Evaluating the Inherent Potential for Displacement of Loose O-Dowels in DBI Paving Operations

-A Technical Note-

by
Mark B. Snyder Ph.D., P.E. – President
Pavement Engineering and Research Consultants (PERC), LLC
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Introduction

Recent innovations in concrete paving dowels have produced many new dowel products that offer improved structural behavior and/or improved corrosion-resistance (through the use of improved dowel coating systems or the use of noncorroding materials). These behavioral improvements and the potential for longer service life, coupled with competitive costs, offer the potential for more sustainable concrete pavement systems. However, pavement owners and managers sometimes question whether some newer dowel products are more likely to become misaligned during construction when installed using dowel bar insertion techniques. The question often arises with tubular dowels.

This technical note identifies factors that make a dowel more or less likely to move from the inserted position during paving and assesses the potential impact of those factors.

Buoyancy

Archimedes Principle states that there is a force acting on a submerged body that is equal to the weight of the volume of liquid displaced by the submerged body. This buoyancy force is offset to varying degrees by the weight of the submerged body itself. We can consider fresh or plastic concrete to be a dense fluid with a typical density of 150lb/ft^3 or 0.087 lb/in^3. By computing the volume of concrete displaced by a dowel and determining the weight of the dowel, we can determine whether the dowel is prone to sinking or floating after insertion and during concrete vibration operations.

Conventional Steel Dowel

A conventional cylindrical steel dowel has a density of approximately 490 lb/ft^3 or 0.284 lb/in^3 (neglecting the contributions of any thin epoxy or paint layers). This is more than 3 times the density of concrete, so solid steel dowels are subject to a net downward force in spite of the buoyancy provided by the displaced concrete. The calculations below determine the magnitude of that force for 18-inch-long dowels with the most common diameters of 1.25 and 1.5 inches.

$$\text{Dowel volume} = 18\pi D^2/4$$
$$= 22.1 \text{ in}^3 \text{ for 1.25-inch dowels}$$
$$= 31.8 \text{ in}^3 \text{ for 1.5-inch dowels}$$

$$\text{Net vertical force} = \text{Dowel Volume}*(\text{Concrete Density} - \text{Steel Density})$$

$= 22.1(0.087 \text{ lb/in}^3 – 0.284 \text{ lb/in}^3) = -4.35$ lb for 1.25-inch dowels
$= 31.8(0.087 \text{ lb/in}^3 – 0.284 \text{ lb/in}^3) = -6.26$ lb for 1.50-inch dowels

The negative net force indicates that solid steel dowels *could* tend to sink within the concrete mass. This is not typically observed with good concrete paving mixtures that are properly vibrated, but is possible with excessive vibration, high paste contents, high w/cm, etc.

O-Dowel
A similar computation can be performed to evaluate the potential buoyancy and net vertical force acting on tubular steel dowels. The computation must consider that these dowels typically are used with a larger diameter than the solid steel dowels that they are intended to replace. O-Dowels are designed to provide structural equivalence by using 0.12-inch wall thickness and increasing the dowel diameter by 1/8 inch over conventional solid steel dowels. Therefore, 1.375-inch and 1.625-inch outside diameter (OD) tubular dowels replace 1.25-inch and 1.5-inch solid steel dowels, respectively.

The displaced concrete force (buoyancy) can be estimated as the product of the dowel volume and the previously estimated concrete density (0.087 lb/in^3) as follows:

Dowel volume $= 18\pi(OD)^2/4$
$= 26.7 \text{ in}^3$ for 1.375-inch dowels
$= 37.3 \text{ in}^3$ for 1.625-inch dowels

Buoyancy force = Dowel Volume*Concrete Density
$= 26.7 \text{ in}^3 * 0.087 \text{ lb/in}^3 = 2.32$ lb for 1.375-in dowel
$= 37.3 \text{ in}^3 * 0.087 \text{ lb/in}^3 = 3.25$ lb for 1.625-in dowel

The weights of the two dowels (ignoring the mass of any coatings or end caps) can be computed as:

$((1.375 \text{ in}/2)^2 – (1.135 \text{ in}/2)^2)*\pi*18 \text{ in} * 0.284$ lb/in3 = 2.42 lb for the 1.375-inch dowel
$((1.625 \text{ in}/2)^2 – (1.385 \text{ in}/2)^2)*\pi*18 \text{ in} * 0.284$ lb/in3 = 2.90 lb for the 1.625-inch dowel

The buoyancy forces for the tubular dowels are computed as the weight of displaced concrete minus the dowel weights, or:

2.32 – 2.42 = -0.10 lb for the 1.375-inch dowel
3.25 – 2.90 = 0.35 lb for the 1.625-inch dowel

The net vertical force (buoyancy minus dowel weight) is approximately zero for each O-Dowel, indicating no significant tendency to either sink or float in the concrete mix.

Other Factors Affecting Dowel Movement After Insertion

Several additional factors influence the potential movement of implanted dowels in concrete pavement. Most of these factors are influences that are external to the dowels and relate to how "fluid" the concrete is (or becomes when subjected to vibration), including:

- Concrete paste content and w/cm
- Aggregate top size, gradation, angularity, and surface texture
- Mixture temperature and degree of cement hydration at time of dowel insertion
- Consolidation energy imparted to the concrete mixture by vibration (amplitude and frequency)
- Any external forces acting directly on the dowel after insertion (there should be none)

These external factors can be assumed to be the same for any type of paving dowel on any given project. However, the size, shape, and net buoyancy of the dowel will affect the degree to which the dowel is prone to move after insertion.

- O-Dowels and conventional cylindrical steel dowels share the same general shape (cylindrical) and length, so dowel shape will play no role in resisting or facilitating dowel movement through the concrete.
- O-Dowels have slightly larger diameters than structurally equivalent conventional steel dowels; the larger diameter should provide more resistance to movement through the fluidized concrete.
- Conventional solid steel dowels have significant net negative buoyancy which provides an external force (gravity) that makes them more prone to post-insertion movement, especially considering the slightly smaller diameter. O-Dowels have a net buoyancy effect that is nearly zero, as estimated previously in this technical note, and greater resistance to movement due to their larger diameter.

Summary/Conclusion

O-Dowels should be less prone to post-insertion movement and misalignment than structurally equivalent conventional solid steel dowels because O-Dowels are essentially buoyancy-neutral and offer greater resistance to movement because of their larger diameter. The much greater weight of solid steel dowels is only partially offset by buoyancy effects, resulting in a net negative (sinking) force, and the smaller dowel diameter provides less resistance to movements due to that force.

It should be noted that the movement of any type of dowel after insertion is unusual and should not occur with good concrete mixtures and proper insertion and consolidation efforts. The point of this technical note is to demonstrate that there is no reason to believe that tubular steel dowels are any more prone to movement than conventional solid steel dowels. The evidence suggests that O-Dowels are likely more stable than solid steel dowels.