Building Better Floors

Low curl extended joint floors

by Jack Gibbons and Joe Nasvik

Owners want floors that are perfectly flat, have no joints or cracks, and require no long-term maintenance. The engineers who design them and the contractors who build them are working to improve the technology to meet those objectives.

The January 2014 issue of *Concrete International* (*CI*) included our article, "Reinventing Floor Construction." That article presented the Ductilecrete system—a method of building floors with reduced curling and increased distances between sawed contraction joints. Ductilcrete Slab Systems, LLC, based in Gilberts, IL, is conducting studies that are helping the industry learn how to build better floors. In the 2 years since the article appeared in *CI*, Ductilcrete licensee contractors have installed over 40 million ft^2 (3.7 million m^2) of floors and exterior pavement. What they are learning pushes the boundaries of what we know about reducing curl and joints in slabs. Here's an update.

The floor slab for the Stratford Ranch warehouse in Perris, CA, was cast under an open sky and hot desert conditions. Note the lack of sawed contraction joints *(photo courtesy of Ductilcrete)*

What is Curling?

Curling is a by-product of differential shrinkage, which results when water leaves the top or bottom of a slab more rapidly than it leaves the opposite side. Usually, the top of a floor panel loses water at a faster rate than the bottom, so the volume near the top of the slab decreases relative to the volume near the bottom of the slab. As a result, the panel cups as the panel edges move higher than the panel centerline. Factors that affect curling include:

- A vapor retarder in direct contact with the slab may increase slab curling as it prevents excess mixing water from being drawn into the base;
- Concrete with excessive water content causes higher drying shrinkage and thus increases curling;
- High concrete compressive strength achieved by increasing the portland cement (and water) content in the mixture results in a high paste content and thus increases shrinkage and curling;
- "Wet curing" methods allow water to seep through contraction joints, potentially keeping the bottom of the slab in a wet condition and leading to reduced shrinkage of the bottom of the slab;
- Highly compressible aggregates result in mixtures with significantly higher shrinkage than those made using harder aggregates;
- Mixture designs with gap graded aggregate portions and/or a small maximum aggregate size result in higher paste content and thus higher shrinkage and curling;
- ASTM C150/C150M Type II and Type I/II cements, for example, generally exhibit less shrinkage than other cement types;
- Ambient conditions that cause rapid surface setting or crusting lead to increased shrinkage and curling;
- Excessive fines in aggregate due to insufficient washing or contamination during handling cause increased shrinkage and curling; and
- Excessive concrete temperature at discharge (exceeding 90°F [32°C]) accelerates initial hydration and surface drying, increasing the likelihood of curling.

When floor panels don't curl, they are supported by the compacted ground everywhere. Subsequently, there is no panel-rocking when forklifts pass over contraction joints. The forklift and the operator thus experience minimal vibration, and there are no parallel cracks along panel edges (cracks that do occur are where curled panels leave the subgrade).

How to Reduce Curling

Greg Scurto, President of Ductilcrete, believes that minimizing shrinkage of the top half of a slab is the most critical consideration when trying to control curling. But minimizing shrinkage and reducing curl in floor panels requires a systems approach—no single additive or process will make the difference. Here's a list of system elements that make a difference:

- Designing well-graded concrete mixtures with the largest top-sized aggregate possible—the goal is reducing cement paste content. Generally, No. 57 (1 in. [25 mm]) aggregate for two lift placements is preferred;
- Including fibers—macro, micro, or steel fibers at higher dosage levels—in the top half of the slab thickness. Fibers reduce shrinkage and increase the ductility of concrete, helping slabs resist internal stresses due to differential shrinkage and curling;
- Incorporating admixtures that reduce shrinkage and keep water content uniform throughout the thickness of a slab;
- Including vapor retarding membranes between the subgrade and the concrete. Double membranes act as a slip-sheet to reduce slab stresses, and they minimize the amount of additional water entering the slab from the subgrade; and
- Providing dense surface finishes to help prevent mixing water from leaving the top portion of slabs (Note, however, that Ductilcrete has successfully installed exterior pavement with broom finishes).

