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Manuscript of Nigel K. Parkes…

Improved Load Transfer and Reduced Joint Spalling Systems for both Construction and Contraction Joints

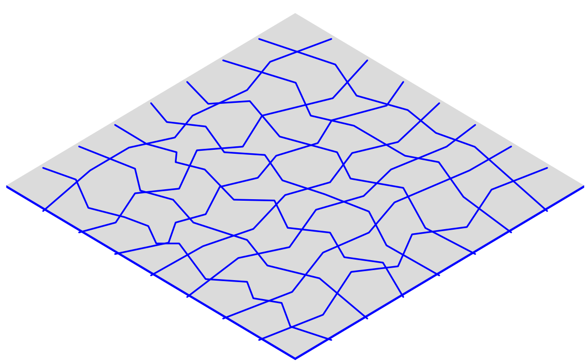
Introduction

The use of plate dowels for load transfer has become widely accepted and is included in nationally and internationally recognized industry standards. Plate dowels have been used with great success in many millions of square feet of concrete floor slab construction worldwide and systems developed for installing plate dowels in the field have been refined and improved, making them easier to use, less expensive and yielding a higher quality product. This paper presents the need for designs that limit restraint and the new systems for installing plate dowels and their benefits.

Proper Jointing is Essential

Joints allow designers to split a continuous slab cast into sections to relieve internal stresses. Formed construction joints allow contractors to define manageable portions of the total slab cast to construct in a single placement. Saw cut contraction joints create a weakened plane in the slab depth that induces it to crack in a controlled manner (below the saw cut.)

Without proper jointing slabs would crack randomly (Fig.1.). These cracks would be subject to curling, faulting and spalling (deterioration of the crack interfaces) under wheeled traffic, and could become a significant maintenance problem, as well as being unsightly. Fig.1.



Floating Slab Panels

It's a fact, concrete cracks when restrained. If concrete slabs were free to shrink and move totally unrestrained they would never crack and there would be little need for joints. Unfortunately designers have to deal with many forms of restraint including sub grade friction, building elements (columns, walls, pits and trenches, etc.), reinforcement (see inset) and conventional load transfer systems. As stated in The American Concrete Institute Report, *Design of Slabs on Grade* (ACI 360R-92), "Restraint from any source, whether internal or external, will increase the potential for cracking."

Ideally each slab panel would be free to shrink and move totally independent of each other or 'float' (Figs.2a. and 2b.), unrestrained in all but one plane, vertically, for load transfer.

Figure 2a.

