Impact of Curling, Warping, and Other Early-Age Behavior on Concrete Pavement Smoothness: Early, Frequent, and Detailed (EFD) Study

National Concrete Pavement Technology Center

Tech Center

Phase II Final Report
January 2007

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16. Abstract

This report summarizes the activities in Phase II of "Assessing the Impact to Concrete Pavement Smoothness from Curling, Warping, and other Early-Age Behavior: Early, Frequent, and Detailed (Project 16)." The purpose of this project is to obtain detailed information about factors affecting pavement smoothness during the critical time immediately following construction by conducting a controlled field evaluation of three concrete pavement construction projects. In Phase II, both field and laboratory testing of the materials and construction process were conducted for two newly constructed Jointed Plain Concrete Pavement (JPCP) test sections; one on highway U.S. 34 near Burlington and the other on U.S. 30 near Marshalltown, Iowa. Extensive pavement profiling was also performed during strategic times after placement. This report fulfills the remaining requirements of Phase II.

As a whole, the data collection effort undertaken by the project team was a success. The result of this project is a large amount of quality data on the early-age effects of curling and warping on pavement smoothness. By using the data from this research and by using the mathematical models developed as part of current FHWA studies and elsewhere, the complex relationships between concrete pavements curling, warping, and other early-age behavior and pavement smoothness were discussed and presented.

This study shows that the curling and warping behaviors at early ages are influenced not only by temperature variation but also by other environmental effects such as the moisture variation, drying shrinkage, and temperature conditions during pavement construction. Within the scope of this project, it can be concluded that measurable changes of early-age pavement smoothness do occur over time from the standpoint of smoothness specifications.

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IMPACT OF CURLING, WARPING, AND OTHER EARLY-AGE BEHAVIOR ON CONCRETE PAVEMENT SMOOTHNESS: EARLY, FREQUENT, AND DETAILED (EFD) STUDY

Phase II Final Report
January 2007

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EXECUTIVE SUMMARY

This document summarizes the activities in the "Study Assessing the Impact to Concrete Pavement Smoothness from Curling, Warping, and other Early-Age Behavior—Early, Frequent, and Detailed (EFD)." The purpose of this investigation is to obtain detailed information affecting pavement smoothness during the critical time immediately following construction to assist ongoing efforts within Federal Highway Administration (FHWA) by conducting controlled field evaluations of three concrete pavement construction projects. During the evaluation, both field and laboratory testing of the materials and construction were conducted. Extensive pavement profiling was also performed during strategic times after placement. Using these data, and by utilizing the mathematical models being developed as part of current FHWA studies and elsewhere, the complex relationships between concrete pavement curling, warping, and other early-age behavior on pavement smoothness were discussed and presented.

This study shows that the curling and warping behaviors at early ages are influenced not only by temperature variation but also by other environmental effects such as the moisture variation, drying shrinkage, and temperature conditions during pavement construction. Within the scope of this project, it can be concluded that measurable changes of early-age pavement smoothness do occur over time from the standpoint of smoothness specifications.

INTRODUCTION

This document summarizes the activities in the “Study Assessing the Impact to Concrete Pavement Smoothness from Curling, Warping, and other Early-Age Behavior—Early, Frequent, and Detailed (EFD).” The purpose of this investigation is to obtain detailed information on factors affecting pavement smoothness during the critical time immediately following construction by conducting controlled field evaluations of three concrete pavement construction projects. During the evaluation, both field and laboratory testing of the materials and construction were conducted. Extensive pavement profiling was also performed during strategic times after placement. Using these data, and by utilizing the mathematical models being developed as part of current FHWA studies and elsewhere, a better understanding will be gained of the complex relationships between concrete pavement curling, warping, and other early-age behavior and pavement smoothness. While this project served to measure very specific types of data, it was not conducted in a “vacuum.” The EFD concept is a part of the overall Strategic Plan that has been advanced as part of the FHWA CPTP Task 15 work—now termed the CP Road Map.

This project was organized into the following four tasks:

- Task 1: Program planning
- Task 2: Pre-visit data collection and briefing
- Task 3: Pavement instrumentation/monitoring and pavement testing
- Task 4: Post-visit documentation and data submission

During Phase I of the project, all tasks were fulfilled for the initial construction project on U.S. 151 near Platteville, Wisconsin. Task 1 was fulfilled prior to the U.S. 151 investigation, and resulted in the development of an Overall Testing Plan. To complete Phase I, tasks 2, 3, and 4 were performed during the construction of U.S. 151 near Platteville, Wisconsin, from October 22 to 27, 2004. During Phase II, Tasks 2, 3, and 4 were completed during construction of US 34 near Burlington, Iowa, from June 7 to 15, 2005, and U.S. 30 near Marshalltown, Iowa, from July 13 to 21, 2005. This report fulfills the remaining requirements of Phase II.

RESEARCH SIGNIFICANCE

The early-age behavior (i.e., before opening to traffic) of portland cement concrete (PCC) pavements have drawn the attention of several researchers (Rasmussen 1996; McCullough and Rasmussen 1999) because of the growing need to expedite construction without compromising on pavement quality to minimize traffic delay and user cost. Even though the concrete pavements are subjected to only environmental loads, including temperature (inducing curling) and moisture (inducing warping), during this period, the volumetric distortion of slab occurring in this period and the associated mechanical and environmental loadings after the opening of traffic could influence long-term performance of PCC pavement. In addition, there are very few studies directly addressing early-age slab distortion behavior corresponding to environmental loads, with the majority of studies focusing on theoretical analysis of temperature induced curling stress (Westergaard 1926; Thomlinson 1940; Ioannides and Salsili-Murua 1989;

Choubane and Tia 1992; Lee and Dater 1993; Harik et al. 1994; Massad and Taha 1996; Mohamed and Hansen 1997; Ioannides and Khazanovich 1998).

Providing smoothness to traveling user is one of the important functions of a pavement. The initial smoothness immediately after construction can significantly affect the pavement service life (Janoff 1990). Smith et al. (1997) reported that pavements constructed smoother stayed smoother over time provided all other factors affecting smoothness remained the same. Many agencies have established and implemented smoothness specifications for newly constructed pavements. Using these specifications, the agencies determine the bonuses or penalties to the contractor, thereby encouraging the contractor to construct smoother pavements with smoothness levels higher than a specified value (Chou et al. 2005). Even though it has been noticed that the change in curvature of slab due to the temperature and moisture variation in climate could have significant influence on pavement smoothness measurements (Hveem 1951; Karamihas et al. 1999), the effect of this distortion of slab on the initial pavement smoothness have not been adequately addressed in the past. Thus, the current research seeks to address these crucial issues related to the early-age behavior of JPCP.

LITERATURE REVIEW

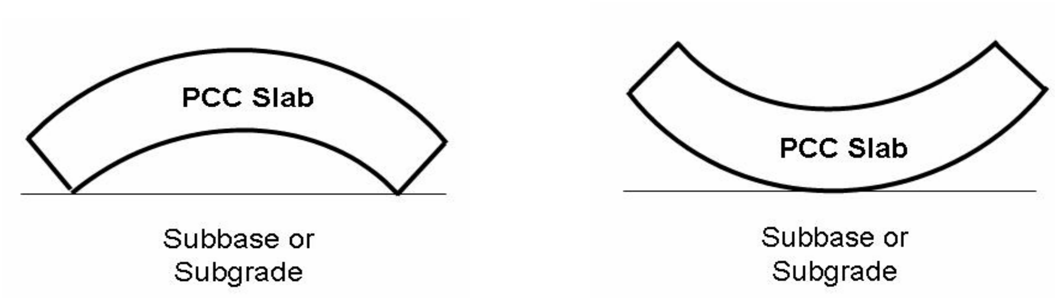
This chapter attempts to present a comprehensive literature review on the early-age behavior of portland cement concrete (PCC) pavement systems under pure environmental loading, the application of finite element method (FEM) in the analysis and design of PCC pavements, and the concept of pavement smoothness.

Early-Age Behavior of Concrete Pavements under Environmental Loads

The temperature and moisture variations across the depth of the PCC slab can generate a bending curvature with respect to horizontal plan in the PCC slab. In addition, many other environmental factors, such as drying shrinkage, pavement temperature gradient during the setting and curing of PCC, and the creep of the slab, may cause this unique curvature behavior during the early age of concrete pavement, in which the concrete transforms from the plastic state to the solid state through a sequence of chemical reactions between the cement components, calcium, and water. Each environmental factor that has an influence on the early-age behavior and curvature of PCC slab is examined in detail and presented in this chapter.

Temperature Gradient

The PCC pavement response to temperature differences through the slab thickness has been recognized as curling. As shown in Figure 1, a positive temperature difference between the top and the bottom surfaces of the concrete slab during daytime causes the slab corners to curl downwards, while a negative temperature difference during nighttime results in the upward curling of slab corners. Since concrete can recover its original shape after the effects of temperature variation are removed, the curling due to temperature variation from daily or seasonal weather condition can be considered as a transient component of slab curvature behavior due to environmental loading (Yu et al. 2004).

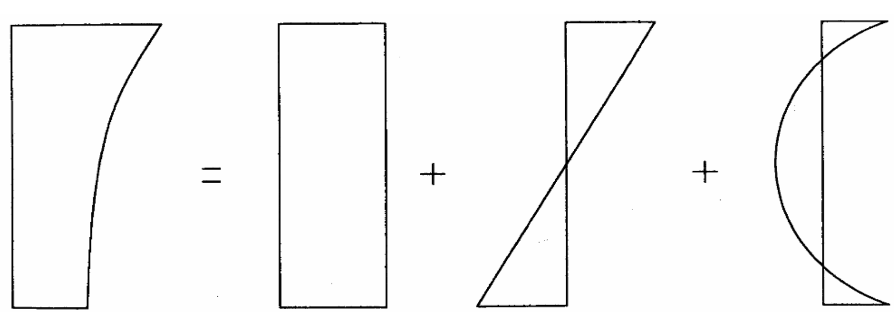


(a) Temp. at top > Temp. at bottom (daytime) **(b) Temp. at top < Temp. at bottom (nighttime)**

Figure 1. Typical slab curling behavior

Curling can create not only slab deformation but also internal stresses in the absence of traffic loading. Westergaard (1926) published the first well known closed–form theory for prediction of PCC slab curling deflections and stress on the basis of assumption of an infinite or semi-infinite slab over dense liquid foundation. Bradbury (1938) later expanded Westergaard's bending stress solutions for a slab with finite dimensions in both x and y directions.

