Control of Slab Curling in Rigid Pavements at the FAA National Airport Pavement Test Facility

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Abstract

The FAA National Airport Pavement Test Facility (NAPTF) is an accelerated test facility which subjects airport pavements to aircraft traffic loading under an indoor environment. During construction cycle one (CC-1) trafficking the rigid pavements developed top down corner cracking at the 28^{th} loading pass. The curling phenomenon at the NAPTF was studied to avoid premature corner cracking of slabs in future testing. A single concrete slab with high flyash content, to reduce the flexural strength of the concrete, was placed on a rigid support. Upward curling at the single slab corners reached 200 mils (5 mm) during a 113 day drying period following wet curing. Corner curling was reduced to 75 mils (2 mm) after rewetting for 59 days. Curling above 20 mils (0.5 mm) can become critical for top down corner cracking under traffic loading. It was evident that if curling were to be controlled the concrete surface would have to be kept continually wet and periodically monitored. This procedure was successfully used in construction cycle two (CC-2), rigid pavement over different support conditions, and construction cycle 4 (CC-4), rigid overlays on rigid pavements. Two additional isolated slabs with no flyash content were placed inside and outside the NAPTF for further investigation of the curling phenomenon. The inside slab performed in a manner similar to the inside slab with high flyash content. The outside slab never developed significant permanent curl due to the mitigating effect of natural rainfall conditions.

INTRODUCTION

The Federal Aviation Administration's (FAA) National Airport Pavement Test Facility (NAPTF) is located at the FAA William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The primary objective of the NAPTF is to generate full-scale pavement response and performance data for development and verification of airport pavement design criteria. It is a joint venture of the FAA and the Boeing Company and became operational on April 12, 1999. The test facility consists of a 900 ft (274.3 m) long by 60 ft (18.3 m) wide test pavement area, embedded pavement instrumentation and a dynamic data acquisition system (20 samples per second), environmental instrumentation and a static data acquisition system (4 samples per hour), and a test vehicle for loading the test pavement with up to twelve aircraft tires at wheel loads of up to 75,000 lbs (334 kN).

A construction cycle at the NAPTF includes test pavement construction with embedded instrumentation, traffic tests to failure, posttraffic testing (includes trenching activities and other tests), and ultimately pavement removal. Construction cycle one (CC-1) included three Portland cement concrete (PCC) test pavements placed on stabilized base, one above low strength subgrade, one above medium strength subgrade, and one above high strength subgrade. The pavements were traffic tested. Top down corner cracking was noted in the slabs of the pavements as early as the 28^{th} loading pass. Upward curl had caused a separation of the slab corners with the pavement layer below resulting in a loss of support. It was of interest to build test pavements capable of enduring 20,000 passes prior to significant failure. Longitudinal and transverse cracking within the slabs would be the normal failure mechanisms typically experienced in rigid airport pavements and incorporated in theoretical predictive models, not the premature corner cracking observed in CC-1.

SINGLE SLAB EXPERIMENT

It was decided to place a single concrete slab in order to study the curling phenomenon within the indoor environment of the NAPTF. The slab would be instrumented to characterize curling, and the data obtained used to identify a method of minimizing it. Additional objectives were to determine the adequacy of the instrumentation system, gather experience in placing concrete around the instruments, and to determine the effectiveness of the monitoring system. The entire effort would serve as the precursor in preparation for the design, placement, and monitoring of the actual CC-2 concrete test items.

The single slab was placed on June 2, 2003. The slab was approximately the same size as those to be used in the test items, 15 ft. by 15 ft. (4.6 m by 4.6 m) by 11 inches (28 cm) thick. The cementitious mix contained 60% class "C" flyash. Ultimately the slabs in the CC-2 test items were 12 inches (30.5 cm) thick and had 50% flyash in the cementitious mix. These values were selected in the final design of the test items in order to provide a thicker curl resistant slab and yet hold the traffic test passes-to-failure down to a target of about 20,000.

The experimental single slab was placed on an existing 20 ft. by 20 ft. (6 m by 6 m) by 9 ¾ inches (25 cm) thick concrete slab which had been previously placed on a stabilized base above the high strength subgrade as part of the original CC-1. Strips of construction paper were placed on the surface of the existing slab to act as a bond breaker between the new single slab and the existing slab. Instrumentation was installed prior to the placement of the single slab. Instruments of particular interest relative to the subject of this paper are Vertical Displacement Transducers (VDT) at slab corners, and center of slab edge), Thermistor Tree (TT) at slab center, other instruments included Horizontal Displacement Transducers (HDT) at center of two slab sides, Vertical Clip Gages (VCG) at slab corners, Concrete Strain Gages (CSG) at the interior, and surface on one slab side), Relative Humidity Sensors (RHS) at the slab center and one edge.

The slab was wet cured for 28 days using burlap strips, timed soaker hoses, and plastic sheet coverings. All coverings were then removed, and the slab was allowed to dry for 113 days. After this period, the burlap strips, soaker hoses, and plastic coverings were reapplied. The slab was kept continually wet for the next 59 days, after which the data retrieval was discontinued. These alternate wet and dry periods allowed for the acquisition of data relative to characterization of the curling.

The sides of the slab were coated with a sealer after the initial 28 day wet curing period. This action provided a simulation of the condition whereby the slab would be drying while being embedded among other slabs as it would have been in an actual test item. Otherwise, the slab was totally free to curl. There were no constraints at the boundaries, thus offering the ideal condition for the curling study. In contrast, the slabs in the CC-2 test items were connected at the edges with the adjacent slabs using steel dowels. Greater structural integrity was achieved in the test items as it would be in many field applications.