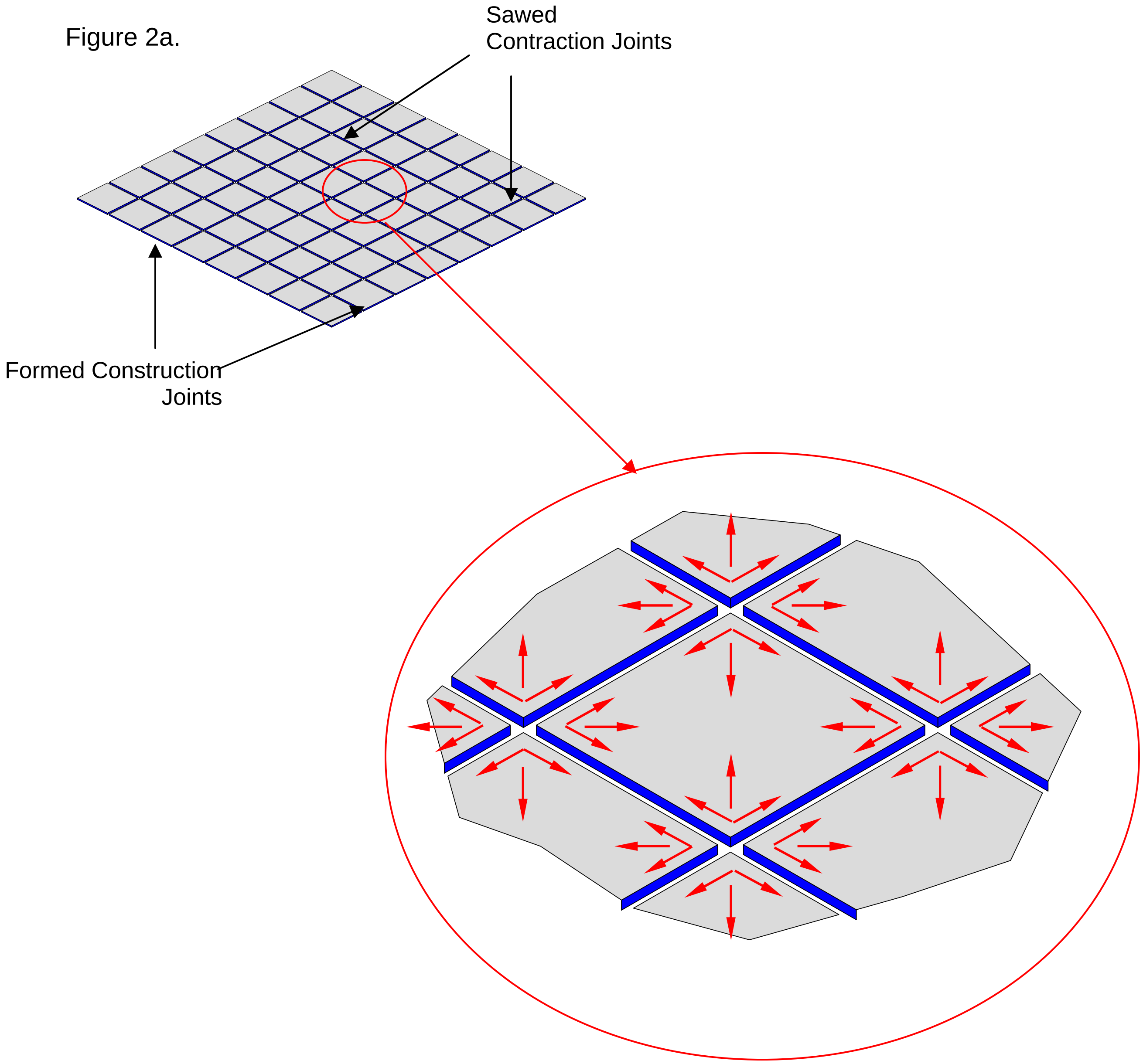


Figure 2b.

Why Load Transfer Across Joints is Critical

For joints to work properly the designer must provide for proper load transfer so that dynamic loads can traverse them without causing faulting or impacting the joint edges thus creating significant spalling. The article, “Joints –The key to Floor Durability” by Steven Metzger states, “*A 1989 survey we conducted of facility professionals showed that joints constituted 79% of their floor problems…not cracks (as most people believe) but joints”.*

Positive load transfer is key to joint stability under load and directly impacts the amount of joint deterioration or spalling but many load transfer systems also induce internal restraint. The Portland Cement Association (PCA) states that, *“the greatest portion of floor repair and maintenance is for joint edge deterioration and crack correction.”* Therefore, the ideal load transfer system is one that allows joints to open freely, provides total vertical load transfer but permits adjacent slabs to shrink and move freely of each other in all other planes.

Ideal Load Transfer Systems

For a load transfer member to perform properly it should:

- be in direct contact with the concrete in the vertical plane to provide positive load transfer, prevent faulting and minimize spalling
- be free of the concrete in the horizontal plane to allow the slabs to shrink and move freely in the transverse direction thus reducing restraint and minimizing stress cracking

Few methods of designing joints achieve both functions (see inset that discusses historical jointing methods.)

The Engineering Benefits of Plate Dowels

The advantages of plate dowels were introduced to the industry in the American Concrete Institute’s publication, *Concrete International*, Plate Dowels for Slabs on Ground, in 1998 by Wayne W. Walker and Jerry A. Holland. The article discusses optimizing the use of material (steel) for load transfer in both formed construction joints and saw cut contraction joints and the resulting engineering benefit of reduced restraint and minimized random cracking.

