R&T UPDATE
Concrete Pavement Research & Technology

CAUSE, PREVENTION, AND REPAIR OF LONGITUDINAL SHEAR CRACKING

An unusual form of early cracking has occurred on a couple of projects across the country. No previous information exists documenting this type of distress, nor its possible causes. From the few projects that we have information on, we noticed one peculiar similarity; the shape of each crack resembles a smile.

We recently had the opportunity to visit and study in detail a project that experienced this cracking phenomenon. The pavement in question was a curved section of ramp ("flyover"-type design) from one interstate highway to another. In this case, we were provided the following design and construction information:

- Existing ramp pavement was one lane of CRCP, which was retained
- Adjacent new 12-ft lane utilized a thickened longitudinal edge of 21 in. along the existing CRCP ramp pavement, tapering over 3 ft to the design thickness of 14 in.
- Doweled transverse joints spaced every 15 ft
- Base course under the new lane was 6 in. of cement-stabilized recycled concrete, topped with 1 in. of asphalt bond-breaker layer (3/8-in. max. agg. size)
- New concrete shoulder is 9 in. thick, 10 ft wide
- Base course under concrete shoulder is compacted aggregate base
- The 12-ft lane was paved first, on 2 September 2003
- The 10-ft shoulder was paved several months later, on 31 January 2004
- Dowel alignment was checked via pavement excavation and found to be within tolerances
- Cores taken through the transverse joints showed that the affected joints are working (cracked)
- Cores taken through affected transverse joints at about 1.5 ft from the longitudinal shoulder joint appeared normal
- Cores taken through affected transverse joints at 1-2 in. from the longitudinal shoulder joint showed mortar and/or saw slurry in initial saw-cut

The distress information was as follows:

- The cracking occurred primarily on the superelevated horizontal curve portion of the ramp
- Cracks occurred only in the 12-ft lane, not in the 10-ft shoulder
- Cracks occurred at approximately every 4th joint (on average)
- Cracks were slightly curved in nature; that is, when looking at a crack from the edge of the shoulder, the crack curves toward the center of the slab from the transverse joint or slab corner (see figures next page)

Typical Crack Pattern

At the time of the initial survey on (June 2004), there were approximately 15 joints with cracks radiating from each side of the joint toward the centers of the adjacent slabs as shown in Figures 1 and 2.

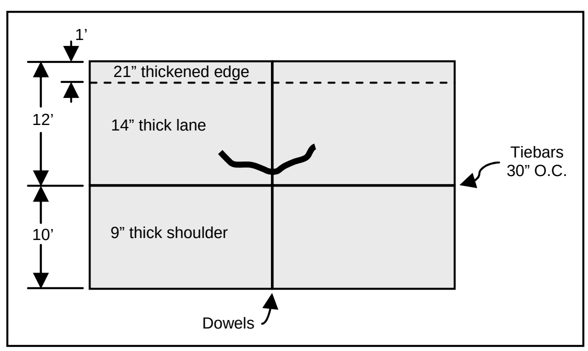

Figure 1. Typical crack pattern.

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Figure 2. Photo of actual crack pattern from subject project. (NOTE: photo taken looking from driving lane toward shoulder).

Approx. Stations of Joints with Cracks

Numbering all of the transverse joints starting with the first joint located approximately at ramp station 110+00, Table 1 lists the stations of the joints with cracks.

Table 1. Stations of joints with cracks

Station of Joint	Joint Number
110+00	1
110+45	4
111+20	9
111+65	12
112+55	18
113+90	27
114+65	32
115+25	36
115+85	40
116+15	42
116+60	45
116+90	47
117+35	50
118+10	55
118+70	59

Based on the plan sheets provided to us, the center of the curve in the ramp was located at station 116+42.55. Note the clustering of cracked joints in that area (this is explained in #4 below).

Factors Involved in Causing the Cracking

The cracking type as shown in Figure 2 is a longitudinal shear cracking pattern. It is caused by restraint at the transverse joints – the open transverse joints are not allowed to close as the concrete expands during warm weather, and the cracks start at the transverse joint and curve toward the center of the slab.

The exact location where the cracks occur depends on where the highest stress concentration may occur. This may be over the first dowel bar, or at some other location near the corner. On the subject project visited for this report, the cracks occurred at various distances away from the corner of the slab. This distance was somewhat proportional to the superelevation of the ramp pavement. Cores taken at the affected transverse joints showed mortar intrusion into the joints in the first placement from the adjacent shoulder placement. The mortar flowed further into the joint when superelevation was greatest.

The following list explains all of the possible causal factors leading to the longitudinal shear cracking:

1. The different ambient temperatures during the placement of the two adjacent pavement sections likely resulted in different equilibrium temperatures for the in-place concrete. This means that the concrete placed and cured at a lower temperature (the 10-ft shoulder in this case) will expand more when temperatures rise than the other concrete (the 12-ft lane), which was cured at a higher temperature initially. The mean monthly temperature in this area for September 2003 was 72°F and 42°F for January 2004.

2. The thickened longitudinal edge (lug), in combination with the high-friction base under the 12-ft lane, restrained the pavement and resulted in every 4th joint working, instead of every joint (i.e., not every joint “popped” right away). This is common on almost every concrete pavement, but can be aggravated by high-strength (high-friction) bases and thicker

pavements that utilize a much "shorter" joint spacing than calculated by formula. In this case, the effective thickness over the 12-ft lane is even greater than the nominal 14 in. once the 21-in.-thick lug is factored in.

3. The granular base under the shoulder provides much less friction and allows more slab movement, therefore more working joints in the shoulder pavement.