Figure 1, derived from [1], shows the curling history of the single slab from the time of concrete placement to the completion of the data acquisition. The upward movement of the slab corners was evident as the vertical transducers sensed the separation of the bottom of the slab from the top of the base. The separation at the corners was considered to be the manifestation of the curling of the slab, acknowledging the fact that there was some movement in the base.

Curling during the 28 day wet curing period was minimal. Less than a 5 mil (0.13 mm) average was recorded. Significant upward curling was observed, however, during the 113 day drying period. The average separation of the corners from the base eventually exceeded 200 mils (5 mm) toward the end of the period. Differential moisture loss through the thickness of a concrete slab has long been recognized as the major factor in contributing to curling. The top of the slab dries and contracts more than the bottom. Note the sharp increases in curl during the July and latter August time periods. High atmospheric temperatures contributed to evaporation of the moisture in the slab. The NAPTF is enclosed but not climate controlled. Relative to the July time period, high curl rate is also expected immediately following the end of wet curing.

The slab did undergo significant recovery during the 59 day rewetting period starting in latter October, with stability being reached in about 25 days. An average residual curl of about 75 mils (2 mm), however, did remain. Reducing curl in concrete slabs by rewetting was previously demonstrated at the NAPTF in November of 2001 [2]. The effort was part a study of non-traffic load effects on pavement responses conducted on the test items of CC-1.

Experience has shown that a separation of 20 mils (0.5 mm) between the corners of a concrete slab and the base can be critical relative to causing premature top down corner cracking under heavy traffic loading. The most significant finding of the single slab experiment was that, if upward curling of slabs in test items were to be held below the critical value, the concrete surfaces would have to be kept continually wet. There cannot be an extended drying period following the wet cure because not all of the curling can be recovered. Wetting procedures for CC-2 test items follow.

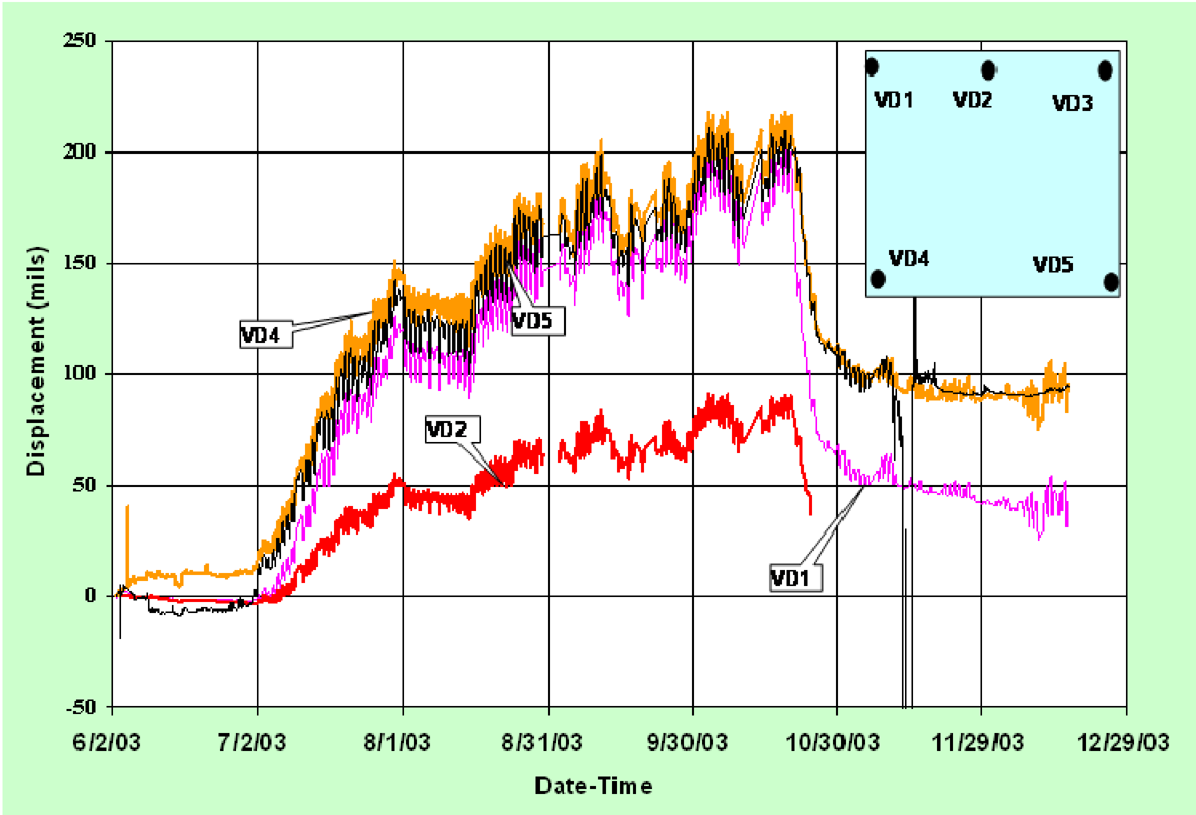

FIGURE 1 Vertical Displacement at the Corners and One Edge, CC-2 Single Slab Experiment.