The industry standard is rapidly shifting to two types of plate dowel, Diamond Dowel® Plates to be used in construction joints and rectangular plate dowels to be used in contraction (control) joints. According to Walker and Holland, “the diamond-shaped plate is the optimum shape for a dowel. It is wide where the bearing, shear, and flexural stresses are the highest and is narrow where the stresses are reduced” (Figs.3a. & 3b.).

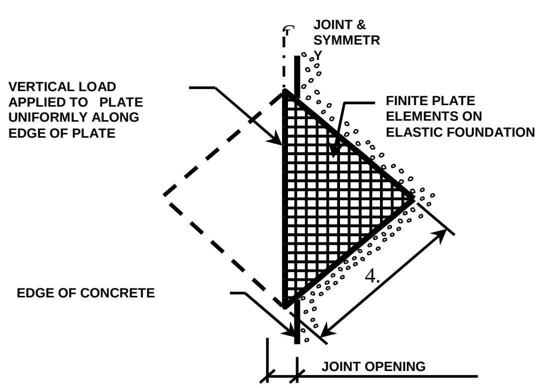


Fig. 3a. COMPUTER MODEL FOR DIAMOND PLATE DOWEL

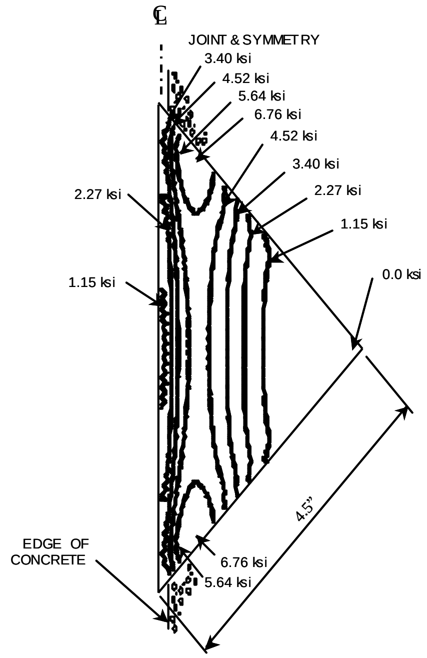


Fig. 3b. FLEXURAL STRESS CONTOURS FOR A 1/4" THICK DIAMOND PLATE DOWEL WITH A ONE KIP LOAD APPLIED TO THE EDGE

Walker and Holland also state, "the diamond-shape allows the slab to move horizontally without restraint when the slab's shrinkage opens the joint." (Figs.4a. & 4b.).

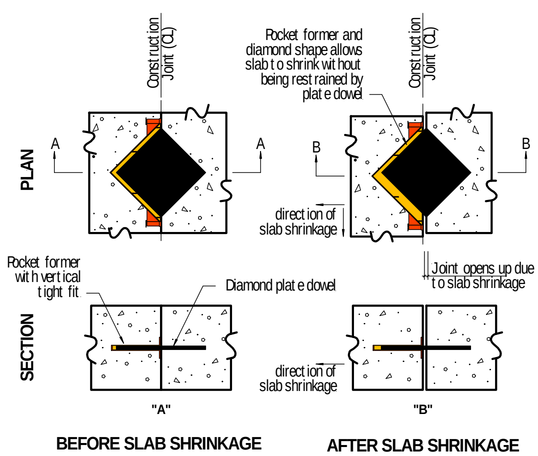
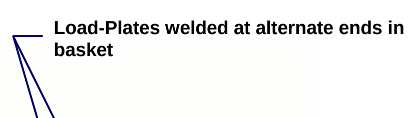


Figure 4a. Figure 4b.

Rectangular plates are recommended since the construction tolerances required make it impractical to use 4.5-inch diamond-shaped plates in contraction joints. Rectangular plate dowels are fabricated into fully welded basket assemblies that support the plates at the center of the slab depth and at the specified centers. These Load Plate Baskets™ (Fig.5.) can be manufactured to suit specific applications with various slab depths and loading requirements.

Figure 5.