Reducing the Number of Contraction Joints

Contraction joints are problematic; maintenance problems usually begin at the joints. Owners therefore benefit from reductions in the number and width of joints. In a typical slab, joint spacing might be 12 ft (3.7 m) in both directions. Scurto says that his company eliminates 70% of the joints with their Ductilcrete process. Ongoing research suggests further reduction is possible—perhaps contraction joints every 100 ft (30 m) can become standard. Ductilcrete also minimizes joint width. Scurto says they now use 1/16 in. (1.6 mm) wide saw blades, hoping to prevent eventual joint widths from exceeding 1/4 in. (6 mm)—reducing forklift vibration.

Dominant joints are especially a problem for floors designed to prevent cracking. When joints don't activate (that is, when cracking doesn't occur between the bottom of a saw cut and the ground), joints that do activate become wider. Wider joints become maintenance issues. One option is to saw contraction joints all the way through the slab thickness. However, this eliminates any possibility of load transfer at the joint. Scurto says that his company's primary success in reducing the number of dominant joints lies in its patented two-lift process. While the first half of the slab placement comprises the basic mixture design for the project, the second half (the top half of the slab) includes shrinkage reducing admixtures and fibers. By saw-cutting almost through this crack-resistant top lift, the company has found that the bottom lift is more likely to crack.

The Ductilcrete System

Scurto says that his company realized when they started Ductilcrete that price would be paramount—the system had to be priced competitively with standard floor construction methods. They've achieved this by excluding unnecessary materials and procedures and adding only the materials and technology needed to achieve the owner's wish list. And their ability to conduct large field studies on floors and exterior pavement helps them refine the system.

When Ductilcrete started, the company decided to guarantee its work against appreciable cracking and curling. To ensure success, Ductilcrete controls their installations from beginning to end. Ductilcrete becomes the Engineer of Record for every floor, providing engineering and specifications, including jointing details, load capacity charts, and concrete mixtures based on local materials and conditions. They then work directly with the licensee contractor during the construction of the slab.

Here are the key features of the current system:

- **Joint spacing**. For the past couple of years, Ductilcrete has placed sawed contraction joints along column lines, so floor panels have ranged from 30 to 60 ft (9 to 18 m) in length. Recent field studies indicate that greater than 100 ft (30.5 m) lengths (every two columns) are possible without cracking;
- **Joint width**. They use 1/16 in. (1.5 mm) thick saw blades for all their work. The goal is to keep eventual joint widths below 1/4 in. (6 mm);
- **Joint filler**. Joint fillers can be problematic, as they can restrict movement or lose bond along an edge. So, Ductilcrete developed compressible joint inserts that effectively seal joints and stay in place;
- **Concrete**. Ductilcrete mixture designs favor well-graded aggregates, with 1-1/2 in. (38 mm) maximum aggregate size if possible. Gradations are selected to reduce cement paste;
- **Two lift placement**. The same basic mixture is used for the top and bottom lifts, but fibers and a proprietary admixture are added to the second (top) lift to reduce differential shrinkage;
- **Reduced thickness**. If both the top and bottom of a slab shrink at the same rate, curling is avoided and floor panels remain in full contact with the ground. This in turn permits Ductilcrete to reduce the thickness of warehouse slabs;

Due to the limited perimeter access on this tilt-up project, the contractor elected to lift the panels with a 300 ton (270 tonnes) crawler crane positioned on the 6 in. (150 mm) thick DuctilCrete slab. There was no need for expensive "crane bays" in the floor to support the crane *(photo courtesy of Commercial Industrial Finishing, Inc.)*

- **Elimination of hardware**. By eliminating dominant joints and curling, load transfer hardware is no longer required; and
- **Curing**. Ductilcrete slabs aren't cured by conventional means. They are self-curing.

Although the system nearly achieves the typical owner's wish list, it remains cost effective by eliminating unnecessary cement paste, floor joints and fillers, floor thickness, and load transfer hardware.

