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CONCRETE CONSTRUCTION

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The World of Concrete

A Jointless, Crack-Free Walkway

A concrete expert experiments at his own home

By Cecil L. Bentley, Sr., Wayne W. Walker, and Jerry A. Holland

In May 2003, following several days of heavy rain in the Atlanta area, a 110-foot-tall, 3-foot-diameter oak tree fell onto the home of one of the authors, Jerry Holland, cutting the house nearly in half, just missing his wife, and damaging a small portion of a 69-foot-long concrete walkway. Since the insurance company agreed only to pay to replace that portion of the walkway that was damaged, which would have looked unattractive, Holland decided to replace the entire walkway. He took this opportunity to design and build a unique jointless, crack-free walkway.

This walkway with re-entrant corner at one end and a curve at the other with no joints remains crack-free after more than three and a half years.

Holland had been evaluating the new high-volume synthetic fibers (HVSF) in relation to mixability, workability, and finishability, plus short-term and long-term performance in terms of curling, linear shrinkage, and cracking. He decided to make himself a guinea pig and replace the walkway himself, with the help of some friends. To give it an exceptionally good test, he decided to construct it with no joints and no steel reinforcing.

The result has been an easily constructed, 69-foot-long, 3-foot-wide, 3½-inch-thick walkway with no joints, a 90-degree turn at one end with an unreinforced re-entrant corner, and an 80-degree curve at the other end. After more than three and a half years of shrinkage and substantial thermal contraction due

The crew struck-off, floated, and edged by hand.

to a drop in temperature of about 90° F, there are no visible cracks—even at the re-entrant corner.

Why HVSF?

Traditional synthetic fibers (such as Forta-Fiber, Fibermesh, or Microfiber) have been used at dosages of 0.5 to 1.6 lbs/yd^3 for almost 30 years—this is low-volume synthetic fiber (LVSF). At these dosages, the benefits are primarily in the concrete plastic state but not significantly in the hardened state. Holland had thought for many years that there would be significant benefits to using a much higher amount of fiber in the mix; however, at higher dosages the mix could not be properly mixed, much less have sufficient workability and finishability. But more recent developments in concrete admixtures, aggregate proportioning, and research with polymer fiber geometry (moving beyond the traditional monofilament or fibrillated fibers) made him realize that using HVSF in production concrete (rather than in "lab-crete") was possible. Although he had 30 years of design, materials, and construction experience with steel fibers and almost as much with LVSF, he felt that HVSF concrete would act in a substantially different manner than either of those materials. His theory was that adding enough of the right amount and type of fiber would fundamentally change the concrete's inherent properties and behavior. For this to be viable in production concrete, though, the problems of adequate mixability, placeability, workability, and finishability would have to be overcome.

Proportioning and mixing

Thomas Concrete of Georgia Inc. provided the concrete, and Forta Ferro fibers were furnished by the Forta Corp. Although Holland had been designing mixes for more than 35 years and proportioning special combined aggregate for more than 20 years, he wanted to use normal production ready-mixed concrete with as little fine-tuning as possible. Therefore, no special aggregate blending was used (although he did analyze the mix design to ensure there would be no potential issues of excessive shrinkage or curling), and a low amount of a normal production midrange water-reducer was added at the plant. The concrete mix included 592 lbs/yd^3 of portland cement, which did not provide the additional workability/finishability that an addition of fly ash or slag would have, but did keep the water-cement ratio below what is recommended for the Atlanta area's freeze/thaw conditions. To reduce the workability benefits that entrained air can provide, the air content was kept to the lowest percentage required to provide proper freeze/thaw protection (about 4%). The fibers were added at the plant at a dosage rate of 7½ lbs/yd^3. Holland and his friends observed the mixing action of the HVSF at the plant, noting that it was quite good, thus requiring no adjustments to the original mix design. They then followed the truck to the house.

Construction performance

The crew closely observed the concrete for uniformity during discharge from the truck and found it very uniform throughout the load. It was a hot day, with temperatures approaching 100° F, but no cooling measures were taken with the concrete mix; this did not, however, present any difficulties during placement and finishing. The forming and grading resulted in a 3½-inch-thick slab with no granular base, only the residual silty soil supporting the concrete. All of the concrete was placed and finished by hand. Most had a 3-inch slump, which was quite workable and finishable.