CONTROL OF CURLING IN CC-2 TEST ITEMS

The CC-2 test items consisted of concrete slabs 15 ft. by 15 ft. (4.6 m by 4.6 m) by 12 inches (30 cm) thick. The cementitious mix contained 50 % class C flyash as previously noted. Each of the three test items was 60 ft. (18 m) wide and 75 ft. (23 m) long. The width accommodated four slabs and the length five slabs. There were transitions 25 ft. (7.6 m) in length between the test items. One test item was placed on conventional granular base (MRC), the second on grade (MRG), and the third on stabilized base (MRS). All were constructed above medium strength clay subgrade of CBR 7.

Each test item was placed on two different days about two weeks apart. The slabs were placed in a “checkerboard” pattern in order to accommodate the installation of steel dowels connecting the sides of adjacent slabs. The need for supporting chairs was eliminated. Figure 2 shows the placement of MRG on the second day. Concrete placement was performed between January 7 and March 2, 2004. Reference [3] provides more detailed information on the construction and trafficking of the CC-2 test items.

The curling of the slabs in the test items was controlled by gradually backing off from the wet cure condition. For the wet cure, the slabs were covered with burlap, wet with a hand held hose, then covered with thermal blankets, and then plastic sheets above the thermal blankets. Thermal blankets were used because concrete placement occurred during the winter months. Daily temperature highs were slightly above freezing within the NAPTF during the day and slightly below during the night.

The addition of water to the burlap was needed three times during the 28 day curing cycle based on visual observation of the condition of wetness. Visual observations indicated that there was a need for watering prior to anything critical being noted in the readings provided by the vertical displacement transducers. Plastic sheets and thermal blankets were temporarily removed from above the burlap. Watering was accomplished using a mobile bridge. The bridge spanned the width of the pavements and rode on the rails of the traffic test vehicle. It was propelled by the test vehicle. The bridge was equipped with a row of nozzles producing what appeared to be a line of rainfall. Figure 3 shows the mobile bridge in operation while conditioning a lift of clay subgrade during an earlier part of the construction. The mobile bridge is now self- propelled.

FIGURE 2 Second Placement of Concrete in MRG.

FIGURE 3 Watering Subgrade Lift.

The thermal blankets were removed at the end of the curing period. The burlap and plastic sheet coverings were retained for as much as two months beyond the curing period. Periodic watering on the burlap was also maintained. The mobile bridge continued to be used. All coverings were removed from the concrete surfaces in early April, 2004 in order to allow for paint markings and preliminary traffic loading. Watering the pavements continued using a hand held hose. The frequency of application was continually reduced until it was found that watering the pavements only twice per week was sufficient to hold curling effects within the acceptable range. This despite the fact that the pavements were no longer covered and there were visible signs of dryness in the concrete surfaces between applications of the water.

Figure 4 shows the history of the readings from a typical vertical displacement transducer at one of the slab corners in MRG. It is apparent that the slabs actually settled into the supporting clay subgrade and stabilized prior to the application of the seating loads by the test vehicle. Separations between slab corners and subgrade, however, had to be judged from the new low position. Note that the separation stayed within the bounds of a 20 mil (0.5 mm) "rebound" between the application of the seating loads on April 12, 2004 and the start of traffic testing on July 6, 2004. Separations were no longer apparent after traffic testing began. The concrete slabs further engaged the supporting subgrade. Watering of the pavement surfaces was continued nonetheless.