Even though the assumption of linear temperature profile through the depth of PCC has been used in the analysis and design of concrete pavements, it is known from the observation of field measurements that the temperature profile through the depth of PCC is nonlinear (Thomlinson 1940; Choubane and Tia 1992). As shown in Figure 2 (Choubane and Tia 1992), total nonlinear temperature profile in a slab can be thought of as having three components: (a) uniform component causing axial expansion or contraction, (b) linear component causing bending of pavement slab, and (c) zero-moment nonlinear component that remains after subtraction of the uniform and linear component from total nonlinear components.



Total nonlinear temperature profile **(a) Uniform component** **(b) Linear component** **(c) Zero-moment nonlinear component**

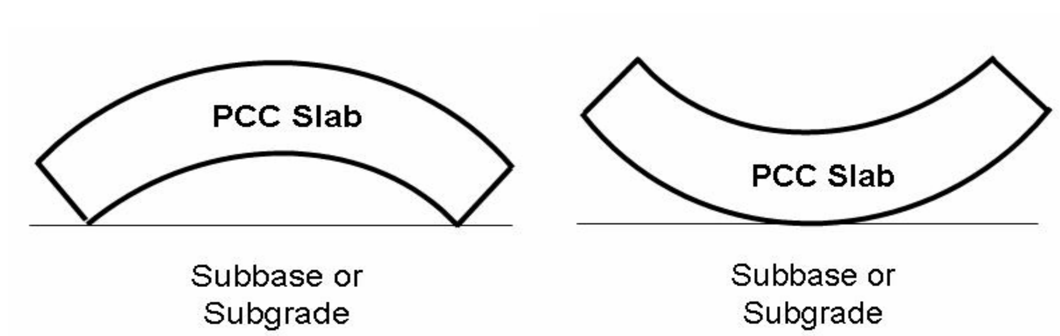
Figure 2. Typical temperature profile through the slab thickness

Even though the lack of knowledge of the zero-moment nonlinear component could lead to higher maximum computed tensile stress during daytime and lower maximum computed tensile stress during nighttime (Choubane and Tia 1992), the zero-moment nonlinear temperature component couldn't have a significant influence in the calculation of curling deflection since the curling deflection could be generated from external moment (Yu et al. 2004).

Moisture Gradient

The moisture gradient through the depth of PCC affects the reversible shrinkage which is recognized as warping. The moisture gradient is influenced by the daily and seasonal weather conditions and the pavement material, such as permeable base and poor drainage soils (Rao and Roesler 2005). Especially, it has been recognized that seasonal variations could be more influential than daily variations due to the low hydraulic conductivity of concrete (Vandenbossche 2003; Yu et al. 2004). The reversible warping from seasonal weather conditions are accounted for in the transient component of slab curvature behavior under environmental loads in the new *Mechanistic-Empirical Pavement Design Guide* (MEPDG) under the National Cooperative Highway Research Program Project 1-37 A (NCHRP 2004)

As shown in Figure 3, a positive moisture difference between the top and the bottom surfaces of the concrete slab causes the slab corners to warp downwards while a negative moisture difference results in the upward warp of PCC slab. However, even in very dry area, the surface of the slab is typically only partially saturated while the bottom is usually completely saturated (Janssen 1987; NCHRP 2004). Therefore, upward warp of PCC slab caused by negative moisture difference, as shown in Figure 3 (b), is usually more obvious than the downward warp as shown in Figure 3 (a) (Jeong and Zollinger 2005) .



(a) Moisture at top > moisture at bottom **(b) Moisture at top < moisture at bottom**

Figure 3. Typical warping behavior

Shrinkage

The shrinkage can be defined as decrease in either length or volume of a material resulting from changes in moisture content, temperature, or chemical changes (Kosmatka et al. 2002). The main volume change of concrete can be divided into early shrinkage (within 24 hours) and shrinkage of hardened concrete. Early shrinkage includes the chemical shrinkage, the autogenous shrinkage, and the plastic shrinkage. Shrinkage of hardened concrete includes the drying shrinkage resulting from moisture loss and the volume change due to temperature variations. The main cause of early shrinkage is the loss of moisture, so early shrinkage could be considered as a special case of drying shrinkage in fresh concrete (Mindess and Young 1981). In addition, the volume change due to temperature in hardened concrete should be related to curling behavior, which makes the slab recover the original shape after removing the temperature effect. The main types of shrinkage causing loss of moisture in concrete are summarized in Table 1.

Table 1. Main types of shrinkage in concrete

Type	Description	Reference
Chemical shrinkage	The reduction in absolute volume of solids and liquids in paste resulting from cement hydration in fresh concrete	Kosmatka et al. 2003
Autogenous shrinkage	The macroscopic volume reduction associated with the loss of water from the capillary pores due to the cement hydration in fresh concrete	Holt and Janssen 1998
Plastic shrinkage	The reduction of volume in surface of fresh concrete associated with the loss of moisture from surface, causing the evaporation and suction by the underlying dry concrete or soil.	Nevil 1996.
Drying shrinkage	The volume change of hardened concrete resulting from the loss of moisture	Mindess and Young 1981

As shown in Figure 4, most of the shrinkage which is caused by the loss of water shows the significant irreversible deformation after rewetting. Mindess et al. (2003) suggested that the origin of this irreversibility could be related to the unstable amorphous nature of C-S-H which produces rearrangement of bond structure due to loss of moisture. This irreversibility of shrinkage could contribute to the permanent deformation at zero temperature gradient and zero moisture gradient (Yu et al. 2004; NCHRP 2004).

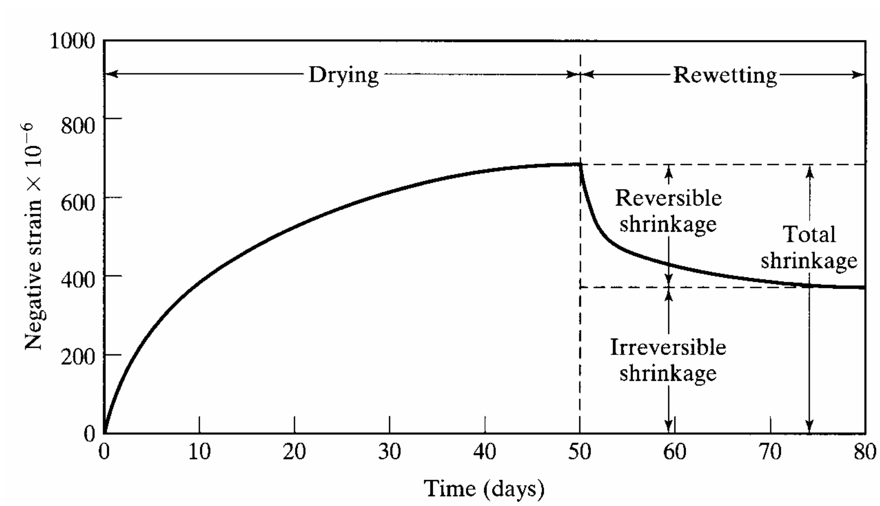
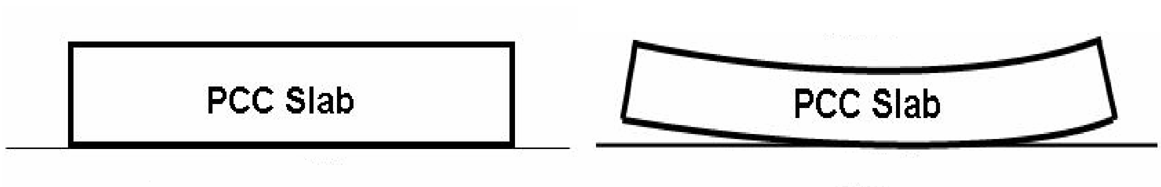


Figure 4. Typical behavior of PCC on drying and wetting

Temperature Condition during Setting of Concrete Pavement

The construction of concrete pavements is typically undertaken during the daytime in warmer months of the years. In this paving period, the top of the slab is typically warmer than the bottom of the slab during the concrete setting time (Rao and Roesler 2005). The retained amount of heat generated from the cement hydration at the surface could also cause this positive temperature gradient (Vandenbossche et al. 2006). Since the concrete slab is set under this condition, the flat slab condition is not associated with a zero temperature gradient but with the positive temperature condition, as shown in Figure 5 (a). When the temperature gradient in the slab is zero after setting time, the slab curls upward rather than staying flat, as shown in Figure 5 (b) (Yu et al. 1998; Rao and Roesler 2005). This curling up behavior at zero temperature gradient combined with unrecoverable shrinkage was defined as permanent curling and warping in the MEPDG (Yu et al. 2004; NCHRP 2004).

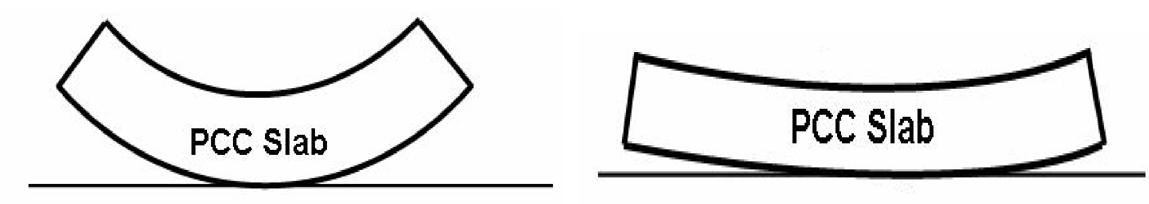


(a) Temp. at top > Temp. at bottom (during setting time)　　**(b) Temp. at top = Temp. at bottom (after setting time)**

Figure 5. Typical slab curvature behavior during and after setting time

Creep

Creep in material can be defined as the time-dependent deformation under a constant load, while relaxation can be defined as the time-dependent stress change under a constant strain condition. Because of the self weight of the slab and also the restraints from the shoulder or the adjacent slab as a constant load, the creep occurred in the already deformed slab can be recovered partially over the time, as illustrated in Figure 6 (Rao et al. 2001).



