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An Alternative to Traditional Round Dowel Bars

Plate Dowel Innovations Driven by Industrial Concrete Paving

Introduction

Round dowel bars have long been the standard load transfer device for concrete pavements with thicknesses of about 8 inches or greater. In general, they have performed well in street, road, highway and airport pavements. However, there have been some applications in which the industry has learned of three primary failure modes if dowels are not designed and installed properly: steel corrosion; loss of effectiveness due to excessive bearing stresses (Figure 1); and panel cracking due to restraint stresses caused by dowel misalignment, particularly when multiple panels are linked together (Figure 2) [1, 2, 3].

Problems associated with corrosion of traditional round steel dowel bars have been reduced significantly through research and application of various alternative materials and coatings, including epoxy coatings, stainless and low-carbon, chromium steel bars, and zinc coated steel bars [2, 4, 5] Elliptical dowel shapes also have been investigated within the industry in an attempt to improve bearing capacity [6]. To date, elliptical bars have not gained acceptance, even when combined with a corrosion-resistant material; this is most likely due to placement and availability concerns.

The latter two dowel failure modes can be accentuated in industrial paving, where wide-bay construction often is used to place expansive areas. Within the past 10 to 15 years, engineers have observed accelerated joint faulting and spalling, believed to be caused by a transition from an industrial vehicle fleet (forklifts and other equipment) with large, pneumatic tires to ones with mostly small, hard wheels. Although such distresses are a result of differential displacement at the joint, the extremely high bearing stresses resulting from round dowels under the smaller, harder wheels are hypothesized as a primary catalyst.

Also of concern, sometimes during construction a socket is created as the dowel is twisted into the pavement edge (Figure 3) to aid form removal [7]. This action results in a void constructed around the dowel before the pavement is placed into service. The net result is similar to an elongated dowel socket caused by many years of service under high bearing pressures. Similarly, enlarged dowel sockets also have been noted in the industrial paving industry at locations where uncontrolled amounts of grease were used as a bond breaker [8].

Lastly, because of the wide-bay construction and two-directional doweling that is characteristic of industrial concrete pavement, dowel misalignment that results in locking of the joint might more easily result in more panel cracking than is typical in other concrete pavement applications; because dowel baskets are installed during the concrete placement sequence in wide-bay construction, they might not be aligned as accurately as might be the case where baskets are placed in a controlled strip or lane placement.

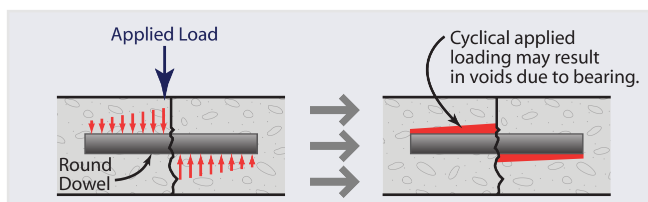

Figure 1. *Illustration of how high bearing stresses at the top and bottom of a dowel bar may result in a void above and below the dowel after sufficient applications of a heavy load.*

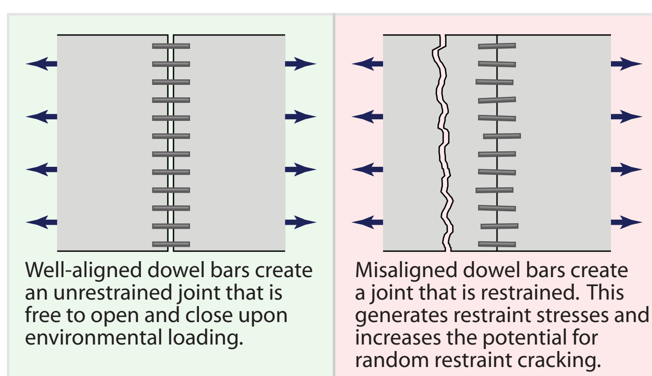

Figure 2. *Illustration of a potential effect of individual misaligned round dowel bars or skewed round dowel baskets.*