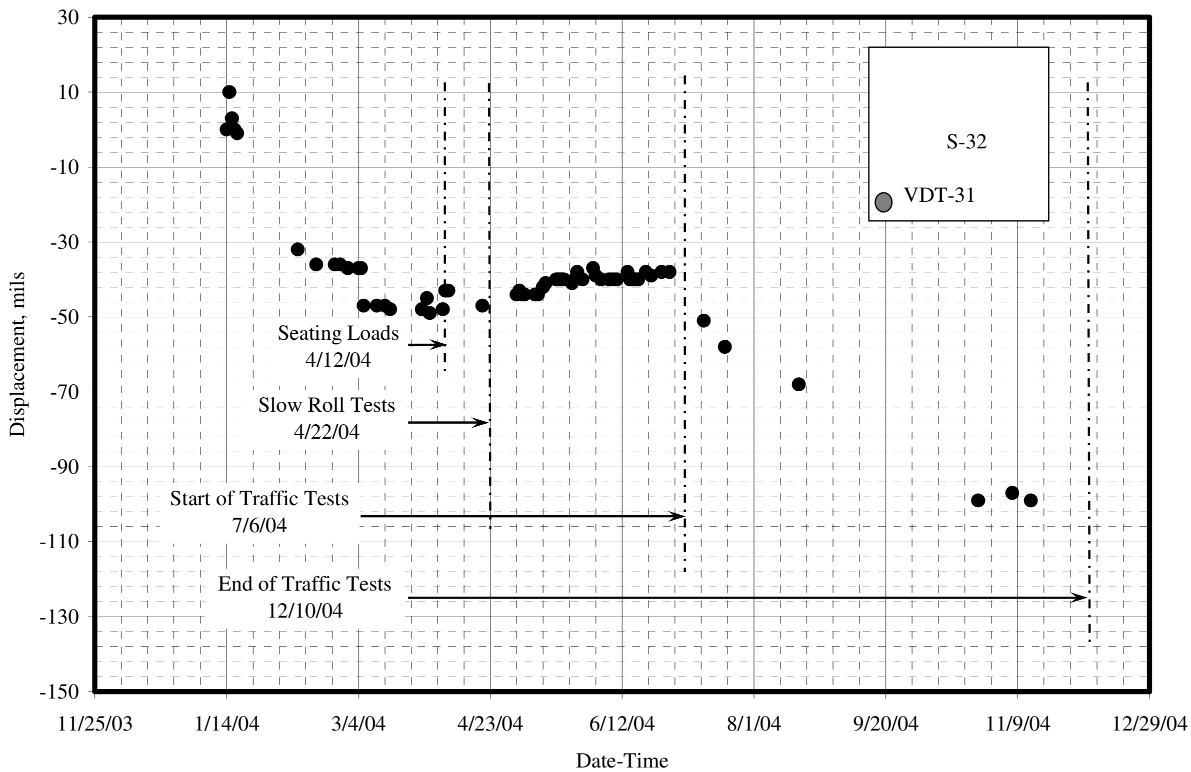

FIGURE 4 Vertical Displacements at the Corner of a Slab, MRG.

TWIN SLABS EXPERIMENT

Although a procedure had been developed to control curling in concrete pavements at the NAPTF, it was still of interest to continue to study the curling phenomenon. It was decided to place two additional concrete slabs, one within the NAPTF and one immediately outside. A comparison of the behavior of these slabs under their respective environmental conditions would further define those aspects of curling unique to the indoor environment experienced within the NAPTF.

The twin slabs each had the same dimensions as the original inside slab. The cementitious mix did not incorporate flyash. Comparison of the behavior of the inside slab with the original would indicate whether flyash had any significant effect on curling. Instrumentation of the twin slabs was similar to that of the original inside slab. Figure 5 shows the instrumentation for the new inside slab. Construction paper is being set in place serving as the bond breaker between the slab and the base. Figure 6 shows the concrete placement. Attention focused on hand packing the concrete around the instruments.

FIGURE 5 Instrumentation and Bond Breaker for Inside Slab.

FIGURE 6 Concrete Placement for Inside Slab.

The twin slabs were placed on an econocrete stabilized base which rested on a granular subbase supported by high strength subgrade. These conditions existed within the NAPTF, but had to be duplicated outside. A temporary canopy had to be erected in order to protect the construction of the outside slab from inclement weather. The twin slabs were placed on October 13, 2004. Wet curing procedures were similar to those used for the original inside slab. Curing lasted for 68 days. The slabs were allowed to dry starting on December 20, 2004. Figures 7 and 8 show the cured slabs in place.

FIGURE 7 Inside Slab (Mobile Bridge in Background).

The separation of the corners of the inside slab from the base during the first year following curing can be seen in Figure 9. Data traces not shown for transducers listed, in this or other figures, is an indication that reliable signals were not received. As in the original inside slab, sharpest increases in separations occurred at the start of the drying period and during the warmer months. The tight variations in the data traces were the result of displacement increases and decreases caused by daily temperature variations. For any given day, curl was usually the highest during the early morning temperature lows, and lowest during the mid afternoon temperature highs. There was no significant movement at the slab center. Figure 10 shows the temperature history of the inside slab for the first year after curing. Temperatures at the top of the slab (IT-1A) were lower than within the slab during the cold months and higher during the warm months.

Figures 11 and 12 show the separation of the corners of the inside slab from the base during the second and third year following curing. Curl in the slab had become permanent. The highest separations approached 200 mils and the lowest 120 mils. Temperature history continued in the slab as it had the first year, Figure 10.

The separation of the corners of the outside slab from the base during the first year following curing can be seen in Figure 13. Figure 14 shows the second year. Rainfall in the outdoor environment prevented any significant permanent curl from developing. Daily variations in vertical displacements were much higher, however, than experienced with the inside slab due to much greater variations in the daily temperatures. Temperature history of the outside slab during the first year following curing can be seen in Figure 15. Temperature history was similar during the second and third years.

FIGURE 8 Outside Slab.

