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"We talked with hundreds of contractors, developers, architects, and specifiers over the three days of the convention. "It seemed that everyone we talked with knew why they wanted to 'build green.' We were grilled about everything from the basics of the FGS system to the chemical reactions that occurred between our dyes and densifiers and the concrete." —*See more on page 4*

green

Step up your slab design with tapered plate dowels

A Decade of Dowel Development

By Nigel Parkes

Experts agree: slabs-on-ground rarely fail structurally, but instead fail through serviceability issues caused by joint spalling.

Joint deterioration in high traffic facilities has been exacerbated more recently with the introduction of smaller, hard-wheeled fork truck equipment. Where historical slab designs are used, the repetitious loading causes more chipping and raveling of the joint arris (spalling), leading to serious issues for everyone involved.

Experience has shown that it takes approximately 25 mils of movement (faulting) across a joint with a typical soft rubber-wheeled fork truck to create joint spalling. It takes even less (approximately 10 mils) with one of the newer generation of hard-wheeled fork or pallet trucks.

Owners pay the price through downtime, maintenance/repair costs and building valuation. Contractors may even be forced to give up their retainage to pay for expensive remedial work.

Better performance, a simple solution

Here's how you can improve your slab without negatively impacting the project timeline or cost: use smart designs that deliver durable, maintenance-free slabs.

A 'strategically reinforced' slab design will prevent joint spalling and cut cost by:

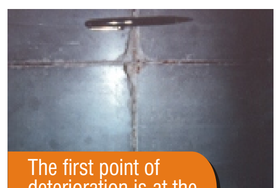
- Providing positive load transfer between joints to prevent faulting of joints and the impact of wheels. (The new industry guidelines recommend the use of positive load transfer devices in all joints, formed construction and saw-cut contraction subjected to wheeled traffic.)
- Using proper joint filling or protection to reestablish surface continuity of the slab profile.
- Omitting unnecessary mid-panel reinforcement.

Load transfer is critical to the slab design

The three design methodologies recognized in the ACI 360R-06, *Design of Slabs-on-Ground* document (the Corps of Engineers, the Wire Reinforcement Institute and the Portland Cement Association) all assume the slab is in intimate contact with the ground. However, slabs warp and curl from differential moisture and thermal gradients, causing the edges and corners to lose direct contact with the ground.

None of these design methodologies account for curling stresses but are sufficiently conservative, with safety factors range from 1.7 to 2.0, to offset this inherent flaw. As a result, we rarely see failures due to overloading.

So what is the most common failure in slabs on grade? The answer is joint spalling. The solution: dowels to provide for the transfer of loads across a joint without faulting.



The first point of deterioration is at the joint intersections

Proper joint filling adds protection to the slab

ACI guidelines suggest there are two ways to protect a joint:

1) Fill the joint with a material to restore surface continuity, or
2) armor the edges with steel plates.

If joint filling is chosen, the guidelines recommend using semi-rigid materials (epoxy or poly-urea) to minimize wear and damage to joint edges. *(See L&M Epoflex SL or Joint Tite 750 on www.lmcc.com)* Both product types, when properly installed, reestablish the slab surface profile and carry the load across the joint without impacting the joint arris if positive load transfer is provided. If joint armoring is chosen, factory fabricated assemblies are available for simple and accurate installation. (See "Innovations for Durable Floors" in the reference list.)

ACI 360R-06 states that "…regardless of the materials chosen for protection, the joint must have adequate load transfer and the surfaces of adjacent slabs should remain in the same plane."

Without sufficient load transfer joints will fault, the semi-rigid materials will become debonded from both sides of the joint and will either be pushed down into the joint or pulled out therefore failing to provide their intended protection. Joints should be filled full depth so that the shoulders of the saw cut can provide support for the filler. If construction schedules dictate the early filling of joints, then the contract documents should assign the responsibility of refilling joints as soon as cracks in the material or adjacent to material exceed the width of a credit card.

"Joint spalling is the most common failure in slabs on grade."

Is mid panel reinforcement necessary in slab-on-ground construction?

Per the industry standards the answer is, "NO, with uniform support and a close joint spacing" (PCA, *Concrete Floors on Ground*, 2001). The industry's move to a slightly more conservative joint spacing has greatly reduced the number of random cracks experienced in slabs-on-ground. Until a slab cracks the reinforcement sits dormant doing nothing but costing money.

ACI states that "…the inclusion of reinforcement (even in large quantities) has very little effect upon the uncracked strength of the slab. The PCA, WRI and COE thickness design methods described in Chapter 6 may all be applied identically to the design of reinforced slabs-on-ground, by simply ignoring the presence of reinforcing."(ACI 360). A 'strategically reinforced' slab design puts the steel where it is needed most—in the joints.

How did we get here?

It seems so simple that properly designed and installed dowels and joint fillers work together to eliminate joint spalling, expensive remedial works and litigation between owners, designers and contractors. But how did the industry move from historical dowelling methods that can induce problems to tapered plate dowel solutions?

The history of dowels

Cracks in concrete are often caused by restraint

Step 1: Round to Square

The problems created by round dowels (restraint inducing stresses and cracking) were recognized in the late 1980s and documented by Ernest K. Schrader in two articles. The articles noted the benefits of moving from traditional round to square dowels to attach a compressible material to the vertical faces of the bar. The foam allowed the slabs to move independently in two planes while providing positive transfer in the vertical plane. At first the compressible material, closed cell foam, was glued or taped to the bars. Problems encountered by contractors—including the displacement or crushing of the foam during the concrete placement—led to the development of a high-density plastic (ABS) clip to position and protect the foam during construction. This clip is still used today in the joints between existing slabs and additions or replacement slabs.