(a) Time = 0　　**(b) Time = ∞**

Figure 6. Typical creep behavior of deformed slab

Finite Element Method in the Design and Analysis of Concrete Pavements

Finite Element Method

The Finite Element Method (FEM) can be described as a numerical method for solving problems of engineering and mathematical physics. Even though it is difficult to determine the origin of the FEM and the precise moment of its invention (Zienkiewicz and Taylor 1987), it has been considered that the modern development of the FEM began in the 1940s in the field of structural engineering with the work by Hrennikoff (1941) and McHenry (1943). After their works, from the early 1950s to present, enormous advances have been made in the application of the FEM to complicated engineering problems, including structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential (Logan 2002).

It is generally not possible to solve the problems involving complicated geometries, loadings, and material properties with mathematical expression (ordinary or partial differential equations) that yields the values of the desired unknown quantities at any location in a total structure and are thus valid for an infinite number of locations in a total structure (Logan 2002). In the FEM, instead of solving the problem for the entire body in one operation, the solution is obtained by formulating algebraic equations for each smaller body or unit interconnected at points, and subsequently solving the combination of formulated equations. Although solution obtained by the FEM is an approximation, it is possible to enhance the accuracy of the result by defining finer elements and providing accurate material properties (Siddique 2004)

FE analysis consists of several steps (Logan 2002). Step 1 involves the division of the structure into the finite elements, and the selection of the element types requires the decision of the analyst. Steps 2 though 7 are usually carried out automatically by a computer program.

- Step 1. Discretize and select the element types (e.g., line element, two-dimensional element, three-dimensional element, axisymmetric element)
- Step 2. Select displacement function (e.g., linear, quadratic, cubic polynomials, and trigonometric series)
- Step 3. Define the strain/displacement and stress/strain relationships
- Step 4. Derive the element stiffness matrix and equations with alternative methods, such as direct equilibrium method, work/energy methods, and methods of weighted residuals
- Step 5. Assemble the element equations to obtain the global or total equations and introduce boundary conditions
- Step 6. Solve for the unknown degrees of freedom (or generalized displacements)
- Step 7. Solve for the element strains and stresses
- Step 8. Interpret the results

Application of FEM in Concrete Pavement Research

With the development of the high-speed digital computers, the application of FEM in the design and analysis of concrete pavement has significantly increased over the past decade (Hammons and Ioannides 1997). The ability of FEM to solve a broad class of boundary value problems provides a better understanding of the critical aspects of pavements response, such as joint load transfer (Armaghani et al. 1986; Ioannides and Korovesis 1990; Ioannides and Korovesis 1992; Davids 2001) and pavement response under dynamic loads (Chatti et al. 1994; Vepa and George 1997) and environmental loads (Ioannides and Salsili-Murua 1989; Beckemeyer et al. 2002; Rao and Roesler 2005), that couldn't have been captured with other analytical solutions.

This advantage of FEM has enabled many researchers to apply FE-based methodology for rigid pavement analysis either by using special-purpose software for rigid pavements or by using the commercially available general-purpose FE software. Table 2 presents an overview of certain key attributes of the more common FE programs applied to concrete pavements as originally reported by Hammons and Ioannides (1997) and modified according to additional information based on latest research.

Most special-purpose FE programs customized for concrete pavement modeling and analysis, such as ISLAB 2000, JSLAB, KENSLABS, and FEACONS III, use two-dimensional (2-D) plate element. The general-purpose FE software, such as ABAQUS and ANSYS, and the special-purpose software EverFE 2.24 choose three-dimensional (3-D) continuum element as their representation of the slab model. The major advantages of using special-purpose FE software are that they are readily available, require only modest computer resources, and have user-friendly interfaces that can be easily accessed by the pavement designer. However, the general-purpose 3-D FE software has the advantage of the ability to more realistically model the pavement structure compared to the ready-made 2-D FE programs. The disadvantages of using the commercial 3-D FE software for rigid pavement modeling are that very few models have been validated and the various features of the software are not readily understood by the pavement designer.

Among the FE programs applied to concrete pavements, ISLAB 2000 and EverFE 2.24 have some special advantages over other FE programs. These two programs have evolved from earlier versions with validation using field data (Tabatabaie and Barenberg 1978; Davids and Mahoney 1999; Khazanovich et al. 2000; Davids et al. 2003) and can simulate field-observed responses well (Wang et al. 2006). In addition, ISLAB 2000 was used as the main structural model cooperating with the neural network for generating pavement responses in the new MEPDG under the NCHRP Project 1-37 A (NCHRP 2004), and EverFE 2.24 is the only available 3-D FE program among the special-purpose FE programs which can be expected to overcome the disadvantage of 2-D FE programs.

Table 2. FE programs for concrete pavements

Type	Program	Slab model	Load transfer	Foundation model(s)	Reference
Special-purpose program	ILL-SLAB & ISLAB 2000	2-D medium-thick plate	Linear spring, beam element on spring foundation	Dense liquid, Boussinesq, nonlinear resilient, two- and three-parameter models	Tabatabaie et al. 1978; Khazanovich, et al. 2000
	JSLAB	2-D medium-thick plate	Linear spring, beam element on spring foundation	Dense liquid	Tayabji et al. 1986
	WESLIQID & KENSLABS	2-D medium-thick plate	Linear springs	Dense liquid	Chou 1981; Huang 1993
	FEACONS Ш	2-D medium-thick plate	Linear springs and torsional springs	Dense liquid (linear and nonlinear spring)	Tia et al. 1987
	EverFE 2.24	3-D brick element	Linear and nonlinear springs, interface elements, gap elements, multipoint constraints, explicit models	Dense liquid	Davids et al. 1998
General-purpose program	ABAQUS	2-D shell element 3-D brick element	Linear and nonlinear springs, interface elements, gap elements, multipoint constraints, explicit models	Dense liquid, 3-D brick element with linear and nonlinear elastic, plastic, and viscoelastic constitutive models, user-defined models	Kuo et al. 1995; Massad et al. 1996; Kim et al. 2003
	ANSYS	3-D brick element	Linear and nonlinear springs, interface elements, gap elements, multipoint constraints, explicit models	Dense liquid	Siddique 2004; Mahboub et al. 2004

Pavement Smoothness

The American Society for Testing and Material (ASTM) Standard E867 (1997) defines roughness of road as deviation of a pavement surface from a true planer surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage. From a road user's point of view, pavement smoothness can be defined as a lack of noticeable roughness and a more optimistic view of the road condition (Sayers and Karamihas 1998; Akhter et al. 2002). Pavement smoothness has been recognized as an important measurement in evaluating pavement performance because it is directly related to the serviceability of road for the traveling public (Ksaibatti et al. 1995).

Perera (2002) suggested that there are several factors that contribute to pavement roughness: built-in construction irregularities, traffic loading, environmental effects, and construction materials. The construction irregularity can result in poor initial smoothness due to variations in the pavement profile from the design profile, and the repeated traffic loading can cause pavement distress, such as cracking, that results in increased roughness. The environmental effects, such as frost heave and volume changes due to shrinking and swelling of subgrade, can also contribute to the propagation of roughness over time. In addition, the non-uniformities in the materials used for pavement construction, as well as the non-uniform compaction of pavement layers and subgrade, can cause roughness. Akhter et al. (2002) reported that the concrete modulus of rupture, subgrade material, number of wet days, and initial roughness could significantly affect the rate of roughness progression, as was observed from the roughness index data collected from 21 concrete pavements constructed after 1992 in Kansas.

Even though it has been recognized that low initial roughness can prevent the developing roughness over time and provide the longer pavement life (Ma et al. 1995; Perera et al. 2002), the factors influencing the initial smoothness of a concrete pavement are not very well discussed in literature. However, it is believed that several factors are related to the initial smoothness of a concrete pavement. These include elements related to the pavement design, material selection, concrete uniformity, climate, and construction practices (Rasmussen et al. 2002, 2004).

A variety of equipments have evolved over the years to measure the roughness of pavements for monitoring the conditions of a pavement network in a pavement management system (PMS) or evaluating the ride quality of newly constructed/rehabilitated pavement. The equipments that are used to measure roughness of pavements can be divided into five categories (Perera et al. 2002), as presented in Table 3.

Because different instruments are available for measuring roughness, a parameter representing the actual measured roughness condition is needed as a common scale. Smoothness Index (or Roughness Index) has been developed and used to fulfill this demand. The most common profile indices that are currently used can be divided into two categories: ride statistic and profile index. Ride statistic can be computed from a statistical model using measured pavement profile as input and include International Roughness Index (IRI) and Ride Number (RN). Profile Index (PI) can be directly obtained from profile trace measured by the profilograph. Currently, most state agencies use the PI for judging the quality of new pavements and a ride statistic such as IRI for monitoring the condition of their pavement network (Perera et al. 2002; Smith et al. 2002).

Table 3. The equipments used for measurement of roughness of pavements

Category	Type	Description
Response type road roughness measurement systems	Bureau of Public Roads (BPR) roughometer, Maysmeter, Portland Cement Association (PCA) roadmeter.	Measuring the response of the road on the vehicle or a special trailer using a transducer
High-speed inertia profilers	Dynatest Road Surface Profiler (RSP), International Cybernetic Corporation (ICC) profiler, Infrastructure Management Services (IMS) Laser RST profiler, K.J. Law DNC 690 profiler, Pathway profiler, Roadware profiler.	Recording the true profile of a pavement surface at highway speed by height sensors
Profilographs	California truss type profilograph, Ames profilograph, Rainhart profilograph.	Recording the response of center wheel to road on a strip chart recorder linked to the center wheel
Lightweight profilers	Ames Lightweight Inertial Surface Analyzer (LISA), ICC dual track profiler, K.J. Law lightweight profiler	Installing similar profile system with inertia profiler on a light vehicle, such as a golf cart or an all terrain vehicle
Manual devices	Road and level, Dipstick, Australian Road Research Board (ARRB) walking profiler, ICC rolling profiler	Measuring true elevation of road and checking the accuracy of other profiler

Summary

PCC pavement shows the unique bending curvature behavior associated with temperature and moisture variations through the depth of PCC slab. In addition, this curvature behavior of early-age PCC pavement is more complicated because several other environmental factors such as shrinkage, pavement temperature condition during the setting, and creep of slab could be also involved.

