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KOMPONENT

1,200-FOOT POST-TENSIONED SLAB WITH TYPE K CEMENT CLEARED FOR TAKE-OFF

19 Years after placement of three demonstration pavements, the post-tensioned design shows best performance

Fig. 1 – The finished 1200 foot slab shortly after pouring, probably the longest unjointed concrete pavement in North America.

Eliminating joints has long been an objective of the Federal Aviation Administration (FAA) that regulates airport runways and taxiways.

When you hear, "This is your captain speaking. Fasten your seat belts, we are expecting a rough ride ahead," you probably think of airborne turbulence. But it could also be deteriorating joints in the runway that are jostling the aircraft. Joints are generally considered requisite to prevent random cracking of the slab, because fresh concrete shrinks and cracks as it dries. But what if joints in pavements were unnecessary?

Eliminating joints has long been an objective of the Federal Aviation Administration (FAA) that regulates airport runways and taxiways. Joints are usually the locus of spalling, which not only causes bumpy rides but also creates a hazardous situation: loose concrete fragments can get sucked into jet engine intakes.

It was the desire to solve the problems caused by joints that led the FAA to construct one of the most unusual concrete slabs in the world at the Rockford, IL airport in 1993. It is a post-tensioned pavement made with fibrous shrinkage compensating concrete using Type K cement. It is 75 feet wide, 1,200 feet long, and has no joints cut into it. When inspected after ten years of hard use, it also had few cracks and virtually no spalling.

GROUND TRAINING

In the 1970's the FAA conducted research on ways to reduce the number of joints in airport pavements. They considered pre-stressed slabs. They also tested the use of Type K cement in shrinkage-compensating concrete.

Type K cement, developed in the 1960s, is a combination of 85% conventional portland cement and 15% expansive hydraulic cement. Concrete made with Type K experiences controlled expansion during the first 7 days of curing, the period when shrinkage-stress most often occurs. If the expansive concrete is internally restrained, (by steel reinforcing bars or reinforcing fibers, for instance) the concrete stretches the steel as it grows. Like a rubber band holding together a deck of cards, this puts compression on the concrete, resisting the stresses that cause cracks.

In the mid-80s the FAA considered a full-scale demonstration project at the Atlantic City, NJ airport. Bruce Raterree, Chief Engineer of Crawford, Murphy & Tilly (CMT), Springfield IL, and his colleague Dr. Ernest Barenberg, Professor of Engineering at the University of Illinois at Champaign-Urbana, proposed two demonstration

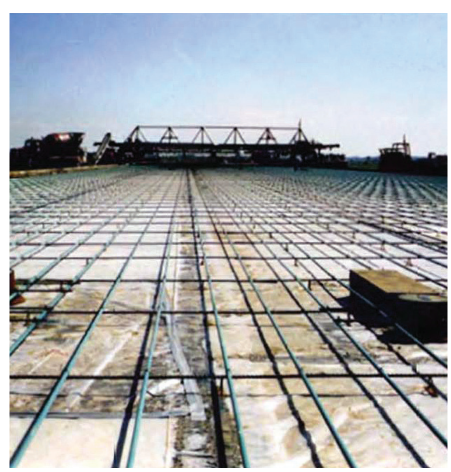

Fig. 2 – 1200-ft-long post-tensioning tendons ready for concrete from the bridge deck paver in the distance

CHRONIC JOINT PAIN

Joints are deemed necessary to concrete slabs because of a fundamental property of conventional portland cement concrete (PCC). In the weeks and months after it is poured, PCC dries and shrinks. If the slab is unrestrained, shrinkage is not a problem because the slab will just get smaller. However, in most situations, friction with the subgrade or interaction with adjacent construction does restrain the slab, creating stresses as the concrete volume contracts. The stress causes cracking.

As a result, standard practice is to cut shrinkage control joints into slabs to encourage the concrete to crack in straight lines at chosen locations. These straight, regularly spaced, predictable cracks are easier to seal and neater in appearance than the random cracking that would otherwise occur. In other words, saw cut joints represent the choice of controlled failure over uncontrolled failure. These joints are a permanent, accepted workaround for a shortcoming in the material.

Joints are also the weak link in many slabs. Drying is not uniform throughout the slab. and exposed surfaces (usually the top and the edges) dry faster, shrink sooner, and cause slab edges to curl upwards. This curling makes joint edges vulnerable to spalling when impacted by traffic. Curling and spalling make the slab uneven, causing bumpy rides on road pavements, hazardous gaps on sidewalks and floors, and unsightly places for debris to collect. Around airports, spalling can also produce debris that can be sucked into a jet engine and cause Foreign Object Damage.