A Typical Result

The Stratford Ranch project, a distribution center in Perris, CA, is a graphic example of Ductilcrete cost efficiencies. A speculative building, the center has about 1.1 million ft^2 (102,000 m^2) of floor slab constructed by Commercial Industrial Finishing, Inc., Norco, CA. The original design called for an 8 in. (200 mm) thick, steel-reinforced slab with 15 ft (4.6 m) joint spacing and load transfer devices at the contraction and construction joints. Ductilcrete designed and provided the developer with a 7 in. (180 mm) thick slab with very wide joint spacing (56 x 60 ft [17 x 18 m] bays).

The distribution center was constructed using the tilt-up process, which meant that floor slabs were placed prior to the construction of the building envelope. Tilt-up construction is very efficient and cost effective, but it leaves floors exposed to the elements for weeks or months until the building is enclosed. Worse, the weather extremes in this project's hot desert climate can place slabs at risk for early cracking and/or curling. But even in these severe ambient conditions, no external curing was performed. The Ductilcrete slab was employed as casting beds for the tilt-up wall panels, and the crane used to lift the finished panels was sometimes positioned on the floor itself.

The first slab was placed on July 30, 2014, and the last was placed on September 11, 2014. Because of the size of the placements and the extreme daytime temperatures, all concrete placements took place at night, beginning at 3:00 a.m. While the nighttime weather in the California desert is typically cool with no appreciable wind, conditions change dramatically as the sun rises. Temperatures can range from a low of 55°F (13°C) to a high of 100°F (38°C). With no cloud cover, temperatures resulting from direct solar load can be much higher. Wind at the start of most placements was about 3 mph (5 km/h), but by midafternoon it could be as high as 16 mph (26 km/h). Worse, the relative humidity levels could be as low as 20%.

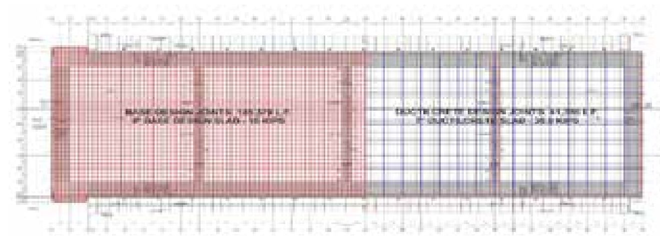
Yet, 14 months later, the floor at Stratford Ranch more than exceeded the developer's expectations. The project attracted a major national corporation as the tenant, and the developer has acknowledged the Ductilcrete slab was their competitive advantage.

Relative to the original design, the Ductilcrete design resulted in:
- Reduction in the amount of concrete by over 3200 yd^3 (2450 m^3);
- Elimination of over 60 tons (54 tonnes) of reinforcing steel; and
- Elimination of 18 miles (29 km) of sawed joints and filler.

Due to the elimination of the reinforcing bars, the concrete was placed directly from the trucks rather than by pump, allowing a 15-day reduction in the placement schedule (as well as eliminating the expense of the pump). And all of these savings accrued with a system that more than doubled the load capacity of the original slab design.

Where to from Here?

Pavement can have many of the same challenges as floor slabs—it cracks and it curls. And pavement joints can be a major durability issue. Ductilcrete is using their system to build parking and public street sections, some of which have now gone through six winters. These pavements are performing well after dozens of freezing-and-thawing cycles, so the company believes that



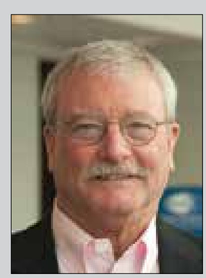
Sawed joints for the Stratford Ranch project: the layout required for a standard floor design—left section; and the layout that was used for the DuctilCrete floor—right section *(illustration courtesy of Ductilcrete)*

pavement is a strong potential market for the Ductilcrete system.

—Ductilcrete Slab Systems, LLC, **www.ductilcrete.com**

Note: Additional information on the ASTM standards discussed in this article can be found at www.astm.org.

Selected for reader interest by the editors.



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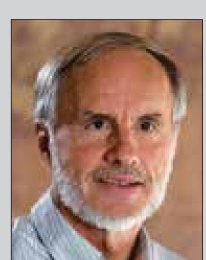

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