A number of FE programs have been developed to understand the critical aspects of concrete pavement responses. Among these FE programs, ISLAB 2000 and EverFE 2.24 have some special advantages over other FE programs and would aid in understanding the complicated behavior associated with environment.

Even though it has been recognized that low initial roughness can prevent the development of roughness over time and provide longer pavement life, the factors influencing the initial smoothness of a concrete pavement, especially the effect of environmental conditions on concrete pavement during early age, have not been very well understood.

PHASE I—PLATTEVILLE, WISCONSIN, PILOT SITE

The data collected for this project include design information, laboratory and materials tests, and in-situ instrumentation and monitoring.

Pavement Design

The field evaluation was conducted during the construction of a 9.5 in. (240 mm) Jointed Plain Concrete Pavement (JPCP). The pavement was constructed upon a 6 in. (152 mm) open-graded granular base. The concrete haul trucks backed down the grade to access the slipform paver. The transverse joint spacing was approximately 15 ft. (4.6 m). The passing lane was approximately 12 ft. (3.7 m) wide, and the travel lane was approximately 14 ft. (4.3 m) wide, which included a 2 ft. (0.7 m) widened lane. An open-graded granular shoulder was added after construction.

Across the longitudinal joints, 24 in. (610 mm) tie-bars (size #4, 0.5 in. or 12.7 mm) were inserted approximately every 33 in. (838 mm). The slipform paver utilized an automated Dowel Bar Inserter (DBI) that placed 18 in. (457 mm) long, 1.25 in. (32 mm) diameter smooth dowels approximately every 30 in. (762 mm) along the transverse joints.

Conventional saws were used to cut transverse and longitudinal joints to a depth of approximately 3 in. (76 mm) and width of approximately 0.5 in. (12.7 mm). Per Wisconsin Department of Transportation specifications, no joint cleaning or sealants were used. Appendix A contains photos of typical construction operations, including concrete delivery, paving, texturing, curing, sawing, and shouldering.

Pavement Materials

Obtaining fundamental properties of the paving materials is a key component of this project and will aid in the correlation between construction projects as well as provide a foundation for future tests on the test sections. The concrete mixture design is provided in Table 4. The Blaine Fineness for the portland cement and fly ash was reported to be 3,774 and 5,337 cm2/g, respectively. The strengths of the subbase and subgrade layers were not reported to the project team.

The Overall Testing Plan also prescribed a series of laboratory tests on the concrete mixture conducted in Iowa State mobile PCC laboratory shown in Figure 7. The splitting tensile (ASTM C 496 1996) and compressive (ASTM C 39 2001) strengths, as shown in Figures 8 and 9, as well as corresponding maturity values, are reported in Tables 5 and 6. The Elastic Modulus test (ASTM C 469 1994), shown in Figure 10, was also conducted at various ages and is reported in Table 7. The coefficient of thermal expansion (CTE) measured from field-fabricated samples tested at 56 days following AASHTO TP-60 (2000), as shown in Figure 11, was reported to be 5.79×10^{-6} ε/°F (1.04×10^{-5} ε/°C). Using measured surface strains in three directions, the project team made estimates of the CTE, as shown in Table 8 and Figure 12. The ultrasonic pulse velocity (UPV) through the concrete was also measured at various ages and is reported in Figure 13. The data show that the set time of the concrete occurred between 5 and 8 hours.

Table 4. Platteville pilot site—concrete mixture design

Component	Description	Batch Weight
Portland Cement	CEMEX - Type 1	395 lbs/yd³
GGBFS		
Fly Ash	ISG - Type C (Spec. Grav. = 2.40)	170 lbs/yd³
Silica Fume		
Coarse Aggregate 1	Hartnett Quarry - Limestone (Spec. Grav = 2.607)	1,826 lbs/yd³
Coarse Aggregate 2		
Fine Aggregate 1	J&R Sand - Natural (Spec. Grav. = 2.612)	1,220 lbs/yd³
Fine Aggregate 2		
Water		203 lbs/yd³
Admixture 1	GRT Polychem VR - Air Entrainer	8.0 oz/yd³
Admixture 2	GRT Polychem 400NC - Water Reducer	17.0 oz/yd³
Water/Cementitious Materials Ratio		0.36
Air Content		7.00%

Figure 7. Iowa State University mobile PCC laboratory

Figure 8. PCC splitting tensile strength test

Figure 9. PCC compressive strength test

Table 5. Platteville pilot site—splitting tensile strength results

Age (hrs)	Maturity, TTF (˚C-hr)	Splitting Tensile Strength	
		psi	MPa
12.	301	188	1.30
24	626	323	2.23
48	1,262	373	2.57
96	2,472	408	2.81
168	4,122	448	3.09

Table 6. Platteville pilot site—compressive strength results

Age (hrs)	Maturity, TTF (˚C-hr)	Compressive Strength	
		psi	MPa
12.	301	1,198	8.26
24	626	2,253	15.53
48	1,262	2,824	19.47
96	2,472	3,408	23.50
168	4,122	4,059	27.99

Figure 10. PCC elastic modulus test

Table 7. Platteville pilot site—elastic modulus results

Age (hrs)	Elastic Modulus	
	psi	MPa
12	1,806,977	1,2458.67
24	2,567,664	1,7703.42
48	2,759,456	1,9025.78
96	3,273,770	2,2571.85
168	3,160,825	2,1793.12
672	4,601,131	3,1723.68

Figure 11. Coefficient of thermal expansion test

Table 8. Platteville pilot site—cumulative results for estimating CTE from surface strains

Direction	Estimated CTE	
	(ε/°F)	(ε/°C)
Longitudinal	7.1×10^{-06}	1.28×10^{-05}
Diagonal	6.6×10^{-06}	1.18×10^{-05}
Transverse	9.2×10^{-06}	1.65×10^{-05}
Average	7.5×10^{-06}	1.35×10^{-05}

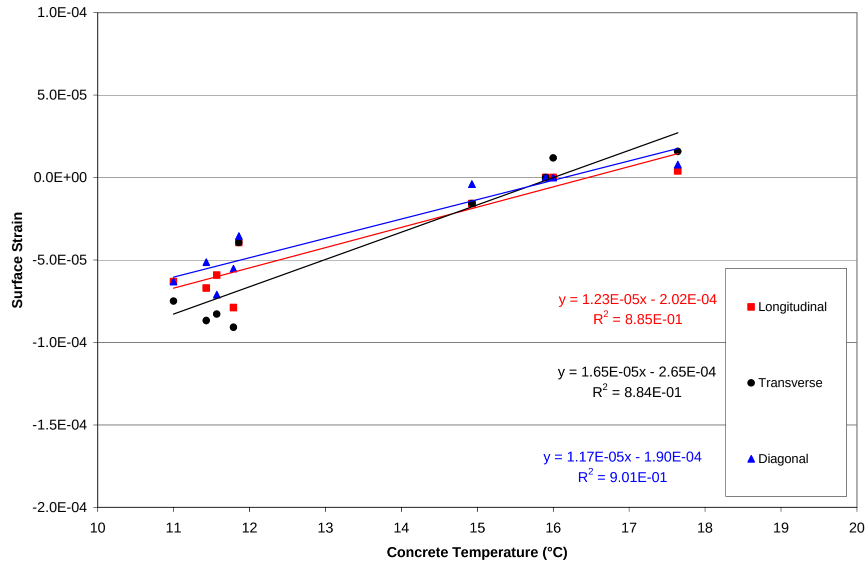


Figure 12. Platteville pilot site—estimation of CTE from surface strains

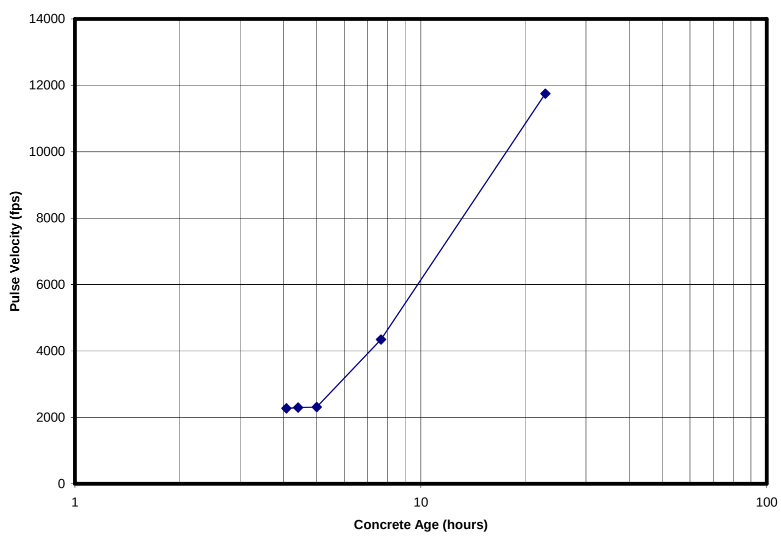


Figure 13. Platteville pilot site—ultrasonic pulse velocity results

Monitoring Early-Age Behavior of Concrete Pavements

Two test sections, as shown in Figure 14, were selected to be representative of the entire pavement length. The selection criteria outlined in the Overall Testing Plan included a relatively flat grade and avoidance of horizontal curves. Figure 15 diagrams the test sections and depicts the location of instrumentation within the 300-foot sections, including the corner Demec instrumentation at the free edge corners of slabs 10 and 11 (typical).

