

A CASE STUDY

EARLY CRACKING OF UNREINFORCED CONCRETE PAVEMENT

by

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INTRODUCTION

At the request of F. L. Burroughs, Construction Engineer, the Materials Division and the Research Council investigated the reasons for early cracking of two sections of unreinforced concrete pavement on ramps at the Route 168 -- I-64 interchange west of Williamsburg in James City County.

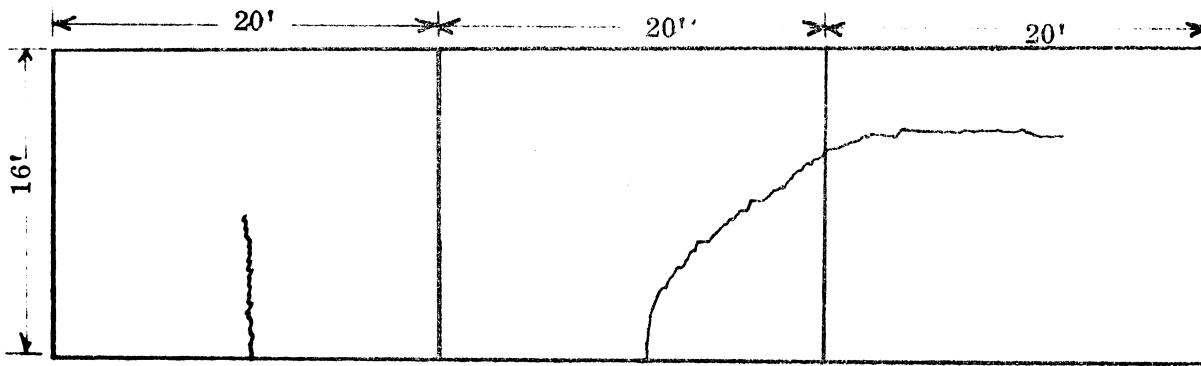
The pavement was constructed in November 1972 and opened to traffic on December 20, 1972. Shortly after it was opened, severe cracking became obvious on two of the ramps. While no one is certain when the cracking first occurred, it was noticed on one of the ramps on December 18, 1972, two days before opening.

Of the two cracked ramps on the interchange one (Ramp A) exhibits both longitudinal and transverse cracking, as indicated in Figure 1. The other (Ramp B) has longitudinal cracks wandering from approximately the centerline to approximately the one-third points of the pavement width. (Except for widening at curb sections all ramps on the interchange are 16 feet wide.)

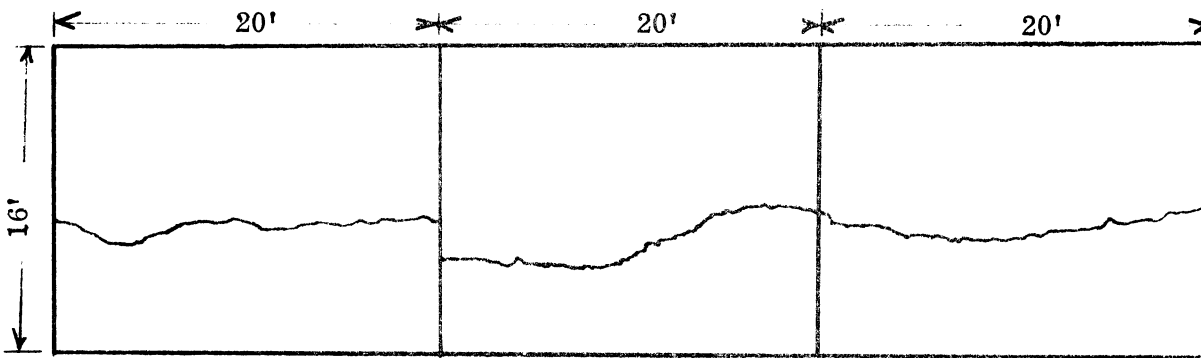
The pavement is 8-inches thick, is unreinforced with contraction joints at 20 feet intervals, and overlies a 6-inch cement treated subbase of local sand and gravel material with a significant clay content. The shoulders were constructed of the same sand and gravel material, which in some cases was treated with lime to reduce the moisture content to a workable level.