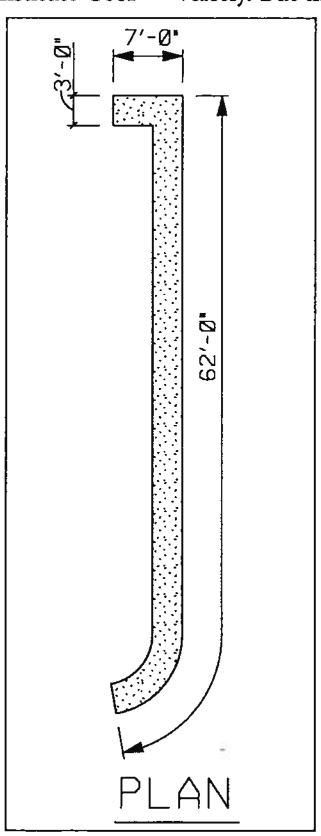
To see if there would be a benefit

Holland and crew found placement and finishing to be no more difficult than normal, in spite of the high volume of fibers.

for hand placement, Holland added enough water to the last portion of the concrete to increase the slump by 1 inch, to about 4 inches. They did not find that a significant improvement. Holland and crew broomed the slab transversely in one direction in order to make the fibers lay down. The high volume of fibers did not cause any problems during brooming and were nearly invisible unless one looked very closely. The entire crew agreed that the finishability was such that if it had not been an exterior slab, they could have achieved a highly polished steel-troweled finish. Holland then cured the walkway for seven days with polyethylene sheeting.

Long-term performance

After three and a half years and four winters, there are no visible cracks in the walkway, even though the ambient temperature has dropped far below freezing many times (a large drop from the high temperature on the day of placement). There is no noticeable curling or other detrimental effects and the surface is extremely hard and durable. The walkway won the Outstanding Achievement Award in the American Concrete Institute Georgia Chapter's Awards Competition in 2004.



Other considerations

The lack of cracks in this walkway is interesting especially when one considers several factors that are nearly universally accepted by those involved with concrete.

1. As slabs on ground shrink linearly, the soil supporting them restrains that shrinkage, thereby inducing tensile stresses in the concrete. The top of the slab will almost always occupy a lesser volume than the bottom and try to lift up (creating curling or warping—see the "For further information"), substantially increasing tensile stresses in the top of the slab. Concrete is up to 10 times stronger in compression than it is in direct tension. These inherent properties of concrete mean that when one sees a crack in a slab on ground, it is almost always caused by the concrete's tensile capacity being exceeded by the applied tensile stresses (curling, restraint to linear shrinkage, volume reduction due to thermal drop, and so on). The most common method of minimizing out-of-joint cracking is to put closely spaced joints into the slab (these joints function as straight, more aesthetically pleasing, cracks). Long-standing recommendations for joint spacing from the American Concrete Institute (ACI) and the Portland Cement Association (PCA) indicate that joints should have been installed every 7 to 10 feet at the very most. This walkway had no joints, so the joint spacing was 69 feet—about 10 times that which is recommended.

2. Concrete slabs do not like to be rectangular in plan; if they are constructed too long between transverse joints, in relation to their width, they will protest by creating their own joints in the form of cracks. Once the length between joints is much more than 1½ times the width, they are much more likely to crack transversely. But the ratio for this walkway is about 23 times the width—about 15 times the recommended; furthermore, the anchoring effect of the change in slab direction at each end makes this length-to-width effect even greater.

3. When concrete slabs on ground change direction, there is substantially more restraint because more linear shrinkage and curling takes place than if they remained straight. This anchorage at each end greatly increases cracking potential near the ends of the straight portions—but the walkway has no visible cracks there.

4. Re-entrant (inside) corners almost always crack, whether or not they are reinforced with diagonal steel bars (diagonal bars typically only limit the width

Cecil Bentley using a wooden darby to float the near the edges.

and length of the crack). The reason for this is that linear shrinkage and curling are occurring in two different directions, at right angles to each other. In the walkway, though, there is no visible crack leading from the re-entrant corner.

Although unanswered questions remain, Holland and his friends believe that this experiment was an unmitigated success and that HVSF will allow some amazing improvements in certain applications, as long as proper design, materials, and construction are provided. Certainly, this project showed that the concerns with mixability, workability, and finishability can be overcome.

For further information

"The First Commandment for Floor Slabs: Thou Shalt Not Curl Nor Crack... (Hopefully)," by Wayne W. Walker and Jerry A. Holland, *Concrete International*, V. 21, No. 1, Jan. 1999, pp. 47–53.