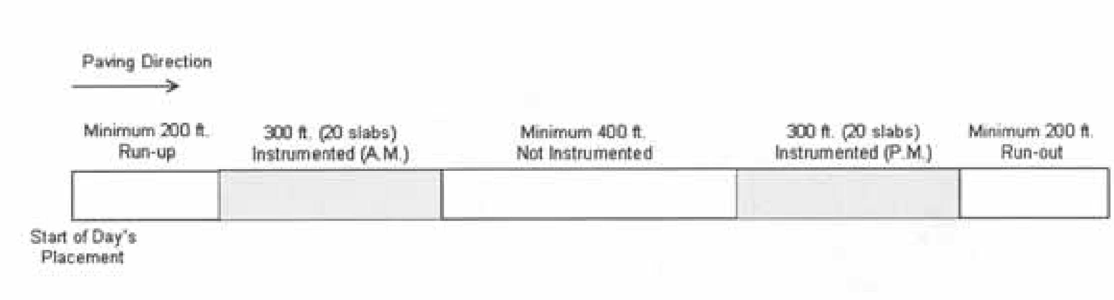


Figure 14. Typical test section layout

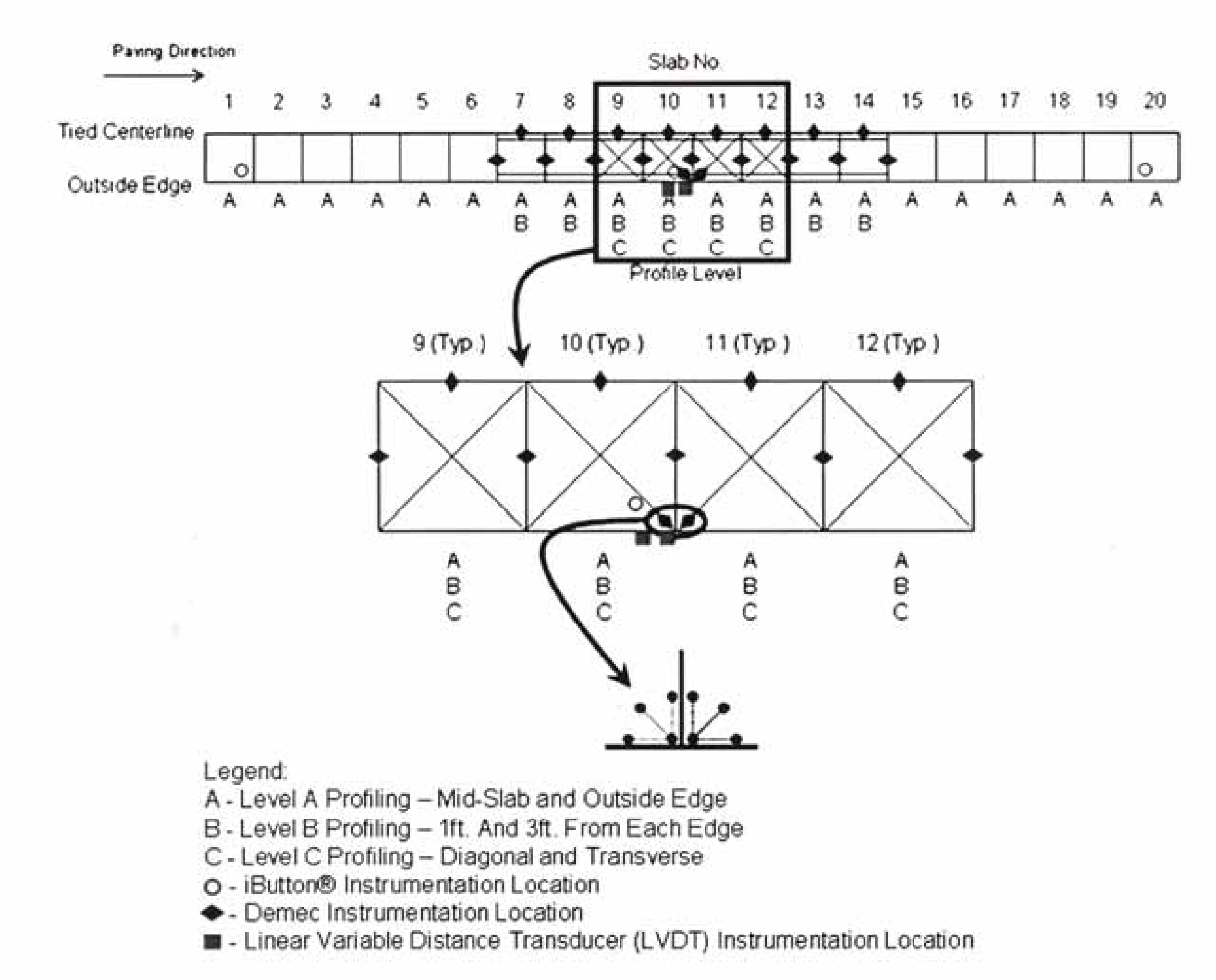


Figure 15. Platteville pilot site—typical instrumentation layout

Diurnal Testing

In order to capture changing slab curvature conditions due to varying slab temperature gradients, field-monitoring activities were performed in a diurnal cycle. For example, it is known that "upward" slab curling, wherein the corners/edges of the slab curl up, occurs when the bottom of the slab is warmer than the top. The maximum upward curling condition generally occurs during early morning hours, just before sunrise. In a similar manner, "downward" slab curling occurs when the top of the slab is warmer than the bottom. The maximum downward curling condition generally occurs around noon or in the very early afternoon, when the surface of the slab is heated by the sun. These "maximum" conditions, of course, are highly dependent on climatic conditions such as cloud cover, but in general, these are the timeframes for the maximum slab temperature gradient. The project team documented the diurnal cycles by continuously recording the environmental conditions before, during, and after construction, as shown in Figure 16.

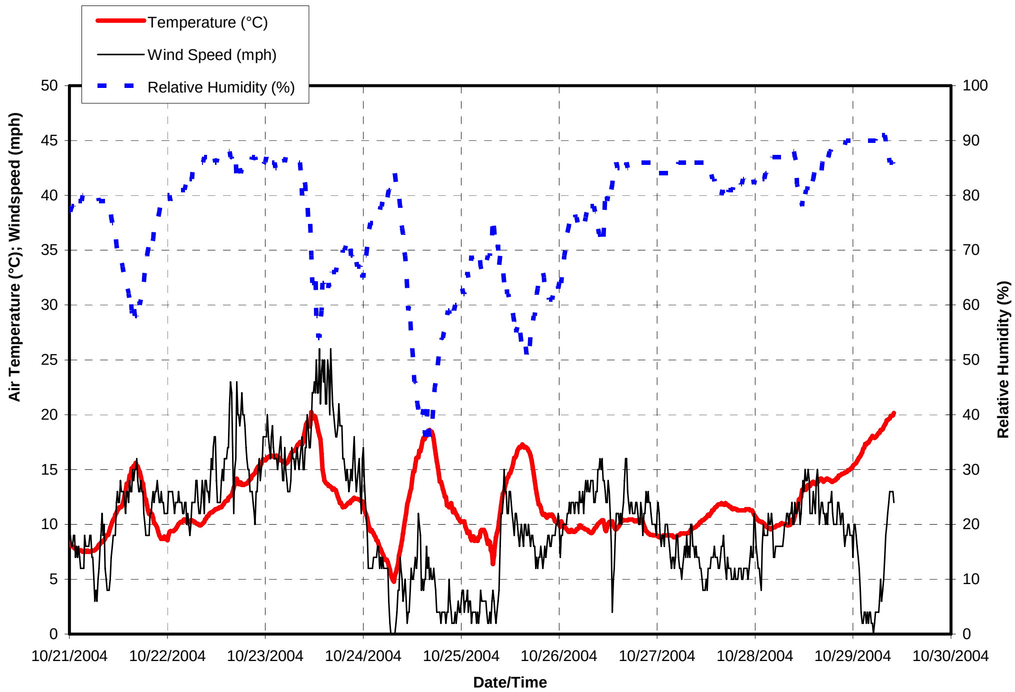


Figure 16. Platteville pilot site—recorded environmental conditions

While, ultimately, the degree of slab curvature is dependent upon "built-in" curvature during construction, the vast majority of jointed plain concrete pavements (JPCP) exhibit diurnal changes in slab curvature. To accommodate for the additional effects of heat generated through cement hydration, two test sections were instrumented corresponding to morning and afternoon construction conditions. This diurnal testing of multiple sections provides a better understanding of the changes in slab curl that occur on a daily basis.

Slab Temperature Gradient

Knowing the temperature gradient in the pavement slab when profile measurements are collected is essential for understanding the correlation between changes in curvature and changes in the temperature gradient. Slab temperature data were logged at five-minute intervals throughout the field-evaluation period. Appendices B and C contain the temperature and maturity records for the two test sections.

Temperature instrumentation consisted of Thermochron iButtons® attached to a stake at different depths and placed before the paver approximately 3 ft (0.9 m) from the pavement edge, as shown in Figure 17.

