By Joe Nasvik

Curling and Shrinkage in Floors

Concrete Construction's Field Test warehouse floor study.

"Concrete is an extremely dense liquid." —Harald Malcolm Westergaard

Six months ago Scurto Cement, Elgin, Ill., along with several companies that contributed products, constructed a warehouse in the Chicago area. As one of the nation's largest floor contractors, Scurto searches for ways to reduce long-term shrinkage and curling in its floors. So Scurto agreed to work with Concrete Construction and a committee of experts on a field test to monitor curling over a two-year period.

Scurto placed eight concrete mixes in the 60,000-square-foot floor to evaluate how each moves and curls. Of special interest were mixes with higher dosages of macrofibers.

Construction took place in early February 2009 under typical Midwest winter conditions, with the building's internal temperature maintained above 50° F. A quality vapor retarder was placed beneath the entire floor. Temperatures and humidity percentages inside the warehouse have remained constant and cool, so surface drying has been minimal. The floor was profiled by a 3-D laser scanner and a D-Meter the morning after each placement, and then one month later; with additional data collection taken every six months during the study.

Concrete mixes

Because the concrete was placed under winter conditions, all mixes include accelerating admixtures: five with calcium chloride and four with a nonchloride accelerator (NCA). One mix was designed to approximate what contractors typically use for floor construction throughout the country: a ¾-inch aggregate concrete with more sand and water than the other mixes and a midrange water-reducing admixture. All but one mix included a polycarboxylate superplasticizer. Three mixes included 1½ pounds of microfiber per yard of concrete, five with 3 pounds of macrofiber, and one with 7½ pounds of macrofiber.

Dan Biddle, Forta Corp's vice president for sales, Grove City, Pa., says the definitions of micro- and macrofibers are currently under review by ACI, but a helpful way to view the difference is by the percent dosage that can be successfully

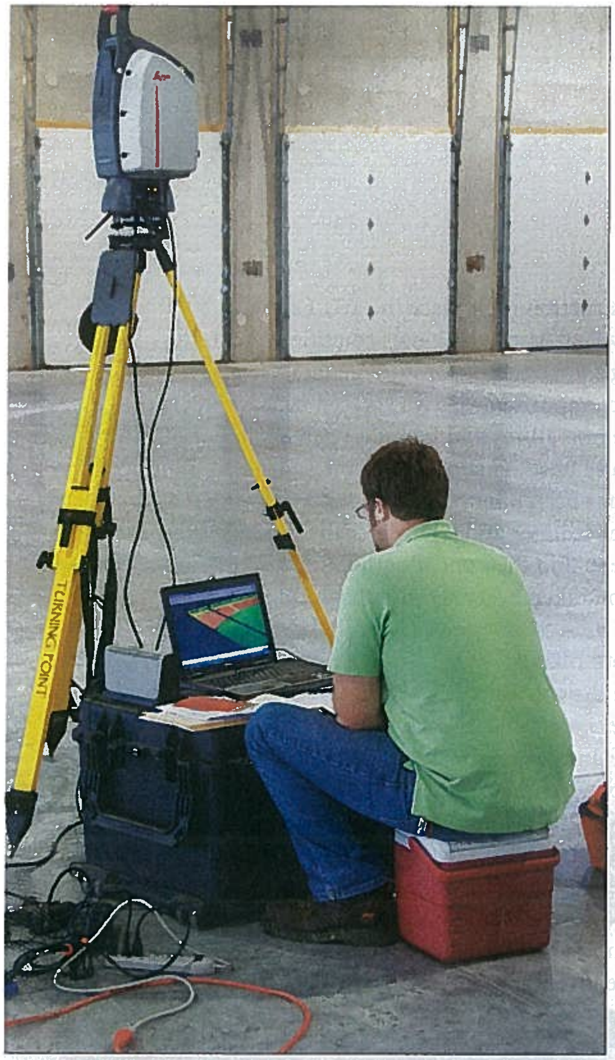
Mike Fischer (left) and Branndon Elsbree (middle) from the SEC Group are using a 3-D laser scanner to profile the floor. Greg Scurto (right), board chairman for Scurto Cement, supplied the floor and helped design the study.
PHOTO: SAMUELS PHOTOGRAPHY