PRELIMINARY INVESTIGATION

Because of the imperviousness of the shoulder material on the project, little or no lateral drainage is possible. For this reason water has accumulated under the cracked slabs and is ejected by wheel loads and by the



a) Cracking typical of Ramp A



b) Cracking typical of Ramp B

Figure 1. Typical cracking of Ramps A and B at Routes 168 and I-64 interchange.

accumulation of water beyond the capacity of the pavement-subbase interface. While shoulder discoloration gives the impression of a serious pumping condition, cores removed from the pavement and subbase showed that there is no significant void under the pavement. Free water is present at the pavement-subbase interface, but examination of cores from the subbase and subgrade showed that there has been no structural damage to the underlying layer, and that the subgrade is not saturated, and that the cement treated subbase is in excellent condition. A core removed from the subbase in one of the worst cracked and discolored areas on Ramp B had a compressive strength of 460 psi at an age of 9 months. Cores taken at the same time from the concrete pavement had compressive strengths of some 4,000 psi, well in excess of the 3,000 psi design strength. It was concluded from these studies that the cracking was not related to a weakness in the supporting layers or in the pavement itself.

Further study of the pavement cores showed that the top portion of the crack (down to about 2-inches) had occurred very early in the life of the pavement, while approximately the bottom 6-inches had not cracked until the concrete had achieved a significant level of its design tensile strength.

CAUSES OF CRACKING

Shrinkage

In a further effort to determine the cause of cracking, project records were reviewed to determine mix and weather characteristics for the two cracked ramps and for several uncracked sections of pavement in the same interchange.

The pertinent data are summarized in Table 1. Note that all cracking is confined to two paving days — November 9, 1972 and November 29, 1972 — when 49 and 40 percent, respectively, of the slabs showed cracking. Several other factors possibly related to early cracking stand out in the data for the two days on which cracking occurred. They are the low relative humidity and the high wind velocity on November 9, 1972; and the low air temperature, low relative humidity, and moderately high wind on November 29, 1972. PCA information on the prevention of early shrinkage cracks suggests that such relative humidities and wind velocities can result in adverse conditions for concrete paving. ⁽¹⁾ Tensile stresses in excess of the concrete's tensile

(1) Design and Control of Concrete Mixtures, Portland Cement Association, July 1968.

strength can be developed when the rate of evaporation exceeds the rate at which bleed water rises to the surface of the concrete. Evaporation rates for the two cracked sections and for the uncracked sections have been computed and are presented in Table II.

TABLE I
MIXTURE AND WEATHER CHARACTERISTICS

Ramp	Paving Date	Averages for Day				No. Slabs	Percentage Slabs Cracked
		Mix. Temp. (°F)	Air Temp. (°F)	Rel. Hum. (%)	Wind Vel. (mph)		
A	11-7-72	73	58	69	5	27	0
A	11-9-72	68	59	49	15	65	49
A	11-10-72	64	50	63	4	50	0
B	11-28-72	66	55	52	11	72	0
B	11-29-72	62	42	43	8	55	40
D	11-13-72	61	48	76	6	53	0
D	11-15-72	59	47	49	14	54	0
D	11-20-72	59	47	84	7	50	0

TABLE II
EVAPORATION RATES AND WARPING STRESSES

Site	Paving Date	Avg. Evap. Rate (lb./sq. ft./hr.)	Avg. Mix Temp. (°F)	Avg. Curing* Temp. (°F)	T** (°F)	Warping Stress (psi)
Ramp A	11-9-72	0.18	68	48	-20	75
Ramp B	11-29-72	0.11	62	36	-26	98
Uncracked	various	0.09	63	50	-13	50

*Average air temperature for 24 hours following end of paving operation.

**Difference between average mixture temperature and average curing temperature.

The PCA guidelines indicate a danger of shrinkage cracking when the evaporation rate exceeds 0.10 lb./sq. ft./hr. and that a moist curing system such as wet burlap is necessary if cracking is to be avoided at rates as high as 0.2 to 0.3 lb./sq. ft./hr. It is considered likely that the high evaporation

rate played a strong role in the cracking of the Ramp A concrete placed at an average evaporation rate of 0.18 lb./sq. ft./hr. The evaporation rate of 0.11 lb./sq. ft./hr. probably played some part in the cracking of the Ramp B pavement, but the nature of the cracking (longitudinal only) suggests that other factors also were present.

Warping Stresses

The nature of the cracking as observed from cores discussed earlier suggests that warping stresses, which are usually too low to cause a problem, may have been significant in the present case. This is particularly true in the case of Ramp B, which cured for the first 24 hrs. at an average ambient temperature of 36°F and consequently could have gained but little strength during this period. Note in Figure 2 in the first few days concrete cured at 40°F gains only a fraction of the strength gained by concrete cured at 73°F or even 55°F.