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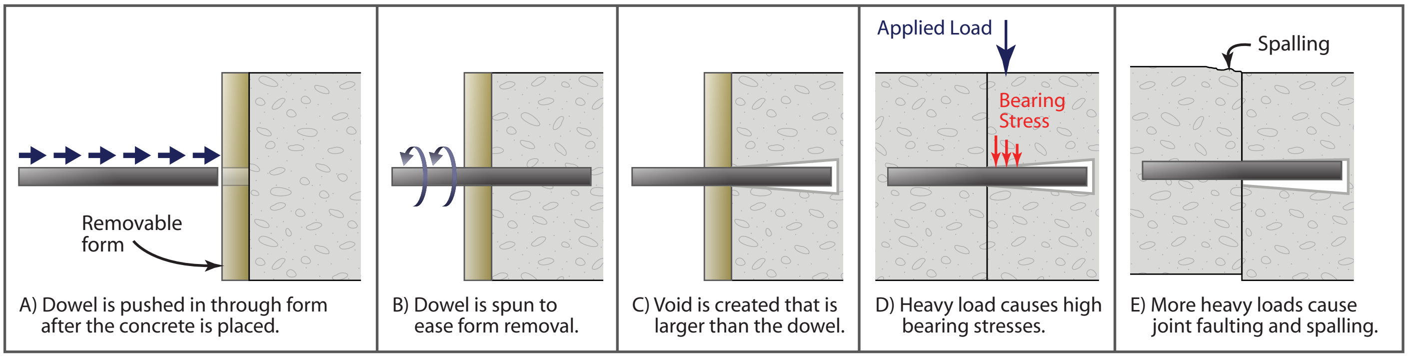

Figure 3. *Dowel sockets, resulting from spinning a dowel bar into place to aid form removal, may lead to accelerated joint faulting and spalling.*

From Round to Plate: Mitigating Bearing Stresses on Dowels

The first attempt to move away from round dowels in industrial concrete paving was made in the late 1980's [9]. This attempt used square dowels with compressible material attached to the vertical faces. The aim of this technology was to maximize the dowel's bearing area (reduce bearing stresses) and provide adequate load transfer while, at the same time, allow for lateral movement of the slabs because of the compressible material on each vertical face. Due to early placement problems, a high density plastic (ABS) clip was added to the square-dowel design to hold the compressible material in place during construction [10].

Extending the square dowel technology, attempts to further decrease bearing stresses resulted in the development of a rectangular plate dowel. This geometry greatly reduces bearing stresses with a cross-sectional area of steel that is similar to round dowel bars and, in turn, allows for increased dowel spacing. Plastic clips with compressible material were also used with the rectangular plate dowels to allow for some misalignment of the dowels [11].

Refinements to the plate dowel geometry led to diamond-shaped and a tapered plate dowels [11, 12, 13]. Both of these geometries allow a reduction of steel by strategically providing more material where it is most beneficial (near the joint) while still greatly decreasing the bearing stresses.

Diamond and tapered plate dowels also are capable of effectively transferring the same load at a significantly larger spacing than traditional round dowel bars. Because bearing stresses dictate size and spacing recommendations for traditional round dowel bars, engineers have calculated equivalent bearing recommendations for plate dowels [8]. Also, the geometries of the diamond and tapered plate dowel bars have proven to greatly reduce restraint without the use of a compressible material on the vertical faces [13].

The evolution of dowel geometry in industrial concrete paving is summarized in Figure 4.