Figure 1. When you place concrete in the field, there can be uncontrolled variables. Ice in aggregates caused some fluctuations in total water but due to water-reducing admixtures, strengths remained high. Note also that air content numbers indicate only small amounts of entrapped air. CREDIT: H.H. HOLMES TESTING

30-DAY AVERAGE TEST RESULTS

Mix	Air Content	Slump (inches)	Average Strength
1	2.00%	5.6	4685
CTL*	1.00%	10.0	5380
2	1.45%	3.3	4925
3A	2.00%	3.0	6070
3B	1.70%	5.0	4280
4A	1.20%	3.3	5450
4B	1.40%	3.8	5760
5B	1.80%	4.0	5090
6A	1.30%	4.3	5555
6B	1.10%	4.3	6400

* Mix used for Kanare's relative humidity testing



Branndon Elsbree uses a 3-D laser scanner and a computer to profile a section of the floor. PHOTO: NASVIK

mixed into concrete. Because of the finer filament shape and resulting higher surface area, dosages for microfibers are limited to about 0.1% by volume (1½ pounds/cubic yard). Macrofiber dosages are in the range of 0.2% (3 pounds/cubic yard) to 0.5% (7½ pounds/cubic yard) and still allow the concrete to remain workable.

Aggregate gradations. With the exception of the ¾-inch aggregate mix (our control mix), the aggregate distributions for all trial mixes were "reasonably graded," with 1½-inch top-sized aggregate down to ⅜-inch aggregate.

Water-cement ratio (w/c). Reasonably graded aggregate mixes depend more on total water than w/c ratios. It's possible for mixes to have less total water with increased w/c ratios. The mixes in this study had between 28 and 33 gallons of water per cubic yard, with w/c ratios from 0.48 to 0.53.

Onsite QC testing. Testing onsite included air entrainment, slump, and temperature for each mix design. In addition, cylinders were cast every 100 cubic yards for each mix design. Thirty-day test results are shown in Figure 1.

Admixtures

The admixtures used in the study include calcium chloride, nonchloride accelerators (NCAs), polycarboxylate superplasticizers, and midrange water reducers.

Calcium chloride. Five mixes were accelerated with calcium chloride in dosages ranging from 1% to 2%. Curling in these panels will be compared to panels accelerated with NCAs.

Nonchloride accelerators. Four mixes included NCAs. The product used contained calcium nitrate, the most common generic compound used for NCAs, according to Richard Shadle, Midwest regional manager for Sika Corp., Ottawa, Ill.

Polycarboxylate superplasticizer. The polycarboxylate superplasticizer used in all but one mix neither retarded nor accelerated setting times, nor added air entrainment to the concrete. The formulation of superplasticizers makes them active enough to entrain air, and practical applications require defoamers, which work to varying levels of efficiency depending on cementitious material chemistry and mixture proportions. It becomes necessary to test the concrete during production to ensure the system is working. Compared to older naphthalene and melamine products, polycarboxylates extend slump life and can reduce mix water requirements by as much as 10% to 15% for slab-on-ground applications.

Shadle says all superplasticizers work through the electrostatic repulsion of cement particles, more evenly distributing water molecules around them. Polycarboxylates create physical barriers between cement particles. To a limited degree, they produce less shrinkage in concrete, though the amounts of cement, coarse aggregate, and water play a more significant role.

Project Committee

The following individuals designed the field study and are monitoring its results.