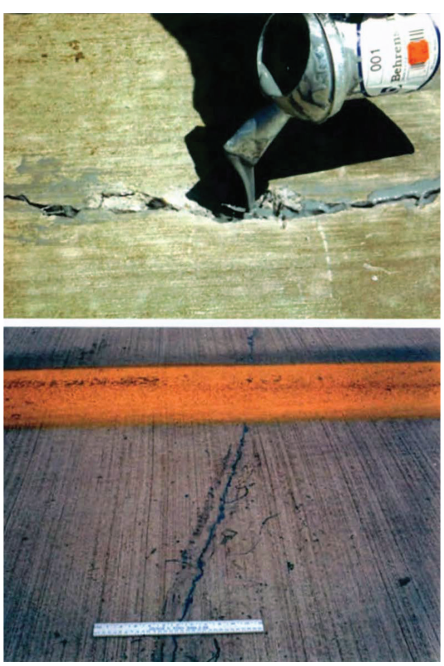

Fig. 3 – The transverse crack in the unjoined slab, repaired with epoxy, has remained closed ever since post-tensioning.

slabs. One was made of shrinkage-compensating concrete with Type K cement and steel fibers. The other used conventional portland cement concrete (PCC) and was post-tensioned in both longitudinal and transverse dimensions to keep it from cracking. The project was fully designed, but funding evaporated before construction.

After their disappointment in Atlantic City, Raterree and Barenberg wondered, over their morning coffee, if the two ideas couldn't be combined into one. Post-tensioned slabs were thought to be limited to the maximum that could be paved in a single day, about 400 feet in length. Trying to combine two days of paving risks shrinkage-cracking from the first day's pour before the post-tension can be applied. Raterree and Barenberg schemed to overcome that limit by using Type K cement's shrinkage compensating properties.

FLIGHT PLAN

Their idea was to construct a long, long slab with no joints at all. Pavements are usually placed in strips about 25 feet wide, with longitudinal joints between the strips. Raterree and Barenberg wanted to use bridge deck paving equipment that could cover the entire width of a taxiway; 75 feet in one pass. According to Stan Herrin, Manager of CMT's Springfield Aviation Group who worked on both the Atlantic City and Rockford projects, the thinking process ran, "We could pave 75 feet wide and use shrinkage-compensating concrete and fibers to provide the transverse pre-stressing that's required. Longitudinally, the Type K cement would allow us to pave for up to a week without having to put the post-tensioning on."

Since the Type K cement keeps expanding for seven days, they figured that was the only time limit before they had to apply post-tensioning. When Rockford Airport's secondary runway was slated for extension, Raterree convinced the FAA to do in Rockford what they had wanted in Atlantic City... and more.

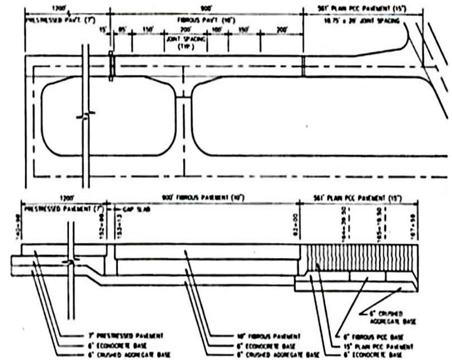

Fig. 5 – Layout of the taxiway, and elevations showing the differing thickness of the pavements.

The Rockford Demonstration Project included three contiguous sections of taxiway paralleling a new runway extension. Each section would be placed in one 75 ft. wide pass using a Rotec bridge deck paver, and each would have identical subgrades.

The "control" section was a conventional pavement 560 ft. long, designed in accordance with FAA Advisory Circular No. 150/5820-6C: concrete with Type I portland cement, 15 inches thick, with 18.75 ft. longitudinal joint spacing and 20 ft. transverse joint spacing. Shrinkage control joints would be saw-cut after placement.

The first innovative pavement slab (IP1) was 900 ft. long, paved with shrinkage compensating concrete made with Type K cement and containing 85 lbs. of steel fibers per cubic yard. The steel fibers added flexural strength, and the engineers calculated they could reduce pavement thickness to ten inches. The objective was to test how far apart the natural cracking of the material would be by increasing the spacing of the joints and seeing if it cracked in between them. Transverse joints would be saw-cut at 85 ft., 100 ft., 150 ft. and 200 ft. There were no longitudinal joints.

Fig. 4 – The bridge deck paver, an 80-foot truss with conveyor belts, and a truck feeding it concrete.

The second innovative pavement slab (IP2) was 1,200 ft. long and used the same fibrous concrete with Type K cement but was post-tensioned longitudinally. This combination of technologies had never been done before on a pavement. The research objective was to build the slab without saw-cut shrinkage control joints; pre-stressing would compress the concrete to prevent shrinkage cracking. Longitudinal pre-stressing came from 1,200 ft. long post-tensioning tendons placed twelve inches apart. There was no transverse post-tensioning because the designers relied on the interaction of the steel fibers and shrinkage compensating concrete to provide pre-stressing across the slab. A double layer of polyethylene film was laid over the base course to act as a slip-sheet to reduce subgrade drag. Barenberg calculated the increase in flexural strength added by post-tensioning, and suggested a pavement thickness of just seven inches.