"Design of Unreinforced Slabs on Ground Made Easy," by Wayne W. Walker and Jerry A. Holland, *Concrete International*, V. 23, No. 5, May 2001, pp. 37–42. ■

— All three authors work with Structural Services Inc. Cecil L. Bentley, Sr. is a concrete consultant with more than 45 years of construction experience, most of which were as president of a successful concrete construction firm; Wayne W. Walker is the director of engineering services and chair of ACI Committee 360, Design of Slabs on Ground; Jerry A. Holland is the director of design services and has more than 40 years of experience in design, construction, and troubleshooting concrete materials and structures and is past chair of ACI Committee 360.

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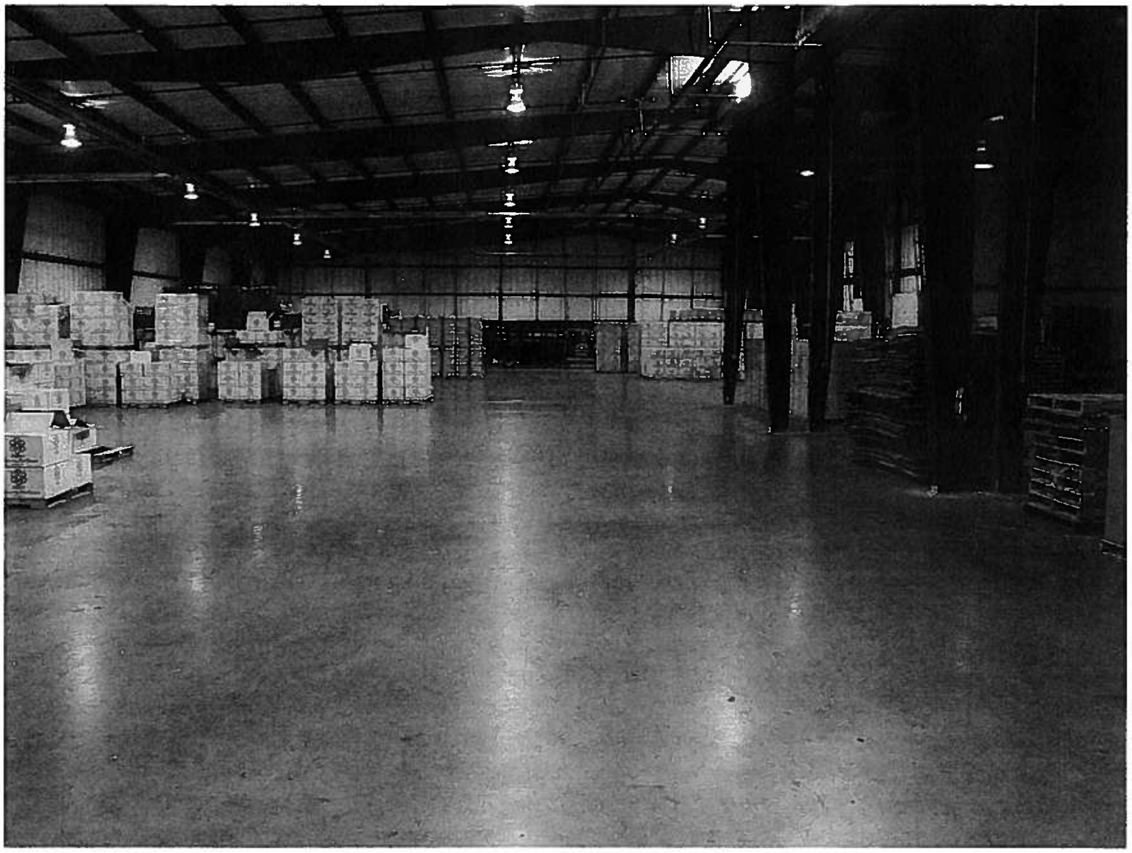

Slab #1 of FORTA addition (127 feet x 60 feet) is crack-free with no steel reinforcement and no control joints.

PROJECT PARTICIPANTS

OWNER: FORTA Corporation, Grove City, PA
GENERAL CONTRACTOR: Struxures, Inc., Seneca, PA
CONCRETE CONTRACTOR: Maya Brothers, Inc., Erie, PA
FLOOR CONSULTANT: Jerry Holland/Structural Services, Inc., Atlanta GA
CONCRETE SUPPLIER: R. W. Sidley, Grove City, PA
FLATNESS TESTING: Professional Services, Inc. Pittsburgh, PA