of the slab (where any resulting distress will not directly affect pavement ride quality or appearance) rather than the top. Note that the proposed cover of each dowel ranges from 2-1/8 in. (for the 3/4 in. dowel in a 5 in. slab) to 4-1/4 in. or more for the 1-1/2 in. dowel.

While an "intended slab thickness" is listed for each dowel bar diameter/basket height combination, it is recognized that larger or smaller dowels could be used for any given pavement thickness. The use of any proposed standard dowel diameter/basket height combination in slab thicknesses that are no more than one column to the left (e.g., the use of "oversized" dowels) results in a vertical translation of 0 to 1 in. (higher than mid-depth) while the use of the same basket in slab thicknesses that are no more than one column to the right (e.g., the use of "undersized" dowels) results in a vertical translation of 1 to 2 in. lower than mid-depth.

Analytical, laboratory, and field studies have all shown that these ranges of vertical displacement will still provide good performance, as is documented

Table 1. Recommended standard basket heights for various round dowel diameters

Dowel bar diameter, in.	0.75	1	1.25	1.5	1.75	2
Height to dowel center, in.	2.5	3	4	5	6	6
Intended slab thickness, in.	5-6	>6-8	>8-10	>10-12	>12	>12
Distance between dowel center and slab mid-depth, in.	0-0.5	0-1	0-1	0-?	0-?	0-?

in *Guide to Dowel Load Transfer Systems for Jointed Concrete Roadway Pavements*.

Recommendations for standardized basket frame design

The following recommendations are based on the information received from the 22 states surveyed by the National Concrete Consortium in 2009, as well as information obtained from contractors, manufacturers, and other industry representatives.

- The basket rail wire diameter should be a minimum of 0.306 in. (1/0 gauge).
- Loop wires should be “U” or “V” style and should be a minimum of 0.243 in. diameter (3 gauge).
- Basket height (distance from bottom of base rail wire to dowel center) should be standardized according to dowel bar diameter (see Table 1).
- Standard basket loops should be spaced 12 in. ($\pm 1/2$ in.) on center.
- Loop wire legs may be installed on either the inside or outside of the rail wires.
- “Spacer” or “tie” wires (used to provide basket stability during shipping and handling) should have a diameter of 0.177 in (7 gauge wire).
- Four equally spaced tie wires should be used in full lane-width basket assemblies; two tie wires should be used in mini-basket assemblies.
- All wire intersections must be welded.
- Baskets should be manufactured so that all dowels are horizontally mounted, parallel to each other, and oriented in the direction of expected slab movement (i.e., parallel to the direction of paving).
- Standard baskets for full lane applications should provide 11 dowels on 12 in. centers (basket length nominally 10 ft), with the intent that the distance from the edge of paving to the first dowel will be a minimum of 9 in. (to minimize potential for interference with and displacement by slipform

paver equipment). Nonstandard basket lengths can be specified and produced as needed for special projects.

- Epoxy-coating of baskets should be left to the discretion of the specifying agency.

Basket stake requirements and other anchoring approaches

Inadequate anchoring of the dowel basket can lead to sliding, tipping, or pulling apart of the basket as the paver passes, which can result in severe dowel misalignment. Therefore, the degree to which the baskets are secured to the subbase or subgrade prior to paving is one of the most critical factors affecting dowel basket performance.

Basket rails should be anchored to the grade to provide maximum resistance to both tipping and sliding. Recommended anchor types vary with the type of base used. Simple pins are commonly used for granular materials and soil, while power-driven anchors may be more effective for use in stabilized bases.

Different foundation types (e.g., asphalt-treated base vs. silty-clay soil) may also require different pin or stake lengths, and layer thickness may dictate orientation of the anchor (e.g., a 6 in. pin cannot be placed vertically in a 4 in. granular layer that overlays a rigid layer).

It is recommended that a minimum of eight anchors be used to stabilize full-lane-width dowel baskets. While it is common practice to place four anchors on each side of each basket, tipping resistance may be improved by placing more (or all) of the anchors on the side of the basket that the paver approaches. Mini-baskets (e.g., short baskets used for small groups of dowels, often concentrated in wheel paths) should be installed with a minimum of four anchors (installed on one or both sides, as described above).

Cutting tie or spacer wires prior to paving

ACPA recommends that dowel basket spacer/tie wires not be cut after basket placement and prior to paving. The wires serve to brace and stiffen the baskets during paving and help to prevent basket movement as the paver passes. Proponents of cutting the wires cite concern that the tie wires will restrain joint movement, but this has not been shown to be a problem anywhere, and simple analyses of pavement contraction forces indicate that tie wires sized and spaced as previously recommended will either yield or will fail at the welds to the basket and will not restrain pavement joint movements (ACPA 2005).

Use of bond breakers and basket pre-coating

The use of bond-breaking materials is typically specified and applied in the field, as necessary, to ensure that pullout forces do not exceed some maximum value (e.g., 60 psi or 3,000 lb). Some states allow (or require) pre-coating of the entire dowel basket with a protective agent that doubles as a bond breaker (e.g., Tectyl 506). Basket pre-coating is an additional step that is not critical to the control of the manufacturing process, so it is recommended that this requirement be left to individual states.

References

- ACPA, 2005. *Dowel Basket Tie Wires: Leaving Them Intact Does Not Affect Pavement Performance*. Publication RT6.01. American Concrete Pavement Association. Skokie, IL.
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