TAKE OFF

The concrete was placed in 1993 at the height of summer, with afternoon ambient temperatures reaching 90°F, the upper limit recommended by the Type K cement's producer. A "Constructability Report': written for the FAA and U.S. Army Corps of Engineers, recorded that "The use of Type K cement did not create any handling, storing or delivery problems" and it handled similarly to concrete with Type 1 portland cement. They did note that, at temperatures around the recommended limit, it became sticky and harder to finish.

The first day's paving was cut short by rain. The contractor was prepared for this, quickly installed an overnight header at the end of the pavement, and laid burlap on the fresh pour to protect it from rain. This intervention of nature eventually provided a piece of key data about the project.

The remainder of the 1,200 feet of concrete was completed on the second day; a curing compound was applied but it was not covered with burlap. The following morning, a 7 /8 inches wide transverse crack was found in the middle of the second day's pour. As the day heated up, the crack began to close. When it was 1/8 inch wide, it was sealed with 5 gallons of epoxy and the stressing of the post-tensioning tendons was begun, effectively clamping the crack shut.

It is believed that the crack was caused by a severe temperature drop in the concrete. Thermal monitoring devices, installed in the concrete as part of the demonstration project, recorded internal temperatures as high as 135°F shortly after the concrete was placed. The next morning, however, the internal temperature was 90°F, a 45° drop.

The first day's pour never suffered such an extreme drop. Its internal temperature never topped 100°F because its protective burlap, wet from rain, cooled the concrete.

Post tensioning was applied it two phases. An initial load of 30 kips was applied when the concrete had reached 2000 psi compressive strength, the morning after placement was completed. The final stressing to 46.9 kips was applied when the concrete reached 3500 psi, one day later. The tensioning was done in a special sequence, innermost tendons first, outermost next, and then the intervening ones, to avoid torquing the slab.

THE JOURNEY

The pavement was inspected quarterly for five years. During the first year, small longitudinal cracks were observed in both IP1 and IP2 slabs, between 10 ft. and 22 ft. on either side of the centerline. These cracks were short and very tight. Stan Herrin believes that these cracks might have been avoided. "Applying post tensioning in the transverse dimension might have helped eliminate longitudinal cracks, but we might have been able to do it with more fibers, too."

The IP1 slab also developed transverse cracks in the first year, some of which have gone the full width of the pavement. The overall crack pattern suggests that the natural crack-spacing for this type of concrete is about 40 ft., roughly double that of control section.

Shortly after the taxiway was completed, United Parcel Service (UPS) selected Rockford Airport as the site for major sorting facility adjoining the taxiway. By the pavement's third year, UPS operations had increased aircraft traffic to more than double what the taxiway had been designed for.

In 2003, ten years after the taxiway was completed, an inspection team surveyed the pavements and evaluated them using the Pavement Condition Index (PCI). PCI, developed by the US Army Corps of Engineers and adopted by the FAA, provides a numerical value between 0 and 100 defines the condition of a pavement, 100 representing an excellent pavement. The control section of the pavement had spalling on almost all its transverse joints. It was rated in Good condition, with a Pavement Condition Index (PCI) of 67.

The non post-tensioned slab (IP1) was rated Very Good. While there's no standard procedure for a PCI of long jointed fibrous pavement, it was estimated at a PCI of 82. Transverse cracks show some spalling, probably from snowplow damage. There are longitudinal cracks in approximately 40% of the slab, but they are straight, tight and show little spalling. The post-tensioned slab (IP2) was rated in excellent condition. Again, there is no standard procedure for a PCI of this kind of pavement, but it was estimated at over 98, a nearly perfect score.

The inspection team included Ed Rubin, one of the engineers who originally developed Type K cement and now a consultant to CTS Cement Manufacturing Co. (CTS), producers of Type K cement. He was awed by the condition of the

Fig. 6 – Bull-Floating Concrete.

Fig. 7 – Steel fibers 2.5 in. long created tensile forces to hold the slab in compression as Type K cement expanded.

Fig. 8 – After 10 years of use, the airport administration reports that the post-tensioned slab has needed only minimal maintenance.

post-tensioned slab. “After a decade, it is still nearly pristine,” he marvels.

Franz Olson, Deputy Director of Operations & Facilities of Chicago-Rockford International Airport, is also pleased with the joint-less taxiway. “The pavement has held up extremely well. The cracking has been very, very minimal. There were some initial concerns with the fibers breaking lose, but that has not occurred. It has not caused any Foreign Object Damage (FOD) concern.