4. The horizontal curve may be adding to the stress build-up because the lug and high-friction base combination likely prevents outward movement of the entire roadway during thermal expansion. The restraint would be most pronounced at the center of the curve (where most of the cracks have occurred), because the tangent roadways from either end of the curve are expanding and trying to push the curved pavement outward.

5. The tiebars along the lane/shoulder joint also may be locking the corners of the slab, preventing the opened joints in the 12-ft lane from effectively closing.

6. Mortar intrusion into the transverse joints from the separate shoulder placement operation influenced the location of where the crack occurred, if not being a direct causal factor.

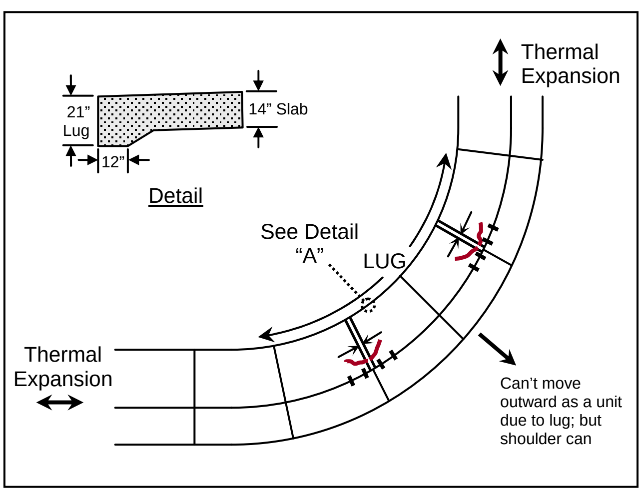

Figure 3. Schematic of factors leading to cracking.

Recommendations

The type of cracking experienced on this (and other) project(s) was unusual and could not have been predicted. The review of the project conditions and consideration of the potential causes leads to a few key points to consider for future projects.

1. Use caution when a longitudinal thickened edge ("lug") is specified. Determine whether it is an essential part of the design or could be eliminated through tapering the thickness (1 to 2 inches for example) across the entire slab, or by simply providing a tied connection to the existing pavement.

2. When constructing pavements on high-friction bases such as cement-treated, asphalt-treated, or econocrete, be aware that not every joint will crack ("pop") right away. This might result in wide joint widths for those joints that do pop. These wide joints will eventually close, however, when the temperature increases in the summer. You can ensure cracks form at joints on a closer interval by reducing the friction at the slab/base interface with a coat of curing compound, or by broadcasting a thin layer of fine sand across the base.

3. Adjacent pavements on different base types will have different movement capabilities and capacities with the same change in temperature. As much as possible, try to use bases with similar characteristics under adjacent slabs. NOTE: Concrete pavement thickness design is not very sensitive to base type, so the cost savings in specifying lower quality base types under non-trafficked areas like shoulders is not cost effective when you factor in the expense of constructing two different base types adjacent to each other.

4. Thermal expansion effects are most pronounced on curves, where the roadway is pushed outward from both tangent ends. This occurrence has also been identified on lower-volume residential streets through anecdotal evidence of driveways being pushed into building foundations by curved or cul-de-sac roadways.

5. When construction staging or equipment limitations require adjacent pavements to be

placed at different times, try to pave the adjacent sections in similar conditions and as close together in time as possible, or take steps to account for differences. For example, place a strip of duct tape vertically on the side of the slab at each sawcut so that it also covers the crack that forms below the sawcut. This will prevent mortar or saw slurry intrusion into the wide sawcuts and joints.

6. Eliminate one or two tiebars in the longitudinal joint near the locations of transverse joints to reduce the potential for locking the corners of the slab. Many longitudinal joint designs are already over-reinforced with tiebars anyway – the assumptions and theories behind tiebar design/spacing are suspect and plans are underway by ACPA to determine new tiebar design methods.

Repair

In most cases, full-depth repairs (full-lane wide) to a point at least six inches beyond the extent of the cracking are appropriate to repair the affected areas. The entire slab on either side of the joint need not be replaced, since the expansion has already taken place and the full-depth repair will allow for two joints instead of one to accommodate for future movement.

Make sure to utilize full-depth sawcuts around the entire perimeter of the area to be repaired, and drill and grout dowel bars into the adjacent slabs (see Figure 4). Do not use tiebars along the longitudinal joint. For more information on full-depth repairs, consult ACPA publication TB002P, "Guidelines for Full-Depth Repair."

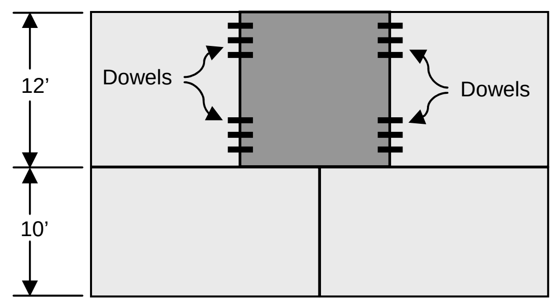

Figure 3. Full-depth repair details.

Summary

As with any uncontrolled cracking occurrence, there is usually not one single cause. It is a combination of factors which leads to the development of the unwanted cracks. In the same vein, there is usually not one single fix that will prevent the problem from recurring. It often requires minor adjustments to many aspects of the pavement design and/or construction details which, in combination, will dramatically reduce the potential for cracking.

In this particular case, the combination of the different placements, longitudinal thickened edge, high-friction base, unbound aggregate base under the shoulder, horizontal curved ramp segment, tiebar design, and mortar intrusion were all contributing factors to the cracking experienced on the project. Preventing the cracking on future projects of a similar nature includes addressing as many of the contributing factors as possible. Repairing the cracks can be accomplished through the use of full-depth repairs extending beyond the cracked areas by at least six inches.

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