- **Jeffery Coleman,** Coleman, Hull & vanVliet
- **Matthew D'Ambrosia,** CTLGroup
- **Allen Face,** The Allen Face Co.
- **Jack Gibbons,** Concrete Reinforcing Steel Institute
- **Pat Harrison,** Structural Services Inc.
- **Jerry Holland,** Structural Services Inc.
- **Howard Kanare,** CTLGroup
- **Kevin MacDonald,** Cemstone
- **Greg Scurto,** Scurto Cement
- **Wayne Walker,** Structural Services Inc.

Using a digital level and bar-coded rod, Chris Harding and Mike Fischer get very accurate readings. The measurements verify the 3-D scans. PHOTO: NASVIK

Midrange water reducers. The midrange water reducer used in two of the mixes included a blend of a polycarboxylate superplasticizer with a lignin-based water reducer dosed at 6 ounces per 100 weight of cement. Shadle says the water reduction of 10% to 12% produces less sticky concrete and a better finish.

Profiling techniques

Per ACI-117, floor slabs must be checked for flatness (F_F) and levelness (F_L) within 72 hours after placement to profile the contractor's ability to place and finish concrete. For this field study, however, the F_F/F_L test also created a set of reference profiles that will be retested at regular intervals. A D-Meter, digital level, and 3-D laser scanner were used the morning after each of the three placements to collect the baseline elevations.

3-D laser scanning. The SEC Group, an HR Green Co., McHenry, Ill., is providing the 3-D laser scanning. SEC's surveying group leader, Mike Fischer, says he uses a Leica Scan Station 2 scanner that reads vertical elevation to within 3 millimeters. When they arrived the first day, they mounted nine control targets on the warehouse walls. They also "shot" targets on the center point of each studied floor panel. He explains the large number of control points provide a strong network for the instrument to locate itself on the grid each time the floor is profiled.

The scans after each placement plotted elevation differences resulting from the placing and finishing process. This became the benchmark for future measurements. Fischer says the group scanned from two locations on the floor one month after it was placed but decided on four scan locations for the six-month evaluation to achieve a higher level of accuracy. He adds that each scan takes about one hour to complete.

With information from the field, Branndon Elsbree, a field technician 2, SEC Group, performs the field and office calculations, then registers or "stitches" all the scans into one coordinate system in the office. He checks overlapping areas for any errors in the data, and then uses Leica Cyclone and AutoCAD software to create a 3-D mesh of the entire floor to show elevations. With this he compares the current floor elevations to the initial ones, resulting in the colored graphic that shows elevation differences. For the sake of this study, scans provide graphic profile information of the entire floor.

Laser digital levels. As a second check, Fischer decided to shoot elevations at each study panel's midpoint with a precise digital level. He uses a Leica NA3003 digital level with a rod marked in bar code, allowing accuracies on the order of 1½ millimeters. They compare the benchmarks for the building with the centers of panels to record elevation changes. In this case, panel center elevations drop as curling develops.

Fischer says using a digital level and 3-D laser scanner together, along with many control points, enables them to check the accuracy of the information.

D-Meter profiling. The D-Meter is a "walking-type" profiler that measures surface elevations on 12-inch centers. According to Allen Face, owner of the Allen Face Co., Wilmington, N.C., at each new "step" down the run line, the instrument's inclinometer measures elevation differences between the front and back feet to within ±0.002 inches. This 12-inch "slope reading" is automatically recorded in the unit's internal memory for subsequent downloading directly into any PC running Windows and Excel.