In fact, the 10-year inspection team found fewer than six visible fibers per thousand square feet of pavement. “Something else very interesting,” continues Olson, “is the question of hot weather buckling. That was a concern, but we haven’t experienced any problems. I believe the post-tensioning tendons keep that from occurring.” The transverse crack that appeared the day after paving has remained closed. “They went out and measured the deflection,” says Stan Herrin, “and the crack was performing as well as the pavement ten feet away.”

Other transverse cracks have appeared, but they are hairline cracks and not the full width of the pavement. A report by the American Society of Civil Engineers described them as, “difficult to find at normal walking speeds.” Only one new transverse crack appeared between the end of 5-year monitoring and the 10-year survey. The longitudinal cracks are tight, typically 2-16 ft. long, and show little spalling.

BLUE SKIES

Based on this performance, Stan Herrin believes the technology could be used for even longer slabs. How long? “Miles! Seven days of paving,” he exclaims. “The only limiting factors might be thermal expansion or wherever you have an approach to a bridge.” While no one is seriously suggesting scaling a quarter-mile long demonstration to such great lengths - at least not yet - his enthusiasm is understandable. Given the excellent condition of the post-tensioned fibrous Type K pavement, the surprise is that engineers and public agencies haven’t used this technology more often. Herrin thinks part of the explanation is the perception of costs. “There’s the belief that initial cost will be higher.”

In fact, this perception may be false. Kyle de Bruyn, a product engineer with CTS, did a cost analysis of the Rockford pavements. Using 2003 prices* for excavation, concrete, post-tensioning, etc. he came up with figures surprisingly at odds with what the FAA paid in 1993. He surmises that, in the intervening decade, post-tensioning has become a more widely-accepted technology, lowering the price. Eliminating premiums that may have been paid because the technologies were novel in 1993, De Bruyn’s analysis, suggests that the post-tensioned pavement would actually cost about $4.00 less per sq. ft., than the other two pavements, roughly an 8% discount. Factoring in the cost of joint maintenance makes the life-cycle costs of post-tensioned pavement even more attractive.

Rockford’s Franz Olson would like to see more jointless pavements. “I think it would be a good technology to pursue further. With airports, you have to pay specific attention to making sure your expansion joints are properly maintained and filled and if they’re not you’re going to suffer damage sooner or later. By using the continuous pour, you get a lot less chance of fatigue at any of those joints, and you’re eliminating all that additional maintenance.”

Ed Rubin thinks the only obstacle is the usual reluctance to try something unfamiliar. He opines, “Someone’s got to have the guts.” But after 10-years documented performance, a decision to specify post-tensioned and shrinkage-compensating concrete is not as daunting as it once was.

Written by: Michael Chusid, RA FCSI

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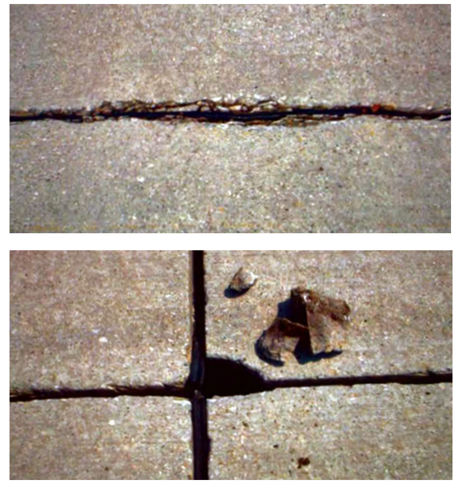

Fig. 9 – Joints in the non-post-tensioned pavement show the spalling typical of 10 years of heavy aircraft traffic and snowplow damage.

Fig. 10 – The fibrous slab also suffered spalling at its sawcut joints..

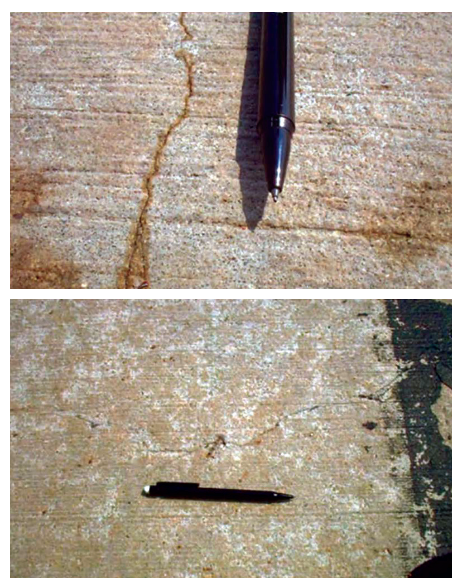

Fig. 11 – The post-tensioned pavement has cracks, but they are tight and less vulnerable to impacts that cause spalls.

* Per the online estimator, Get-A-Quote.net.