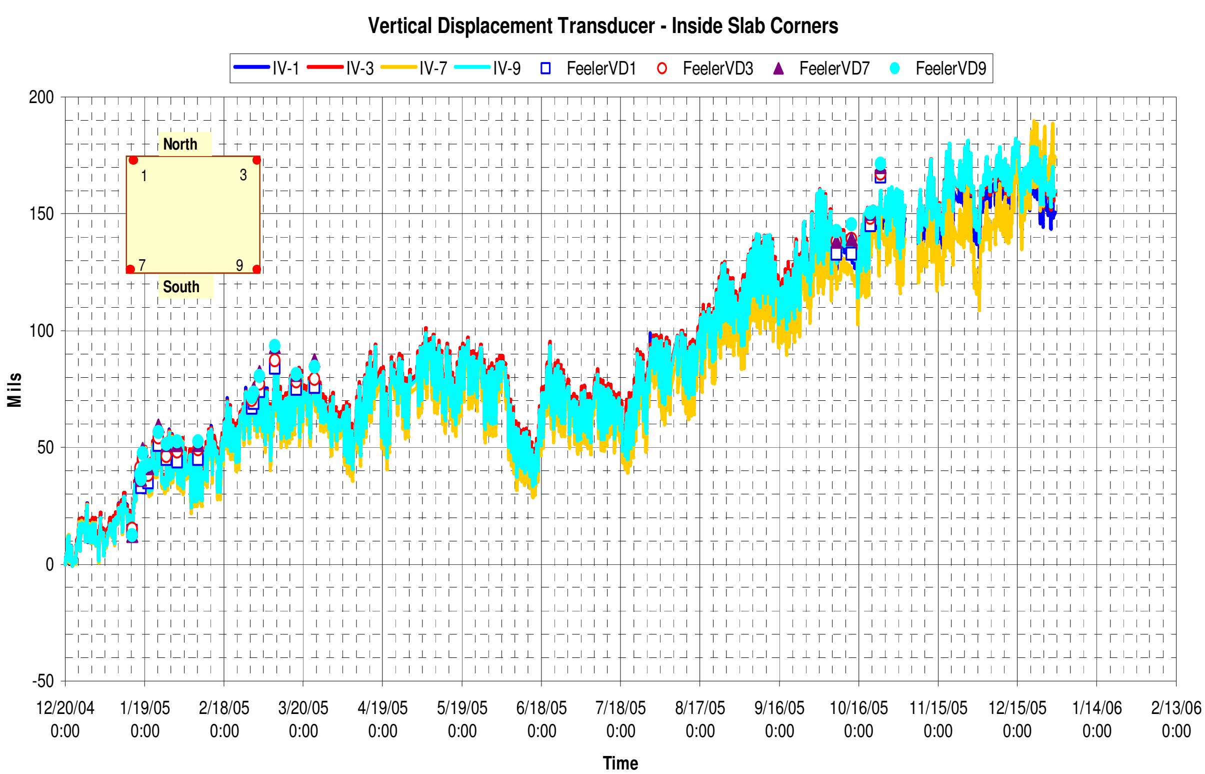

FIGURE 9 Upward Displacement of Corners, Inside Slab, Year 2005.

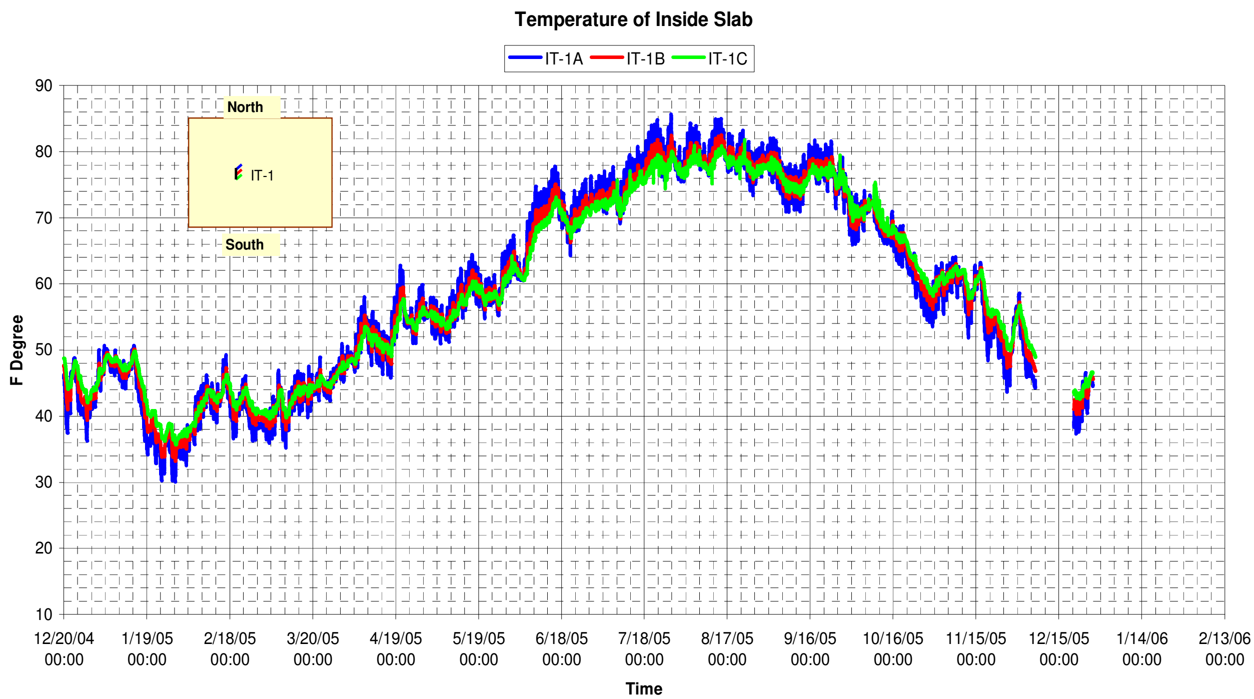

FIGURE 10 Concrete Temperatures Through Thickness of Inside Slab, Year 2005.