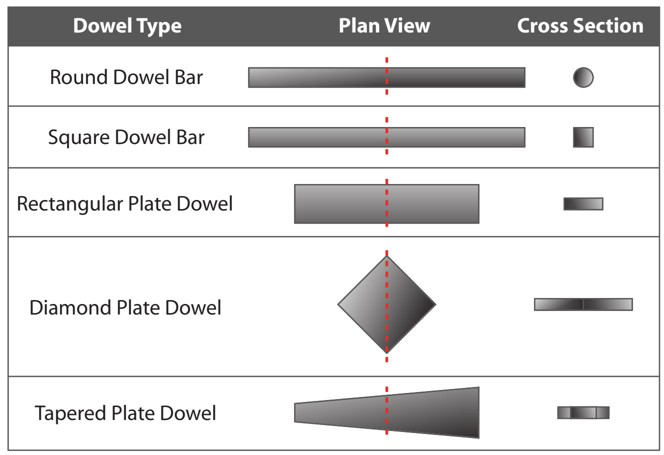

Figure 4. *Dowels in industrial concrete paving evolved from round dowel bars to square dowel bars and rectangular plate dowels and then to the current state-of-the art diamond and tapered plate dowels.*

Reduced Restraint with Innovative Plate Geometries

Initially, geometric changes to traditional dowel bar designs were made in an attempt to mitigate bearing stresses. This is evident in the attempts in industrial concrete paving to first try square dowel bars and then rectangular plates and in other concrete paving applications by research into technologies such as elliptical dowel bars. None of these alternative geometries, however, successfully reduced restraint stresses caused by dowel misalignment even though some mitigation of restraint was provided by the inclusion of the compressible material on the vertical faces of the square dowel bar and rectangular dowel plates. The most recent innovations, however, provide the first attempts to mitigate restraint on the basis of dowel geometry alone.

Because of the unique geometries of the diamond and tapered plate dowels, openings of the joint due to environmental loadings will produce a void that is larger in plan view than the dowel itself (Figure 5). The bearing area and contact between the top and bottom dowel surfaces and the concrete, however, will still be maintained. This inherently larger void is capable of allowing a relatively significant misalignment of individual dowels without resulting in lateral restraint, as shown in Figure 5.

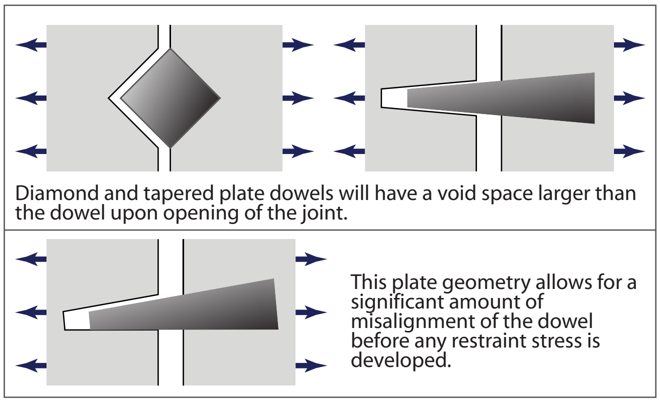

Figure 5. *The geometries of diamond and tapered dowel plates allow for a significant amount of dowel misalignment.*

Typical Dowel Arrangements

Diamond plate dowels are used in construction joints. To install a diamond plate dowel, pocket formers are attached at the proper location on the forms (Figure 6). After the pavement has been placed and the forms removed, a diamond plate dowel is slipped into each pocket former (Figure 7) [13]. As a result of this typical installation procedure, every diamond plate dowel is placed such that it is nearly-perfectly centered over the construction joint; all diamond plate dowels currently must be installed in this manner to ensure proper location due to the short embedment length.

Figure 6. *Installation of a diamond plate dowel pocket former [photo courtesy of PNA Construction Technologies].*