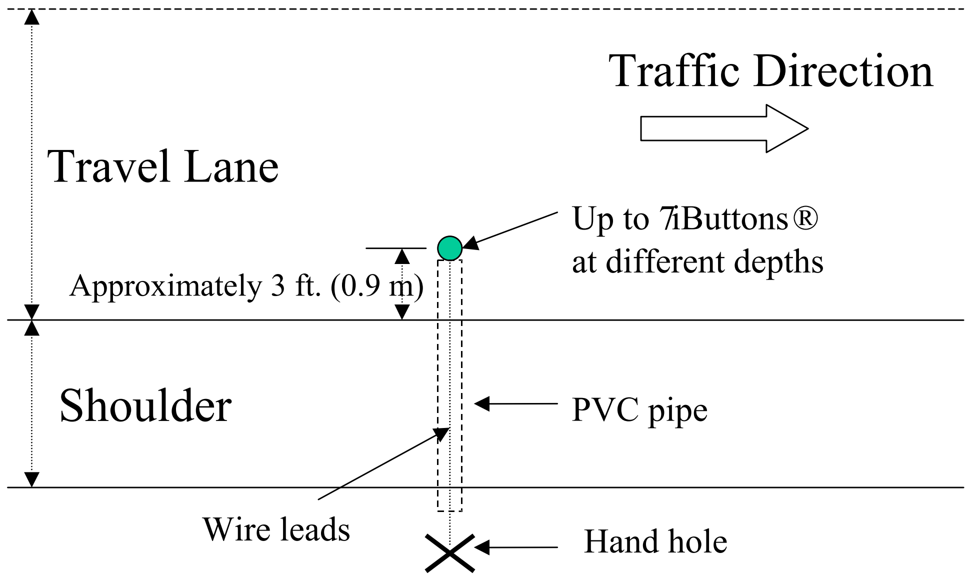


Figure 17. Typical temperature instrumentation layout

Thermochron iButtons® are self-contained temperature sensors that measure and log temperature along with date and time. This information is used to determine the temperature profile during diurnal tests, as well as maturity-estimated strengths. A typical instrumentation setup is shown in Figure 18. In addition to logging slab temperature profiles during the evaluation period, the project team resets the iButtons® to log at 3-hour intervals for seasonal monitoring, allowing up to 256 days before downloading is necessary. Instrumentation leadwires were extended beyond the shoulder in a pipe and buried to facilitate future access, as shown in Figure 19.

Figure 18. Typical temperature instrumentation

Figure 19. Typical temperature instrumentation leadwire protection for future access

Relative and Absolute Joint Opening

To aide in the characterization of slab curling and warping, it was necessary to characterize the movement of transverse and longitudinal joints immediately following construction as well as during diurnal cycles. Beginning shortly after construction, the project team attached stainless steel discs to the pavement surface to be used with DEMEC caliper measurements. Figures 20 and 21 show the discs on the concrete surface for joint movement and surface strain measurements, respectively. These points were installed at the prescribed locations for each instrumented test section as follows (please refer to Figure 15):

- 9 Successive Transverse Joint Locations—Joint Movement
- 8 Successive Longitudinal Joint Locations—Joint Movement
- 2 "Peacock" Patterns at Slab Corners—Surface Strain (CTE)

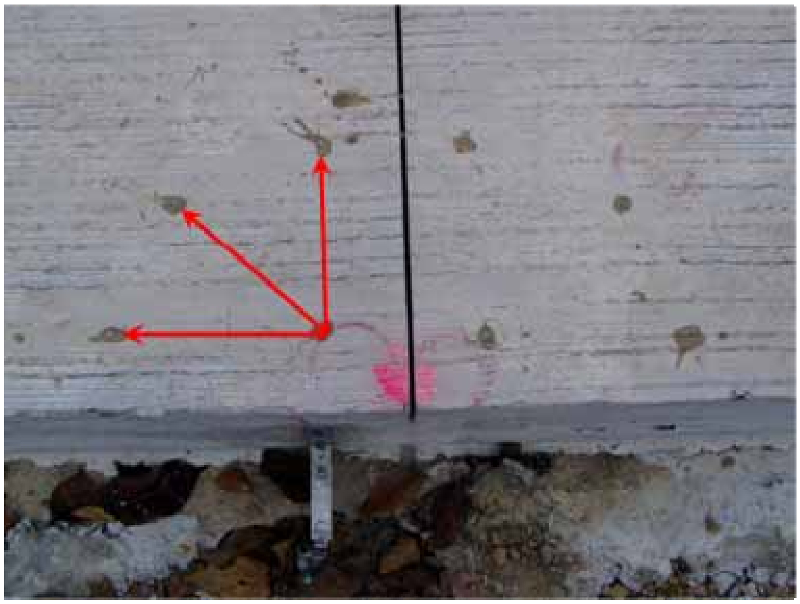


Figure 20. Typical Demec points in the "Peacock" pattern

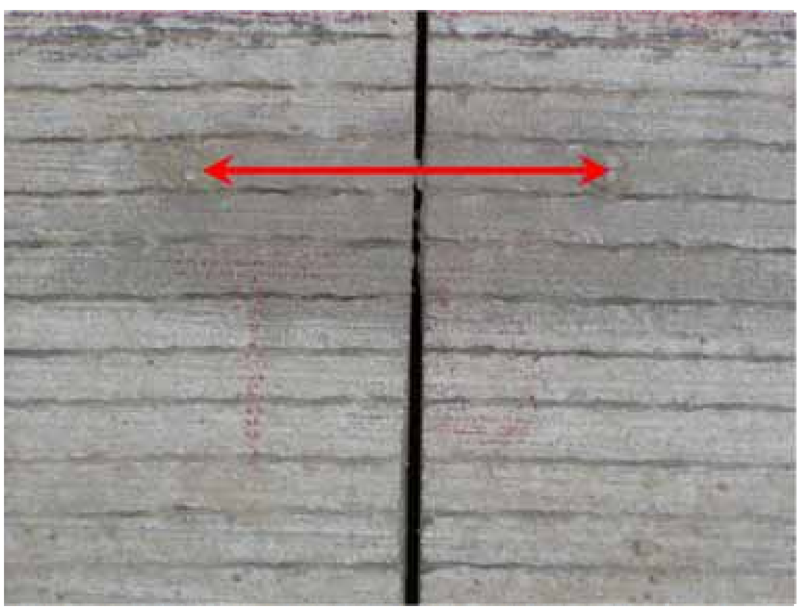


Figure 21. Typical Demec points across a transverse joint

Since this instrumentation involved a new concrete pavement with joints that had not fully began to open and close in direct response to temperature changes, the project team has referenced all relative joint movements to the initial reading taken at each location. To further aid in the analysis, the date, time, concrete age, and average concrete temperature have been provided with each recording. Figure 12 and Table 8 provide the cumulative results for surface strains observed in the "peacock" pattern. It should be noted that this construction took place late in the paving season and resulted in a relatively small range of concrete temperatures. Cumulative results for relative joint movements are provided in Appendices B and C for the morning and afternoon paving test sections, respectively.

Vertical Slab Movement

The project team installed linear variable distance transducers (LVDT) at strategic locations within the slab within each test section. In addition to LVDT installations at the corner and mid-slab free edge (as depicted in Figure 22), an additional six LVDTs were installed in the same slab (as illustrated in Figure 23) to provide data. These measurements are used by the project team as a reference to the absolute slab movement due to curling and warping. The LVDTs were connected to dataloggers, which logged data every 10 minutes. The data for both test sections are provided in Appendices B and C for the morning and afternoon paving test sections, respectively.

Figure 22. Typical LVDT installation (Transtec)

Figure 23. Typical LVDT installation (Iowa State)

Pavement Surface Profiling

The central feature in this research program is the extensive early-age smoothness measurements. The project team used a Dipstick®, an inclinometer-based profiler, to measure pavement surface profiles in three patterns during diurnal cycles, as shown in Figure 24. Level A profiles followed a loop along the outside pavement edge and the mid-slab for all 20 slabs. Level B profiles followed a loop at 1.5 ft. and 3 ft. from the outside free edge and 1 ft. and 3 ft from the longitudinal joint for four successive slabs near the center of the 20-slab test section. Level C profiles followed a "butterfly" pattern of transverse and diagonal traces for the same slabs tested in Level B. Due to the time required to measure all profile patterns during a single diurnal cycle, the testing plan was modified by only collecting Level B profiles in the mid-afternoon diurnal period and by reducing the number of slabs in the Level B profile pattern.

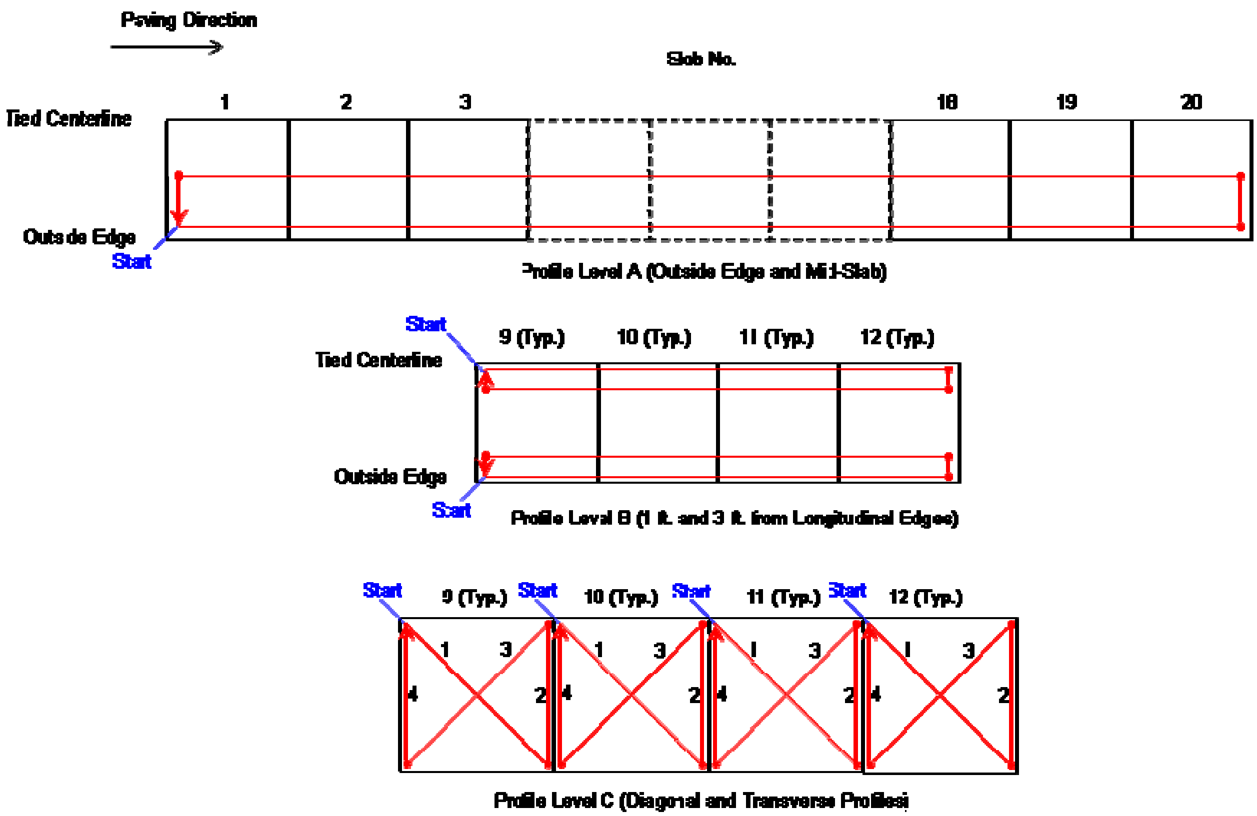


Figure 24. Platteville pilot site—profiling levels and paths

The profile information on the longitudinal paths (Levels A and B) was processed using the FHWA Pavement Profile Viewing and Analysis (ProVAL). Since the Dipstick® profiler records raw elevation data, which includes long wave length content, the profiles were passed through a Butterworth bandpass filter to remove trends from grade changes for visual evaluation. Ride statistics, namely the International Roughness Index (IRI), Pre-transformed Ride Number (PTRN), and Ride Number (RN), were calculated directly from the raw profiles. The calculated ride statistics, as well as other measured parameters, such as pavement temperature, are summarized in the following tables:

- Tables 9 and 10—Level A—Morning Paving Test Section
- Tables 11, 12, 13, and 14—Level B—Morning Paving Test Section
- Tables 15 and 16—Level A—Afternoon Paving Test Section
- Tables 17, 18, 19 and 20—Level B—Afternoon Paving Test

Plots of filtered profiles from Levels A and B are also provided in Appendices B and C for the morning and afternoon paving test sections, respectively.

The “butterfly” pattern of Level C was profiled to measure individual slab curl in diurnal cycles. Due to skewed joint sawcuts, creating non-square slab corners, each of the four profile segments were measured independently. Each segment was first filtered to remove the effect of grade changes and then normalized to the initial profile for comparison purposes. However, the joints had not begun to fully form and move with the diurnal cycle, which would have complicated the analysis. The DEMEC measurements of relative joint opening are necessary to explain the Level C profile results. The results from each path on the four slabs of each test section are reported in Appendices B and C.

Table 9. Platteville pilot site, morning paving—level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
1A121E	10/21/2004 7:00	21.25	67.1	46.4	93	151.4	3.41
1A122E	10/21/2004 10:30	24.75	66.0	50.4	96.1	172.7	3.23
1A31E	10/22/2004 6:00	44.25	59.7	50.7	94.8	175.6	3.21
1A33E	10/22/2004 13:00	51.25	58.6	52.9	92.9	172.8	3.23
1A41E	10/23/2004 7:30	69.75	60.1	62.4	100.6	145.3	3.46
1A43E	10/23/2004 13:00	75.25	63.1	65.1	98.4	149.8	3.43
1A51E	10/24/2004 9:00	95.25	52.9	45.7	97.2	150.4	3.42
1A53E	10/24/2004 14:00	100.25	59.2	62.1	98.6	150.6	3.42
1A61E	10/25/2004 6:30	116.75	52.9	46.8	96	143	3.48
1A63E	10/25/2004 13:10	123.42	57.0	61.0	96.5	146.9	3.45
1A71E	10/26/2004 8:30	142.75	53.2	49.1	93.3	148.2	3.44
1A81E	10/27/2004 6:45	165.00	51.6	48.6	94.5	144.4	3.47
1A83E	10/27/2004 13:00	171.25	52.9	51.6	94.4	147.1	3.45

Table 10. Platteville pilot site, morning paving—level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
1A122M	10/21/2004 10:30	24.75	66.0	50.4	70.7	120.9	3.68
1A41M	10/23/2004 7:30	69.75	60.1	62.4	83	127.3	3.63
1A43M	10/23/2004 13:00	75.25	63.1	65.1	73.8	114.3	3.75
1A51M	10/24/2004 9:00	95.25	52.9	45.7	76.5	116.9	3.72
1A53M	10/24/2004 14:00	100.25	59.2	62.1	78.1	114.7	3.74
1A61M	10/25/2004 6:30	116.75	52.9	46.8	73.3	117.7	3.71
1A63M	10/25/2004 13:10	123.42	57.0	61.0	73.3	106.4	3.82
1A71M	10/26/2004 8:30	142.75	53.2	49.1	72.4	108.3	3.8
1A81M	10/27/2004 6:45	165.00	51.6	48.6	78.7	111.4	3.77

Table 11. Platteville pilot site, morning paving—level B profile summary (1.5 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
1B143	10/23/2004 14:00	76.25	64.2	59.0	62.2	134.2	3.56
1B153	10/24/2004 15:00	101.25	60.4	64.0	71.1	115.6	3.73
1B163	10/25/2004 14:10	124.42	58.8	62.6	64.2	121.6	3.68
1B173	10/26/2004 14:00	148.25	53.8	49.3	64.2	128.6	3.61
1B183	10/27/2004 14:00	172.25	53.2	52.5	68.3	138.2	3.53

Table 12. Platteville pilot site, morning paving—level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
1B243	10/23/2004 14:00	76.25	64.2	59.0	94.2	151.1	3.41
1B253	10/24/2004 15:00	101.25	60.4	64.0	96.9	166.4	3.28
1B263	10/25/2004 14:10	124.42	58.8	62.6	88.2	143	3.48
1B273	10/26/2004 14:00	148.25	53.8	49.3	83.8	142.8	3.49
1B283	10/27/2004 14:00	172.25	53.2	52.5	84.1	136.3	3.54

Table 13. Platteville pilot site, morning paving—level B profile summary (3 ft. from long joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
1B343A	10/23/2004 14:00	76.25	64.2	59.0	109.5	157.3	3.36
1B353A	10/24/2004 15:00	101.25	60.4	64.0	121	177.3	3.2
1B363A	10/25/2004 14:10	124.42	58.8	62.6	117.3	180.3	3.17
1B373A	10/26/2004 14:00	148.25	53.8	49.3	122.1	167.7	3.27
1B383A	10/27/2004 14:00	172.25	53.2	52.5	120.8	170.8	3.25

Table 14. Platteville pilot site, morning paving—level B profile summary (1 ft. from long joint).

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
1B343B	10/23/2004 14:00	76.25	64.2	59.0	87.8	113.5	3.75
1B353B	10/24/2004 15:00	101.25	60.4	64.0	89.2	127.9	3.62
1B363B	10/25/2004 14:10	124.42	58.8	62.6	89.8	123	3.66
1B373B	10/26/2004 14:00	148.25	53.8	49.3	96.7	135.3	3.55
1B383B	10/27/2004 14:00	172.25	53.2	52.5	91.3	125.4	3.64

Table 15. Platteville pilot site, afternoon paving—level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
2A23E	10/21/2004 16:00	23.75	68.2	59.5	99.2	211.9	2.93
2A31E	10/22/2004 8:30	40.25	58.3	50.2	101.4	190.3	3.09
2A42E	10/23/2004 9:45	65.50	61.2	65.7	99.8	164.9	3.3
2A43E	10/23/2004 15:15	71.00	64.2	56.7	89.5	165.2	3.29
2A51E	10/24/2004 7:30	87.25	54.5	50.5	92.5	158.8	3.35
2A53E	10/24/2004 12:00	91.75	57.2	57.6	90.4	156.2	3.37
2A61E	10/25/2004 8:20	112.08	52.9	47.1	85.1	149.1	3.43
2A63E	10/25/2004 15:15	119.00	61.3	63.0	88.2	144.9	3.47
2A71E	10/26/2004 6:30	134.25	53.8	49.3	88.1	162.8	3.31
2A81E	10/27/2004 8:30	160.25	51.6	49.3	88.5	145.8	3.46
2A83E	10/27/2004 15:00	166.75	53.8	53.2	91.3	148.3	3.44

Table 16. Platteville pilot site, afternoon paving—level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
2A31M	10/22/2004 8:30	40.25	58.3	50.2	73.4	122.1	3.67
2A42M	10/23/2004 9:45	65.50	61.2	65.7	84.1	269.4	2.53
2A43M	10/23/2004 15:15	71.00	64.2	56.7	71.9	112.6	3.76
2A51M	10/24/2004 7:30	87.25	54.5	40.6	67.4	114.8	3.74
2A53M	10/24/2004 12:00	91.75	57.2	57.6	71.7	121.4	3.68
2A61M	10/25/2004 8:20	112.08	52.9	47.1	69.9	117.6	3.72
2A63M	10/25/2004 15:15	119.00	61.3	63.0	74.7	119.7	3.7
2A71M	10/26/2004 6:30	134.25	53.8	49.3	68.9	124.9	3.65
2A81M	10/27/2004 8:30	160.25	51.6	49.3	68.1	122.9	3.67
2A83M	10/27/2004 15:00	166.75	53.8	53.2	72.6	118.6	3.71

Table 17. Platteville pilot site, afternoon paving—level B profile summary (1.5 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
2B143A	10/23/2004 16:15	72.00	63.9	55.9	61.2	159.8	3.34
2B153A	10/24/2004 13:00	92.75	59.0	61.0	60.3	135.1	3.55
2B163A	10/25/2004 16:15	120.00	62.4	62.4	60.1	121.9	3.68
2B183A	10/27/2004 16:00	167.75	53.8	53.2	55.6	127.3	3.63

Table 18. Platteville pilot site, afternoon paving—level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
2B143B	10/23/2004 16:15	72.00	63.9	55.9	60.4	145.5	3.46
2B153B	10/24/2004 13:00	92.75	59.0	61.0	72.9	137.4	3.53
2B163B	10/25/2004 16:15	120.00	62.4	62.4	58.4	116.9	3.72
2B183B	10/27/2004 16:00	167.75	53.8	53.2	59.2	106.2	3.82

Table 19. Platteville pilot site, afternoon paving—level B profile summary (3 ft. from long joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
2B243A	10/23/2004 16:15	72.00	63.9	55.9	47.7	118.1	3.71
2B253A	10/24/2004 13:00	92.75	59.0	61.0	48.8	105	3.84
2B263A	10/25/2004 16:15	120.00	62.4	62.4	47.4	109.5	3.79
2B283A	10/27/2004 16:00	167.75	53.8	53.2	44.2	107.2	3.81

Table 20. Platteville pilot site, afternoon paving—level B profile summary (1 ft. from long joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
2B243B	10/23/2004 16:15	72.00	63.9	55.9	70	148.7	3.43
2B253B	10/24/2004 13:00	92.75	59.0	61.0	67.4	138.1	3.53
2B263B	10/25/2004 16:15	120.00	62.4	62.4	56.8	109.3	3.79
2B283B	10/27/2004 16:00	167.75	53.8	53.2	54.7	84.8	4.04

Using measured smoothness indices presented in Tables 9 to 20, the results with respect to measurement times are summarized in Table 21. The measured smoothness indices showed some apparent variations with respect to measurement times (morning and afternoon). Also, the dataset was not complete to conduct statistical analysis.