Tensile warping stresses develop at the top of a slab when the top is colder than the bottom so that the top is trying to shrink but is restrained by the warmer concrete below. Simultaneously, the edges are attempting to curl upward while the weight of the slab works to restrain this curling. When the warping stresses exceed the tensile strength of the concrete cracks will form. If such cracks form early in the life of the concrete the cracking will have the characteristics discussed earlier, i. e. the cracks wander around rather than through coarse aggregate particles. Under normal circumstances 20 ft. x 16 ft. slabs such as used on the present project would have warping stresses maximum in the 20 ft. direction. However, in the present case it is reasonable to assume that the cracking occurred at such an early age that the transverse contraction joints had no opportunity to open so that aggregate interlock was 100% effective, and for warping purposes the pavement was functioning as a continuous ribbon of unreinforced concrete. If such an assumption is made, the warping stresses tending to cause longitudinal cracking become maximum.

Warping stresses computed for both the cracked and uncracked sections are summarized in Table II above. The stresses were computed from equations given by Yoder⁽²⁾ and with the following assumption:

1. Subgrade modulus = 500 psi.
2. Concrete modulus = 1,000,00 psi.
3. Top of slab temperature = avg. air temperature.
4. Bottom of slab temperature = avg. mixture temperature.

(2) Yoder, E. J., Principles of Pavement Design, John Wiley & Sons, 1959.

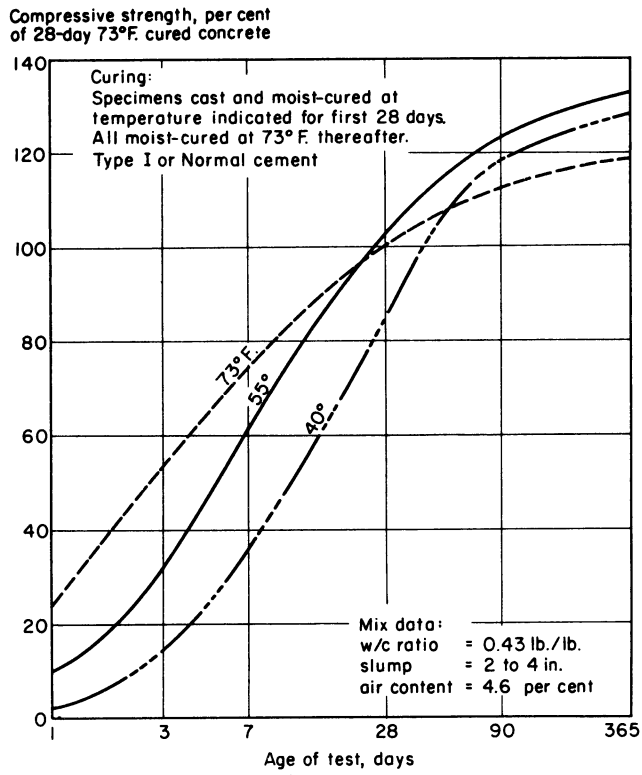


Figure 2. Effect of low temperatures on concrete compressive strength at various ages.

Note in Table II that the warping stresses for the cracked portion of Ramp B are nearly twice those for the uncracked sections of pavement. While the computed tensile stresses of from 50 to 98 psi would cause no problem with mature concrete, it is entirely possible that they would exceed the tensile strengths of the present concrete, which obviously gained strength very slowly due to the low curing temperatures.

Conclusion

In summary, it appears likely that the two badly cracked ramps were cracked because of the adverse weather conditions at the time the concrete was placed. The cracking mechanism seems to have been a combination of both high drying shrinkage stresses and high warping stresses relative to the strength of the concrete. Once this early cracking at the top of the slabs had occurred, the effective concrete thickness was so reduced that normal hydrothermal slab movements resulted in cracking the rest of the way through. Thus, the appearance of later cracking at the bottom is explained.

Several suggestions which might help prevent the recurrence of such cracking on cold weather paving are as follows:

1. Avoid paving on days when atmospheric conditions indicate a combination of low relative humidity and high wind velocity.
2. Paving should be avoided on cold days when it is likely that a substantial overnight drop in air temperatures will occur.
3. If the above conditions develop during the paving operation, extra precautions in terms of early application of curing compounds and possibly insulation of the pavement may be necessary.

SUGGESTED CORRECTIVE ACTION

The study of cores from both the concrete and subbase, along with an examination of the in-place subgrade and subbase, suggest that there has been no structural damage to the pavement except for the cracking. The situation has been aggravated by the poor lateral drainage, which is being corrected by the excavation of shoulder material and backfilling with an open-graded aggregate. Since this action will probably stabilize the condition of the pavement, no further corrective action other than sealing of the longitudinal cracks is recommended at this time.