The total length recommended for rectangular plate dowels is 12 inches, that comprises two times the 4 inch embedment length (see note) plus 4 inches for the construction tolerances required in positioning the Load Plate Basket™ and saw cut (Fig.6.).

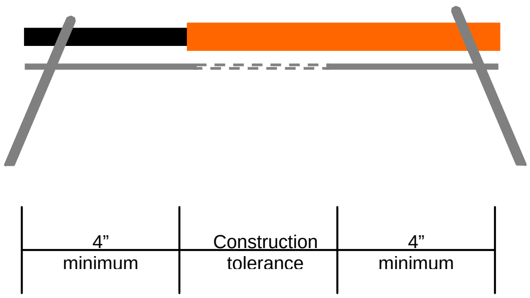
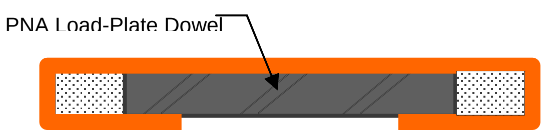


Figure 6.

NOTE: According to Walker and Holland, "the stresses reduce significantly beyond the first inch of the dowel past the joint".

A specially designed plastic clip holds a compressible material to the vertical sides of the plate dowels (Fig. 7.). This part of the assembly accommodates the slab's horizontal movement parallel to the joint and also allows for some misalignment of the basket. The clip and compressible side material is essential to the current systems performance. Without it, any degree of misalignment would restrain the joints activation; induce stresses into the concrete and cause random cracking.

Figure 7.



Load-Plate and Clip Section

<u>Recent Improvements to the Diamond Dowel® System</u>

The diamond shaped load plate remains the most efficient and economical way of achieving load transfer in formed construction joints so the shape and size of the Diamond Dowel® Plate is unchanged but the system and procedure for installing the plates has been improved. The contractor is now provided with a simple two-component system comprising a pocket former and plate. The pocket former is simply nailed to the form (Fig.8.) with the nails provided and the concrete is cast as normal.

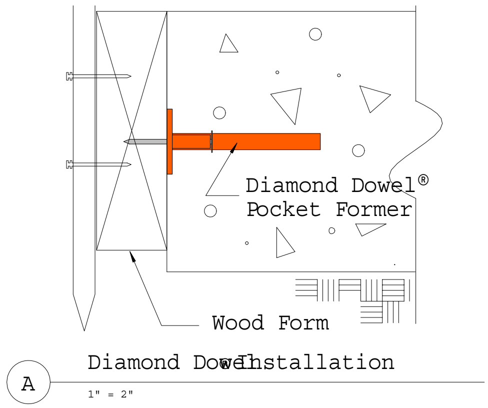


Figure 8.

As soon as the forms are removed the plate can be inserted into the pocket former ready for the second slab cast (Fig.9.). These refinements have simplified the installation and form removal, and have reduced both the material and labor costs.

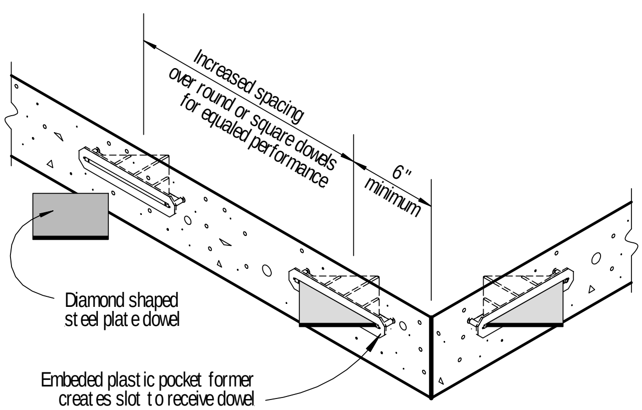


Figure 9.