To start the process, a limited number of floor panels within each concrete mix area were selected as sites for collecting data—the panel being measured (nine panels to each bay) is the center one that is always surrounded by sawcuts, with no corner restricted by a column (pinwheel cuts at the columns) or construction joint. To locate each panel's test runs, chalk lines were snapped along both panel diagonals. The point where the chalk lines intersected—which corresponds to the panel's centroid—then was marked permanently by drilling a small hole. Permanent marks also were placed at each end of both chalk lines at the furthest distance possible in whole feet—the same number of feet in each direction from the panel's centroid. So

Becky Kazmierski with H.H. Holmes Testing Laboratories uses a D-Meter to measure curling in floor panels.
PHOTO: NASVIK

Evaluating Finishes

Concurrently with the main warehouse floor study, Howard Kanare and Matthew D'Ambrosia at the CTLGroup, Skokie, Ill., are studying and evaluating the effects of surface finish on drying rates with a 150-sq.-ft. utility room floor. The concrete mix in this room contained 517 lbs. of cement per cubic yard, a 0.5 water-cement ratio, normal weight aggregates, and no fibers. The study area features six different finishes:

- **Ride-on trowel burnished**
- **Lightly steel-troweled by hand**
- **Lightly broomed**
- **ASTM C309 membrane-forming curing compound**
- **Spray-on silicate**
- **Shotblasted to ICRI CSP-2 guidelines**

Probes are monitoring the internal relative humidity (RH) of the concrete at depths of ½, 1, 2, and 4 in. Preliminary results indicate relative humidity under several surface treatments is still in excess of 95% at the 2-in. depth.

The rule of thumb for installing these floor coverings is one month of drying for each inch of concrete thickness after the building is enclosed and protected from weather. Although the slab was placed under cover, ambient relative humidity in the enclosed room above the slab has been in the range of 75% to 85% over the past several months. The apparent slow drying rate may be partly attributed to the high ambient RH. The study is ongoing and in the next report, data on moisture gradients in the large warehouse will be evaluated along with more detail of the moisture gradients under the various surface treatments.

there are five holes in each bay that is tested with the D-Meter. The end marks become the starting and stopping points for each run. This setup allows the D-Meter to test the same points along each diagonal every time, providing accurate measurement of any curling-induced profile changes in the panel.

Becky Kazmierski, staff geologist for the H.H. Holmes Testing Laboratories, Wheeling, Ill., collected the D-Meter readings onsite, following specific procedures each time. "When the instrument is taken out of the box, it must first be checked for level by zeroing out the meter. It's important to start each session on the same diagonal and travel in the same direction each time the test is performed. The goal is to start on the same point and end on the same point each time. One foot of the instrument also should touch the center point of the panel," she says. When field measurements are complete, she downloads the information to an Excel spreadsheet that Face uses to produce the run profile elevation information.

D-Meter readings, which are more accurate than 3-D laser scans, are presented as numbers on a chart for a portion of a floor. 3-D scans provide the viewer with a less accurate, but instant look of what's happening to an entire floor.

When ideal conditions aren't best

On the one hand, it's fortunate to have an open floor without pallet racks and heavy forklifts rocking panels as they pass. The floor moves and responds only to stresses generated by the concrete. July temperatures in Chicago were the coldest on record and, as of press time, the summer season has remained unusually cool, so the floor is under ideal conditions.

When the floor was cast, concrete temperatures were approximately 50° F. After six months they reached 68° F. The relative humidity in the building has remained a constant 75%—ideal conditions for concrete. When the floor was profiled 30 days after placement, results showed a small amount of curling and a small decrease in elevation at the centers of panels. (Visit www.concreteconstruction.net to view those results.) However, profiling data at six months shows curling at the panel edges to be less than at 30 days for all mixes. Saw joint widths for all mixes revealed only a ⅜-inch increase in 114 feet, half the expected amount. These measurements were approximately the same 30 days after placement as well.

Six-month results

To summarize, we hoped to see significant curling differences due to the concrete mixes, admixtures, and fiber reinforcements, but this hasn't occurred yet. The next profile measurement will be in March 2010. Maybe more drying will be evident by that time. Visit www.concreteconstruction.net to see past articles about this project, photos, additional graphic information, and more. **CC**

www.concreteconstruction.net

To learn more about this topic, visit our Web site and click on the "News & Articles" tab, then click on "Editors' Picks."