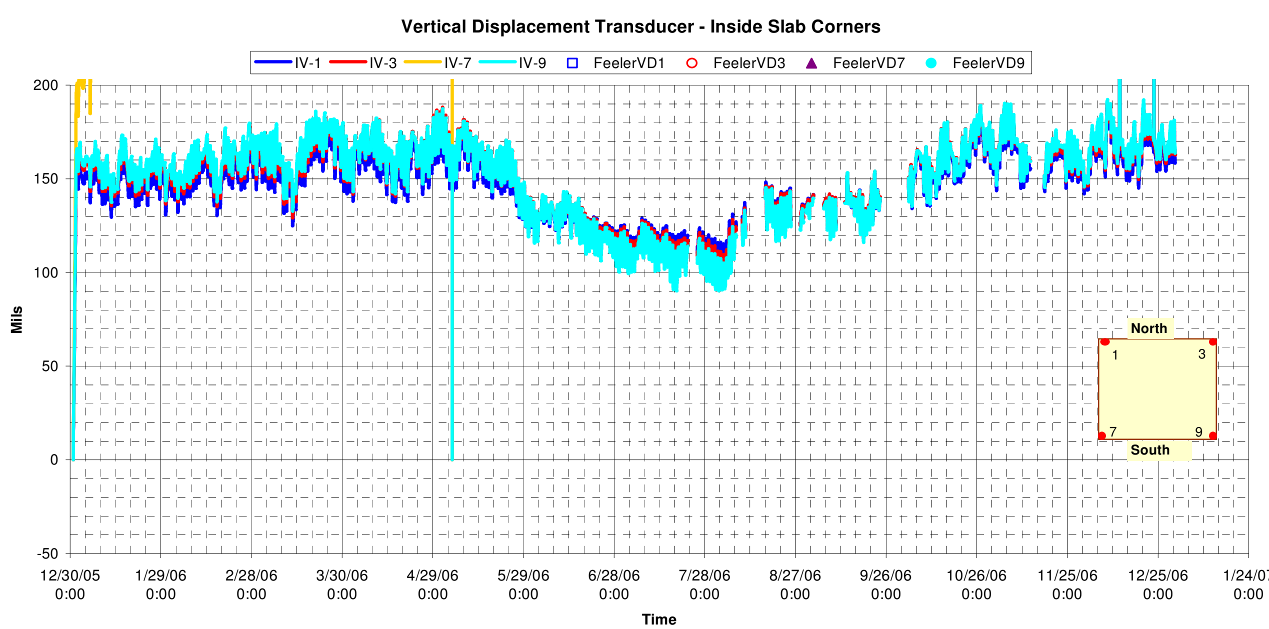

FIGURE 11 Upward Displacement of Corners, Inside Slab, Year 2006.

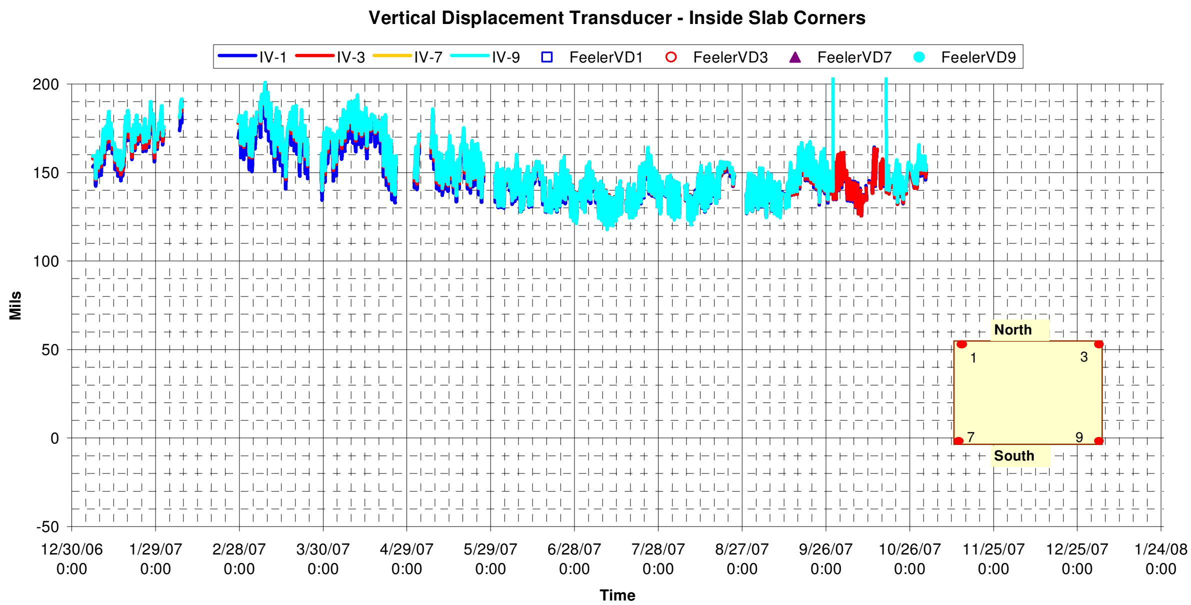

FIGURE 12 Upward Displacement of Corners, Inside Slab, Year 2007.