<u>Inset 1. - Reinforcement Causes Restraint</u>

A commonly held misconception is that, steel reinforcement prevents cracking in concrete slabs. In fact reinforcement induces restraint to the normal drying shrinkage of concrete and therefore actually induces cracking. It is true that if the reinforcement is correctly designed (sized and spaced), positioned accurately in the field and supported during the concrete placement procedure that it will hold the cracks tightly closed and that the resulting cracks will not become a serviceability problem. The American Concrete Institutes, *Guide for Floor and Slab Construction* (ACI 302.1R-96) states, “Reinforcement restrains movement resulting from slab shrinkage and can actually increase the number of random cracks experienced, particularly at wider joint spacing. Reinforcement in nonstructural slab-on-ground installations is provided

Figure 11.

primarily to control the width of cracks that occur." "Reinforcement will not prevent cracking. However, if the reinforcement is properly sized and located, crack widths should be held to acceptable limits." Designers should therefore consider the merits of designing reinforced slabs on ground if the owners' expectation is for a crack free slab. If the slab is nonstructural and the intent is to provide a slab free of cracks whether they are held tightly together or not then an unreinforced design with close attention to proper joint spacing and joint design may have more merit.

Inset 2. - Comments on Historical Jointing Methods

Most of the historical methods of designing joints either provide positive load transfer or allow for lateral movement between adjacent slab panels but very few do both.

Reinforcement through the joints – The continuation of reinforcement through joints induces stresses in the concrete by both resisting joint activation (opening of the joint) and restraining shrinkage (movement) laterally between adjacent slabs. ACI 302 states, *"Continuation of part of the slab reinforcing through contraction joints can provide some load transfer capability without using dowels, but increases the probability of out-of-joint cracking."* I suggest that designers should consider the wisdom of this choice. At best this alternative offers a poor compromise between providing low level load transfer and preventing total restraint of the concretes' normal drying shrinkage. Continuation of all of the steel through the joints will restrain the joints activation, totally limit each individual slab panel's ability to 'float' independently and induce stress cracking.

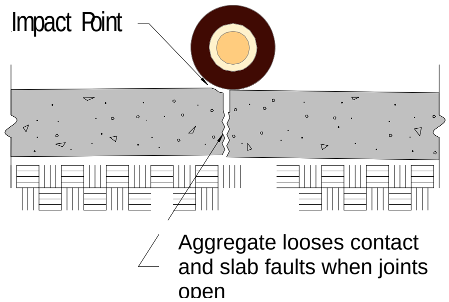
Keyways – Keyed joints constructed in a continuous section allow slabs to move freely of each other in the horizontal plane and would be a more desirable method of jointing if they provided effective load transfer. Keyways are usually formed in a trapezoidal shape so when the concrete shrinks the two sides of the keyed joint loose contact. The slabs are then free to fault at the joint interface enabling fork truck traffic wheels to impact the joints and create significant spalling (Fig.14.). If the contractor could effectively construct a square shaped key, some level of positive load transfer would occur. However, the amount of transfer capacity would be controlled by the concrete's shear strength in one third (1/3) the slab depth. Since many keyed joints fail under traffic, ACI no longer recommends their use in this application.

Aggregate Interlock – The use of aggregate interlock as a means of providing load transfer is flawed in a similar way to keyed joints. Individual pieces of aggregate act as small keys and provide load transfer, until the joint opens and the aggregate pieces (small keys) loose direct contact with the adjacent slab cast. Again the joint is able to fault under traffic (Fig.15.).

Repetitious loading causes the aggregate to shear, become less effective and increases the faulting and spalling rate. Per ACI 302, *"aggregate interlock should not be relied upon for effective load transfer for wheeled traffic if the expected crack width exceeds 0.035 in. (0.9mm)."* The average shrinkage of concrete is one eighth of an inch (0.125 in.) in 20 feet, therefore, designers should space joints at an impractical distance of less than 6 feet on center to keep joint widths in this range.

Figure15.