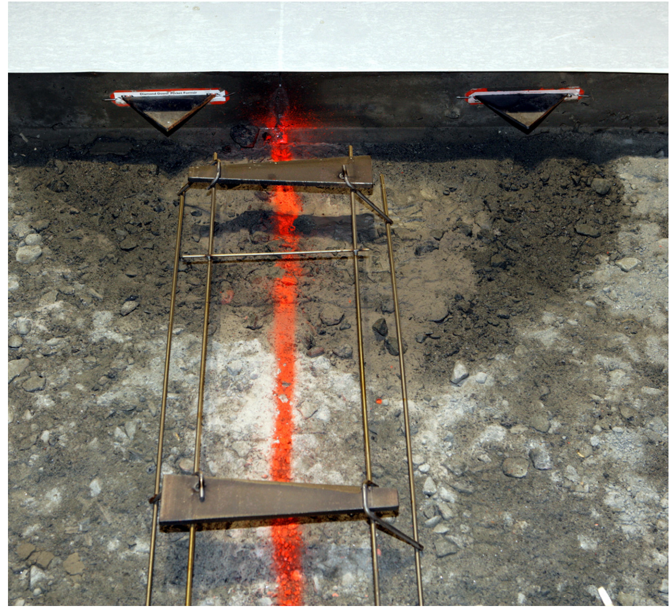

Figure 7. *Diamond plate dowels installed in pocket formers along a construction joint and a tapered plate dowel basket placed along a marked line where a contraction joint will be sawed [photo courtesy of PNA Construction Technologies].*

Tapered plate dowels are used in contraction joints in many industrial paving applications. Embedment length requirements create a tolerance of ± 2 in. for the sawcut on either side of the centerline [8]. Tapered dowel plate baskets alternate the direction of the dowels to compensate for installation tolerances and ensure adequate load carrying capacity. Thus, when a joint opens, the void around the narrow end of the tapered dowel plate is created on alternating sides of the joint, allowing for some lateral movement (Figure 8). This void also allows for a certain degree of misalignment along the length of the dowel basket without restraint stresses developing.

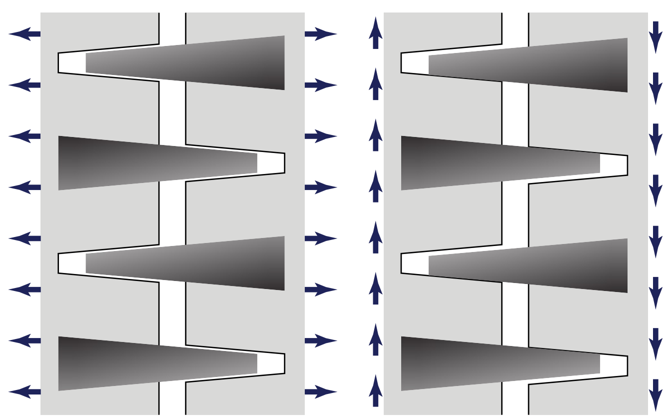

Figure 8. *Tapered plate dowel baskets feature alternating dowel orientations, a configuration that causes a void at the narrow end of the dowel to develop to allow for some unrestrained lateral movement [after 8].*

Corrosion: an Issue under Development

Corrosion of the steel plates remains an area of development. Because most industrial concrete pavements are placed in the confines of indoor or covered facilities, corrosion has not been a major roadblock to the use of plate dowels in industrial concrete paving. Knowing that corrosion protection likely will be a concern for most outdoor applications, plate dowel manufacturers currently are investigating corrosion protection alternatives similar to those discussed earlier for round dowels.

Alternate Geometries can Save Steel

Diamond and tapered plate dowels may reduce the quantity of steel required compared to conventional round dowels without sacrificing load transfer performance. A round dowels with a 1¼ in. diameter has a cross-sectional area of 1.2 in^2. One equivalent to the 1¼ in. round dowel is a 4.5 in. square diamond plate dowel at a thickness of ¾ in., resulting in a cross-sectional area of 4.8 in.^{2} at the joint. Thus, 4 times more steel is placed at the critical location (near the joint) with the diamond plate dowel than with a traditional 1¼ in. round dowel. Due to this strategic placement of the steel, diamond plate dowels may be placed at a significantly larger spacing than round dowels.

Current round dowel embedment specifications are based on providing a sufficient length of dowel to mitigate bearing stresses [8]. The ability of the diamond plate dowel to effectively minimize bearing stresses requires it to only have an embedment length of slightly over three inches. This, coupled with the potential to increase dowel spacing, can result in an overall reduction in the quantity of steel required at each joint.