Step 2: Square to Plate

By the mid-nineties many industrial slab specifications included square dowels, but contractors often resisted the move for the following reasons:

- Square dowels cannot be rotated and removed like round dowels, which makes it very difficult to remove the forms. Note: 90% or more of all round dowels installed in the US are removed to facilitate form removal.
- Square dowels, spaced at the same centers, with the clips almost doubled the cost of the doweling.

The development of two products assisted in the installation of square dowels:

Photo A

1) a simple dowel aligner device **(Photo A)**, which provides an oversized hole in the form, or 2) a tube and base cap that creates a void to insert the dowel.

Both of these products negated the need to remove the dowels to strip the form. However, the additional cost prevented a wholehearted industry change.

Discussions between contractors and designers at numerous industry forums (including ACI 302 and 360 meetings) prompted several forward-thinking engineers to consider how dowels work or fail. Their experience troubleshooting slab failures reinforced that joint spalling is the most common failure of slabs. But why, if the joints incorporated round or square dowels?

Further research into the development of the industry standards for the size and spacing of round dowels showed that the weak link in conventional dowels was the bearing stress. This work led to the development of rectangular plate dowels, which have a greatly increased bearing area for a similar cross section. The inclusion of a similar plastic clip with compressible foam allowed for some misalignment of the dowels.

Step 3: Rectangular Plate to Tapered Plate

For saw-cut contraction joints, dowel basket assemblies were adapted to include rectangular plate dowels and clips. For formed construction joints, contractors tried sink-routing holes in forms to accept rectangular plate dowels but forms would bind on the plates and stress the green concrete during form removal operations. Micro-cracks in the concrete caused significant spalling.

Recognition that the stresses in the plate and on the concrete are greatest at the intersection of the joint indicated that a tapered plate dowel offers the optimum shape for a dowel. The development of the diamond-shaped plate dowel system answered both challenges: the pocket former offered contractors a simple, effective and inexpensive method of installation **(Photo B)** and the diamond shape load plate provided 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," (Walker & Holland). Since the publication of Walker and Holland's article, "*Plate Dowels for Slabs on Ground*" in 1998, plate dowels have been included in almost all of the industry guidelines (see reference list) and used in billions of square feet of placed concrete.

Installation shot of tapered plate dowels at formed construction joints using installation template.

Tapered plate dowels for both formed construction joints and saw-cut contraction joints **(Photo C)** are readily available throughout the US and offer the most complete package of advantages to the industry. Tapered plate dowels:

- Provide the optimum use of material (steel for load transfer),
- Negate the need for an expensive plastic clip in contraction joints,
- Offer a fully comprehensive load transfer system so that construction and contraction joints can be interchanged to provide the most flexibility in construction sequencing,
- Can be located "within 6 inches of the intersection of joints," (ACI 302.1R-04) where the curling is most exaggerated, and
- Cannot be misaligned (far better suited to the Laser Screed placement of slabs where dowel baskets need to be installed during the concrete placement).

Tapered plate dowel basket at saw-cut contraction joints and diamond-shaped plate dowels used at the construction joint.

A cautionary note to contractors…

The specification of load transfer at joints is the responsibility of the designer, but contractors accepting projects without details and specifications calling for load transfer should bring the most recent ACI guidelines to the designer's attention prior to proceeding with the project. Contractors' retainages are withheld far too often because joint spalling is wrongly identified as a construction defect. Joints without proper load transfer and joint filler will often deteriorate within the first year of service.

And to owners…

Don't be fooled by realtors who try to sell you a building with a reinforced slab. The use of nominal reinforcement mid-panel offers no provision for load transfer in the joints and the joints will always be the weak link without the proper load transfer and filler.

Conclusions

Tapered plate dowel systems have been used with great success in more than one billion square feet of floor slabs in more than 15 countries worldwide. When compared to traditional round dowels, tapered plate dowels:

- Minimize the designer's liability with a more reliable load transfer option.
- Reduce the contractor's call backs with an easier installation method.
- Provide owners with a lower total cost of construction.

When used together in a 'strategically reinforced' slab, tapered plate dowels and semi-rigid joint fillers eliminate one of the owners' biggest frustrations: joint spalling. And by providing a low maintenance floor incorporating the latest industry guidelines, designers and contractors reduce their project risk and liability.

References

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About the author:

ACI and ASCC member Nigel Parkes is the Executive Vice President for PNA Construction Technologies, Inc., Atlanta, GA.

During his 19-year tenure with PNA, Parkes has specialized in the design of products that improve the performance of concrete slabs-on-ground and result in durable, maintenance-free floors including all of the doweling systems discussed here.

He is a voting member of ACI Committees: 360, Design of Slabs on Grade; 325, Concrete Pavements; and 330, Concrete Parking Lots and Site Paving, and is an associate member of ACI Committee: 302, Guide for Concrete Floor and Slab Construction. He is also a member of the ASCC Manufacturers Advisory Council.

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Nigel is due to speak at the upcoming World of Concrete 2007 in Las Vegas.