Impact point



Sawed Contraction Joint Section

Round Dowels – Round dowels are still the most widely used method of providing load transfer in formed construction joints despite the challenges they pose to contractors; *"Conventional dowels have to be re-moved to allow for the removal of forms. They then must be replaced before the adjacent slab is placed. Unless workers take extreme care during this operation, they easily can hollow out a cone-shaped hole in the freshly placed concrete, which can reduce the load bearing capacity of the dowel significantly."* ('Innovations for Durable Floors,' Concrete Construction, 2002). Small misalignments of individual round dowels can cause portions of a construction joint to lock causing semi-circular or moon shaped cracks to form adjacent to the joint. Contractors often use significant amounts of grease on round dowels to help decrease their bond and offset some of the restraint caused by dowel misalignment. This grease also creates an oversized hole in the slab and decreases the ability of the dowel to provide 'immediate' load transfer.

The use of round dowels in saw cut contraction joints has increased dramatically since the Portland Cement Association (PCA) published the effectiveness of aggregate interlock testing results. Designs with round dowel baskets specified at all saw cut joints have become far more prevalent.

Round dowels offer positive load transfer but do not allow for any movement in the horizontal plane. Slight misalignments of round dowel baskets can cause entire lengths of joint to lock. If one saw cut locks then the next often opens twice as wide (Fig.16.) to accommodate the slabs' total shrinkage. This creates a situation where adjacent slab panels, divided by saw cuts, are moving in different directions. The dowels through these joints restrain the differential movement and induce stress into the concrete. All standards for the use of round dowels suggest they should be positioned parallel to the slabs surface and at 90˚ to the joint.

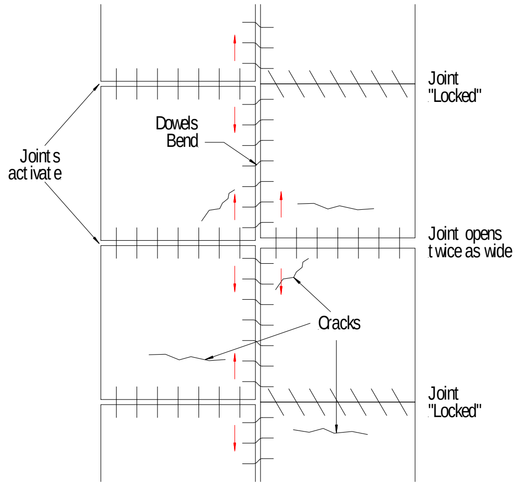


Figure 16.

Fully welded dowel basket assemblies in contraction joints are recommended but tolerances for the positioning of these bars is not generally published. That is because any misalignment of the bars induces restraint. You should also consider the practicality of positioning dowel basket assemblies in industrial floor slabs on grade. How often does the contractor have time to set all of his baskets in place and carefully check their positioning prior to placing the concrete? Today's production schedules, competitive markets and stringent flatness tolerances dictate that contractors have to truck dump concrete and LaserScreed most slabs. With this in mind the contractor cannot lay out the basket assemblies ahead of time. Dowel baskets are installed in an ongoing placement sequence as follows:

- Measure and mark on the forms where the saw cuts are designed to intersect with the construction joints.
- Pull string lines between the marks on the forms then mark (spray paint) the sub grade to indicate the correct position of the baskets (this is normally completed for the whole placement prior any concrete placement.)
- Place one row of baskets (this procedure is completed in just a few minutes so as not to impact productivity.)
- Place concrete over the baskets (workers hold the baskets in place by stepping on them while the concrete is placed on top and around them.)
- Screed the concrete (while trying not to move the accurate positioning of the baskets.)
- Use the same marks on the construction joint forms to snap string lines and saw cut.

It is unrealistic to assume the contractor can perform these steps and ensure a perfect alignment of the dowel baskets. Although round dowel baskets offer an efficient system of achieving positive load transfer in saw cut joints you should expect the restraint resulting from their use will increase the frequency of stress cracking (Figs.17a & 17b.)