As an example, Table 1 lists dowel dimensions, spacings, dowels per a 15 ft joint, and steel per 15 ft joint for traditional 1¼ in. round dowel bars and equivalent alternative dowels. As illustrated, the limited increase in bearing area of a square dowel bar also limits its additional spacing when compared to a round dowel bar so a joint with square dowel bars will use more steel than one with round dowel bars. Also shown, the use of rectangular, diamond, or tapered plate dowels may result in significant reductions in steel usage.

Potential Applications of Plate Dowels

Despite their widespread use in industrial concrete paving, plate dowels have not been introduced to other paving applications. Tapered plate dowel baskets could be designed to be substitutes for traditional round dowel bar baskets for use in many of these applications, potentially resulting in reductions in steel usage and translating into less costly and lighter dowel baskets. The tapered plate dowel basket technology recently was used for the first time in conjunction with slipform paving operations with great results (Figure 9). Although this project was for an industrial paving application, it indicates the immediate viability of substituting tapered plate dowel baskets for traditional round dowel bar baskets.

Table 1. *Alternative dowel dimensions, spacings, and steel usage compared to traditional 1¼ in. round dowel bars [after 14, 15].*

	Dimensions (in.)	Spacing (in.)	Dowels per 15 ft Joint	Total Steel per Joint (in^3)	Steel Reduction per Joint
Round	1¼ x 18	12	15	330	-
Square	1¼ x 18	14	13	365	-10%
Rectangle	¾ x 2½ x 12	18	10	225	32%
Diamond	¾ x 4½ x 4½	20	9	135	59%
Tapered	¾ x 1.67 to 3.33 x 12	18	10	150	55%

Figure 9. *Slipform paving an industrial pavement that includes tapered plate dowel baskets [photo courtesy of PNA Construction Technologies]. Note that the pavement was 8 in. thick and the increased installation tolerances of the tapered plate dowel baskets aided in their placement in front of slipform paving operations, in turn allowing the prepared subgrade to be utilized as a haul road.*

Other more specialized applications might derive greater performance benefits from these technologies. For example, tapered dowel plates might be used in concrete pavements thinner than 7 in. (as noted in a very recently published ACI document [16]). Seven inches is the current recommended limit for the inclusion of round dowel bars in most concrete pavement specifications. Also, the unique ability to allow for some lateral movement might benefit joints in curves, such as in an embanked curve or a round-about, where traditional dowel bars might lock a joint even if they are properly aligned. This ability to allow lateral movement might also be useful where four joints meet, a location where excellent load transfer is extremely beneficial but placing dowel bars too near the joint might cause corner cracking (Figure 10); current ACI guidance allow diamond plate dowels to be within 6 in. of a joint [15], with current typical recom-mendations for round dowel bars being no closer than 12 inches [14, 15].

Based on the successes in industrial concrete paving and the escalating cost of steel, evaluation of plate dowel technologies for other concrete paving applica-tions is likely to occur rapidly. This development is likely to be spurred on by the recent inclusion of plate dowel technologies in several ACI publications, including ACI 302.1R-04, "Guide for Concrete Floor and Slab Construction," ACI 330R-08, "Guide for the Design and Construction of Concrete Parking Lots," and ACI 360R-06, "Design of Slabs-on-Ground."

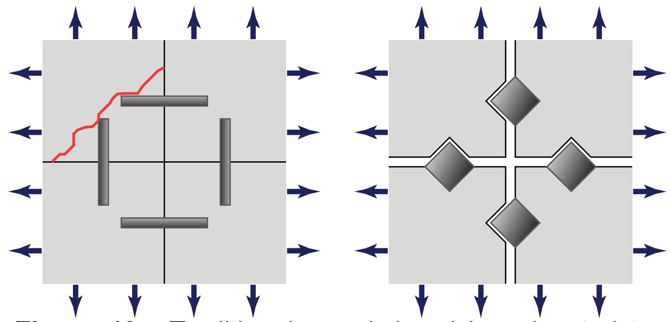

Figure 10. *Traditional round dowel bars located too close to a joint intersection may cause corner cracking due to restraint stresses; the freedom to move laterally mitigates restraint stresses with diamond plate dowels.*

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