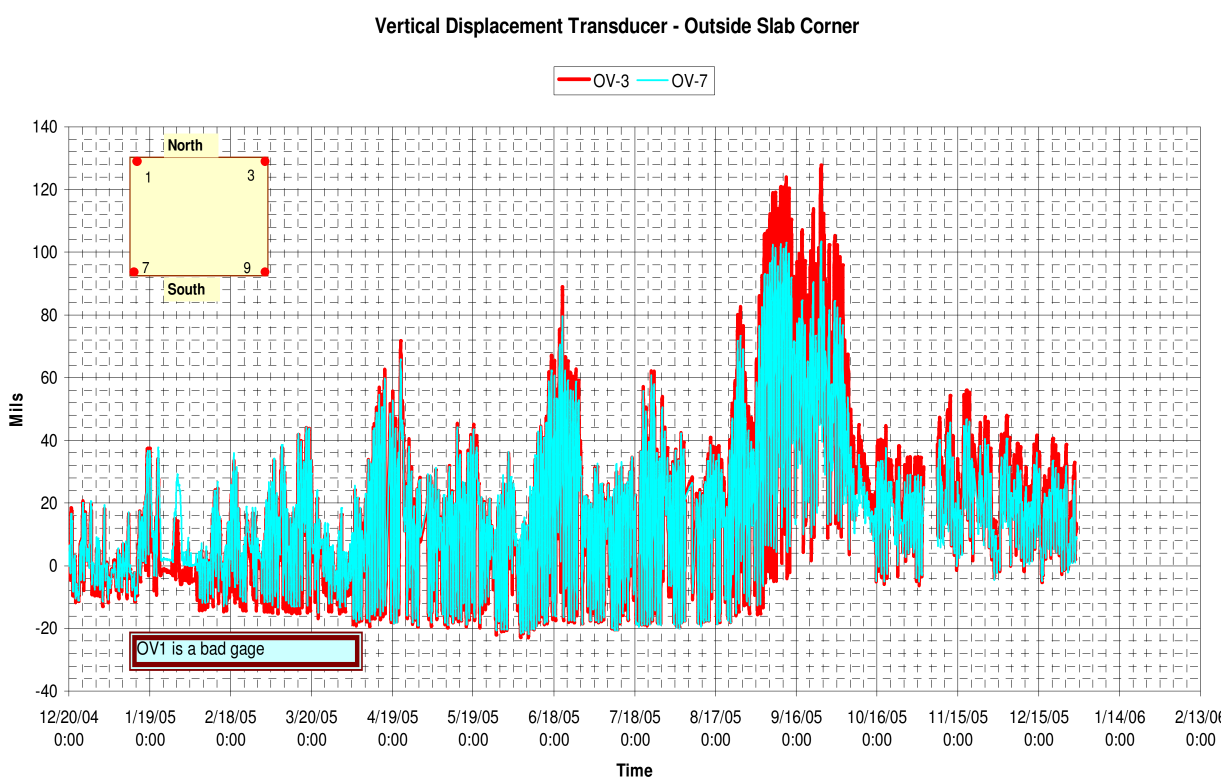

FIGURE 13 Upward Displacement of Corners, Outside Slab, Year 2005.

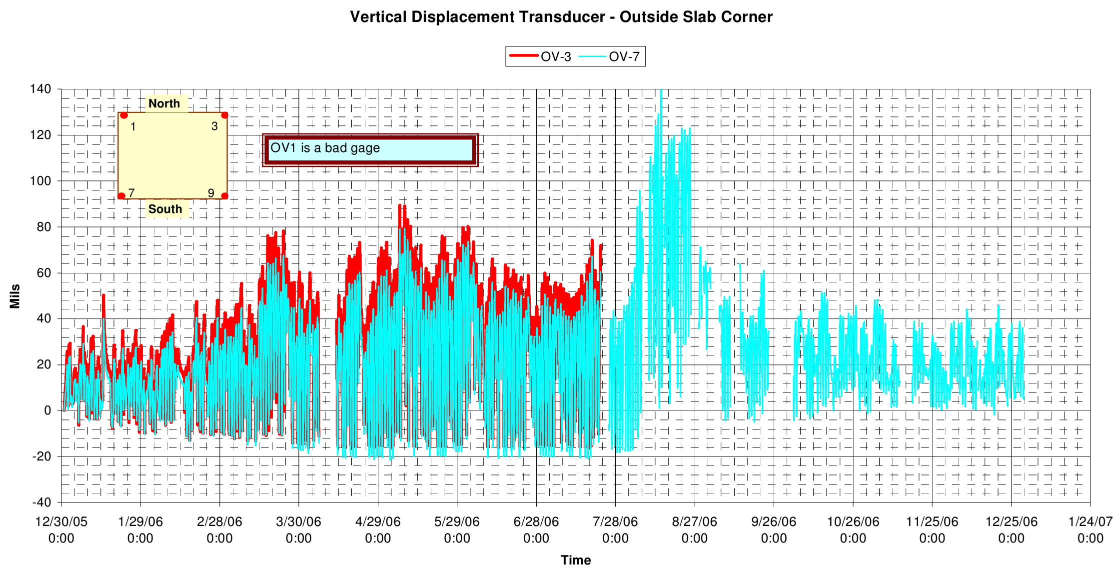

FIGURE 14 Upward Displacement of Corners, Outside Slab, Year 2006.