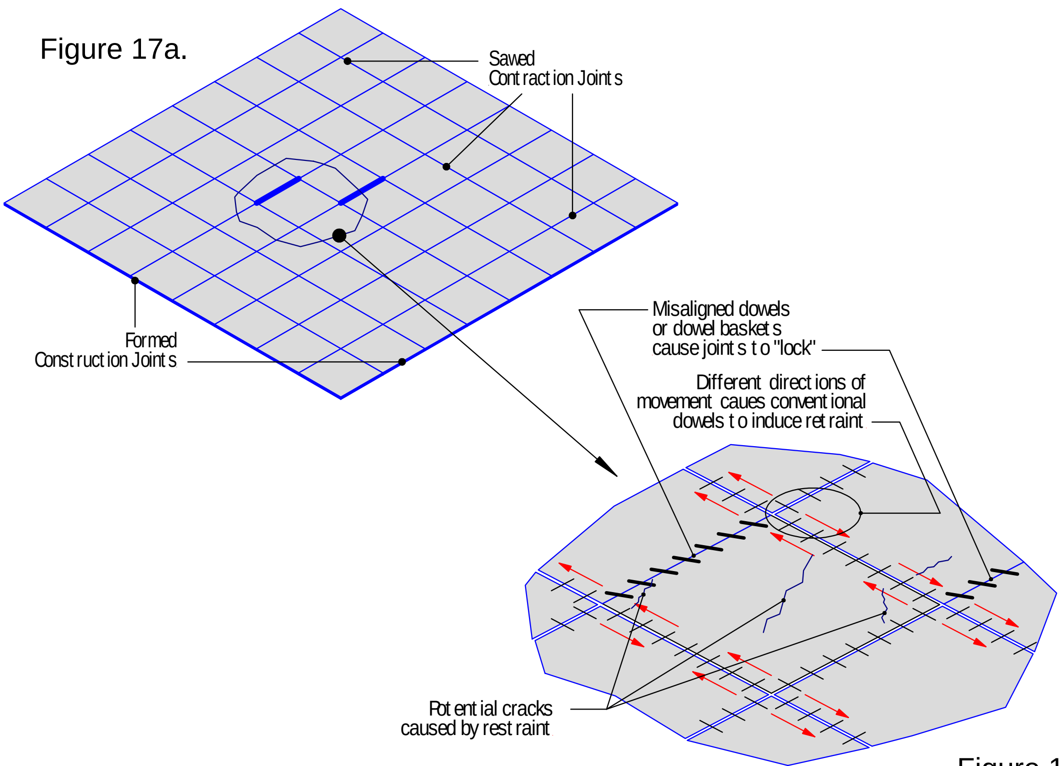


Figure 17a.

Figure 17b.

Steel Fiber – Testing proves slabs with well-mixed concrete containing steel fibers have increased joint stability (load transfer). Assuming the individual fibers act like tiny round dowels, their misalignment also restrains joint activation. To achieve proper joint activation in slabs containing high dosages of steel fiber, many engineers specify deeper saw cuts. Obviously, saw cuts sever the fibers in that portion of the slab depth minimizing the amount of fiber left for load transfer. Lower amounts of steel fiber do not 'lock' joints but they do not offer much increase in joint stability either. Designers are faced with the challenge of balancing joint activation with fiber dosage and saw cut depth. Again, the amount of vertical load transfer achieved with steel fibers that cross the crack below the saw cut is directly proportional to the amount of restraint created in the horizontal direction.

Conventional design methods mentioned here that achieve positive load transfer do not allow for the differential directions of movement (Unlike Fig.2.) and shrinkage rates of adjacent slab panels.

Conclusions

Most traditional systems for providing load transfer have design flaws:

- Either they do not provide suitable load transfer to prevent faulting and spalling;
- Or they induce significant restraint and stress into the concrete.

Several systems allow for the lateral movement between adjacent slab panels; others provide positive load transfer but very few accomplish both criteria required to make a load transfer system completely effective.

Plate dowels are proven to offer improved load transfer without restraint at a reduced cost. The engineering study and resulting data provided by Walker and Holland has been accepted by the industry and their recommendations for the size and spacing of plate dowels have become standards.

Recent improvements in the systems for installing plate dowels in formed construction joints have further reduced their cost and simplified their application in the field.

Acknowledgements
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I would also like to thank my PNA Colleagues, Russell Boxall, President and Pat Harrison, Director of Consultative Services for their support.

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