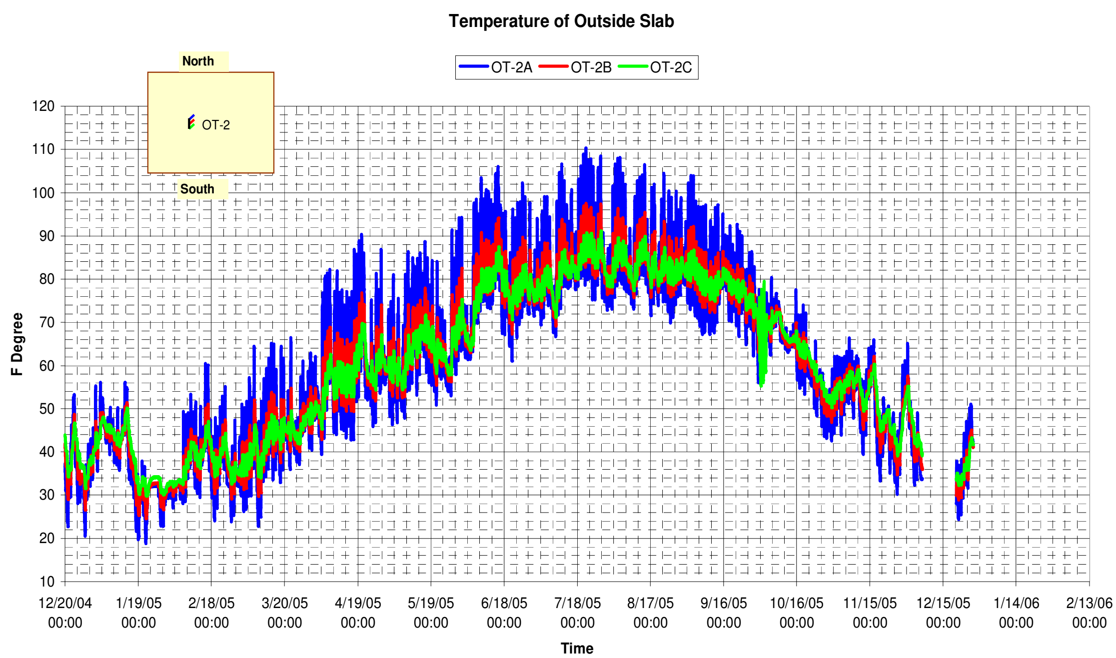

FIGURE 15 Concrete Temperatures Through Thickness of Outside Slab, Year 2005.

Accordingly, upward displacement, or "reverse curl," was noted at the center of the outside slab. At the time the center separated from the base, the corners were back in contact. Figure 16 shows reverse curl undergoing a daily cycle at the slab center during the first year following curing and was noted again during the second. Sunlight in the outdoor environment caused the phenomenon of reverse curl, starting in latter morning, peaking in mid afternoon, and ending in latter evening. The 20 mil (0.5 mm) offset, seen in Figure 16, was the result of an unexplained shift in the data and not indicative of anything related to the slab behavior. The vertical transducer at the center of the slab was affected by the outdoor environment and no longer delivered reliable signals after the middle of the second year following curing. It should be emphasized that there was no reverse curl at the center of the inside slab.

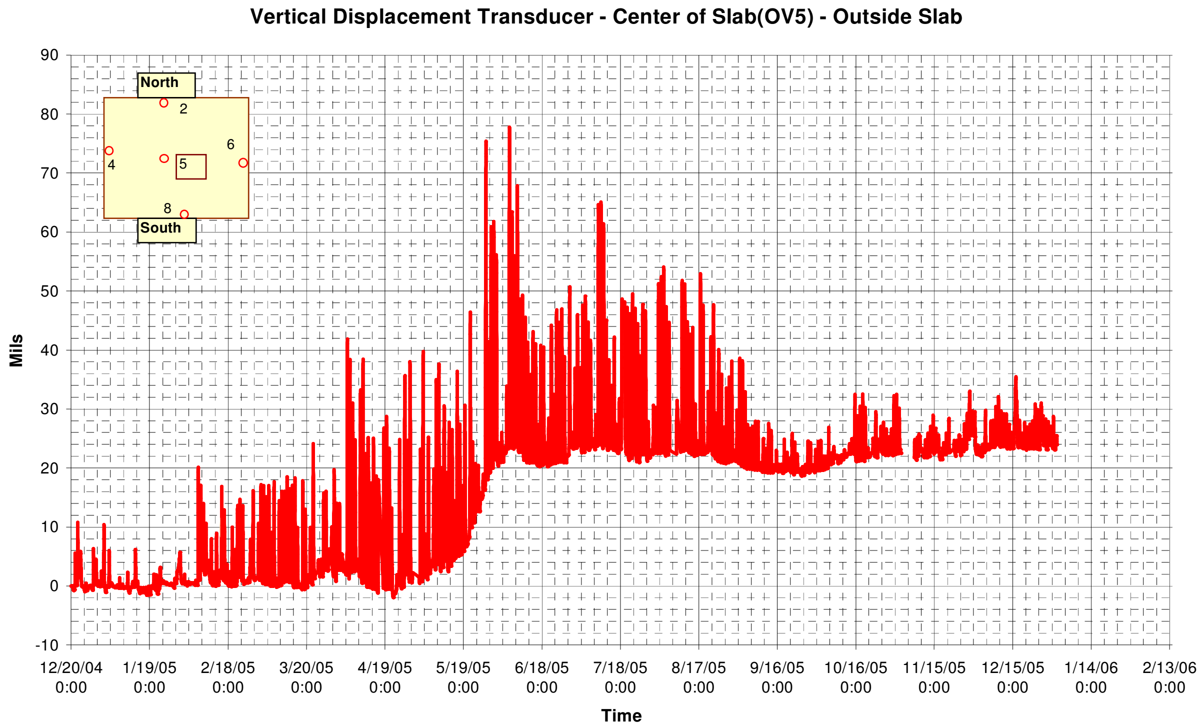

FIGURE 16 Upward Displacement of Center, Outside Slab, Year 2005.

SUMMARY

The individual slabs of a concrete pavement, placed in the indoor environment, will tend to undergo significant permanent curl during their lifetime. Slab corners can be expected to separate from the supporting base. The curl can be such that premature top down cracking is likely to occur at the slab corners when the pavement is subjected to test loading unless procedures are adopted to mitigate the curl. Keeping the pavement continually wet was found to be an effective procedure at the NAPTF. Daily variations in concrete temperatures, and consequently in the curl, are not as severe in the indoor environment as they would be in the outdoor environment. Concrete slabs are not expected to experience reverse curl in the indoor environment.

ACKNOWLEDGEMENT/DISCLAIMER

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