Table 21. Summary of the measured smoothness indices at different times—Platteville pilot site

	IRI (in/mi)		PTRN (in/mi)		RN	
Test section	Mean @ morning (- temp. diff.)	Mean @ afternoon (+ temp. diff.)	Mean @ morning (- temp. diff.)	Mean @ afternoon (+ temp. diff.)	Mean @ morning (- temp. diff.)	Mean @ afternoon (+ temp. diff.)
Morning paving	85.1	85.2	135.7	130.9	3.55	3.59
Afternoon paving	85.8	71.1	139.0	134.7	3.52	3.57

However, this comparison combines the smoothness metrics calculated from profiles collected at various locations on the slabs and for each of the "morning" and "afternoon" events. It is also noted that a small difference in the smoothness indices can change the grade of pavement from "full pay range" to "penalty range," for instance, based on State smoothness specifications. More than three-fourths of all current PCC smoothness specifications are centered around the Profile Index (PI). The IRI specification for new concrete pavements used by Virginia is reported by Smith et al. (2002) and is presented in Table 22.

Table 22. Virginia DOT smoothness specification for concrete pavements

Index	Bonus range	Full pay range	Penalty range	Correction range
IRI (in/mi)	≤ 60	60.1 - 80	80.1 - 100	>100

For the Platteville pilot site, the measured IRI ranges at different locations during the field evaluation periods are summarized in Table 23 and assigned the corresponding smoothness specification grade (i.e., "full pay," "penalty," or "correction") based on Table 22. From this table, it is clear that changes in IRI during the early age can influence the smoothness specification grade of new concrete pavements. For instance, at the mid-slab location corresponding to morning paving condition, the minimum IRI value was 70.7 in./mi, which entails "full pay," whereas the maximum IRI value, 83.0 in./mi, falls in the "penalty" range. Thus, the differences in measured IRIs during the early age can be significant from the standpoint of smoothness specifications. Similar results were obtained for Burlington and Marshalltown sites, as discussed later on.

Table 23. Summary of the measured IRI range at different locations—Platteville pilot site

Test Section	Location	IRI (in/mi)	
		Maximum / Pavement grade	Minimum
Morning paving	Edge	100.6 / Correction	92.9 / Penalty
	2ft from shoulder	71.1 / Full pay	62.2 / Full pay
	3ft from shoulder	96.9 / Penalty	83.8 / Penalty
	Mid - slab	83.0 / Penalty	70.7 / Full pay
	3ft from longitudinal joint	122.1 / Correction	109.5 / Correction
	2ft from longitudinal joint	96.7 / Penalty	87.8 / Penalty
Afternoon paving	Edge	101.4 / Correction	85.1 / Penalty
	2ft from shoulder	84.1 / Penalty	67.4 / Full pay
	3ft from shoulder	61.2 / Full pay	55.6 / Bonus
	Mid - slab	72.9 / Full pay	58.4 / Bonus
	3ft from longitudinal joint	48.8 / Bonus	44.2 / Bonus
	2ft from longitudinal joint	70.0 / Full pay	54.7 / Bonus

Phase I Summary

As with any aggressive field instrumentation and monitoring plan, the project team faced several issues on the first construction site. It was immediately evident that the capabilities of the inclinometer profiler selected were inadequate for the schedule outlined in the Overall Test Plan. The short amount of time in the early morning diurnal cycle combined with the relatively slow speed on the profiler forced the project team to only collect a shortened Level B profile in the mid-afternoon diurnal period.

In addition to the inadequacy of the profiler, it was also readily evident that the Overall Testing Plan was too aggressive for temperature instrumentation. It was found that only small variations existed between the three instrumentation locations within each test section. In addition, some issues concerning the prescribed laboratory tests in the Overall Testing Plan were not followed precisely and some laboratory samples were compromised.

PHASE II—BURLINGTON, IOWA SITE

The first monitoring project for Phase II took place during the construction of U.S. 34 near Burlington, Iowa. This evaluation generally followed the same activities as for the Pilot site, except for a change in inclinometer profiler type, number of temperature instrumentation locations within each test section, installation of LVDTs in adjacent slabs from only one of the two test sections, as well as the installation of Hygrochron® relative humidity sensors.

Pavement Design

This evaluation was conducted during the construction of a 11.0 in. (280 mm) JPCP. The pavement was constructed upon a 6 in. (152 mm) open-graded granular base. The concrete haul trucks traveled adjacent to the grade and fed the concrete into a spreader, which placed the concrete before the paver. The transverse joint spacing was approximately 19.7 ft. (6.0 m). The passing lane was approximately 11.8 ft. (3.6 m) wide, and the travel lane was approximately 13.8 ft. (4.2 m) wide, which included a 2 ft. (0.6 m) widened lane. An open-graded granular shoulder was added after construction.

Across the longitudinal joints, 35 in. (900 mm) tie-bars (size #5, 0.63 in. or 15.9 mm) were inserted approximately every 29.5 in. (750 mm). Dowel baskets were placed before the paver at transverse joints. The specifications called for smooth dowels of 18.1 in. (460 mm) in length, 1.5 in. (38 mm) in diameter, and spaced at approximately 11.8 in. (300 mm) intervals. The sawcut joints were cleaned and sealed with a hot asphalt sealant.

Early-age saws were used to cut transverse joints to a depth of approximately 1.25 in. (32 mm). Conventional saws were used to cut the longitudinal joint to a depth of approximately 3.7 in. (93 mm). Appendix D contains photos of typical construction operations, including concrete delivery, paving, texturing, curing, and sawing.

Pavement Materials

The concrete mixture design is detailed in Table 24. The strengths of the subbase and subgrade layers were not reported to the project team. The splitting tensile (ASTM C 496 1996) and compressive (ASTM C 39 2001) strengths, as well as corresponding maturity values, are reported in Tables 25 and 26, respectively. The Elastic Modulus test (ASTM C 469 1994) was also conducted at various ages and is reported in Table 27. The coefficient of thermal expansion (CTE) measured from field-fabricated samples tested following AASHTO TP-60 (2000) was reported to be 6.25×10^{-6} ε/°F (1.12×10^{-5} ε/°C). As in the Platteville Pilot site, the project team made estimates of the CTE from measured surface strains in three directions. These results are provided in Table 28 and Figure 25. Due to inclement weather in the time following paving, the project team did not measure the ultrasonic pulse velocity (UPV) to estimate set time. However, the Iowa State University mobile laboratory measured penetration resistance to determine the elapsed time to initial set (6.4 hours) and final set (8.3 hours).

Table 24. Burlington site—concrete mixture design

Component	Description	Batch Weight
Portland Cement	Lafarge - Type 1 (SM)	443 lbs/yd^3
GGBFS		
Fly Ash	Chillicothe - Type C (Spec. Grav. = 2.61)	111 lbs/yd^3
Silica Fume		
Coarse Aggregate 1	River Products (Col. Jct.) - Limestone (Spec. Grav = 2.55)	1,502 lbs/yd^3
Coarse Aggregate 2	River Products (Col. Jct.) - Limestone (Spec. Grav = 2.55)	449 lbs/yd^3
Fine Aggregate 1	Cessford (Spring Grove) - Natural (Spec. Grav. = 2.66)	1095 lbs/yd^3
Fine Aggregate 2		
Water		222 lbs/yd^3
Admixture 1	Brett AEA 92 - Air Entrainer	5.55 oz/yd^3
Admixture 2	Brett Euchon WR - Water Reducer	22.15 oz/yd^3
Water/Cementitious Materials Ratio		**0.40**
Air Content		**6.0%**

Table 25. Burlington site—splitting tensile strength results

Age (hrs)	Maturity, TTF (˚C-hr)	Splitting Tensile Strength	
		Psi	MPa
12	466	89	0.61
24	941	224	1.54
48	1850	296	2.04
96	3718	319	2.20
168	6427	415	2.86

Table 26. Burlington site—compressive strength results

Age (hrs)	Maturity, TTF (˚C-hr)	Compressive Strength	
		psi	MPa
12	466	685	4.72
24	941	1,481	10.21
48	1,850	2,710	18.69
96	3,718	3,738	25.77
168	6,427	4,952	34.14

Table 27. Burlington site—elastic modulus results

Age (hrs)	Elastic Modulus	
	psi	MPa
12	2,239,424	15,440.28
24	2,369,168	16,334.84
48	3,178,214	21,913.02
96	3,829,728	26,405.04
168	4,479,009	30,881.68
672	4,621,292	31,862.68

Table 28. Burlington site—cumulative results for estimating CTE from surface strains

Direction	Estimated CTE	
	(ε/°F)	(ε/°C)
Longitudinal	7.9×10^{-06}	1.42×10^{-05}
Diagonal	8.9×10^{-06}	1.60×10^{-05}
Transverse	8.2×10^{-06}	1.47×10^{-05}
Average	8.3×10^{-06}	1.50×10^{-05}

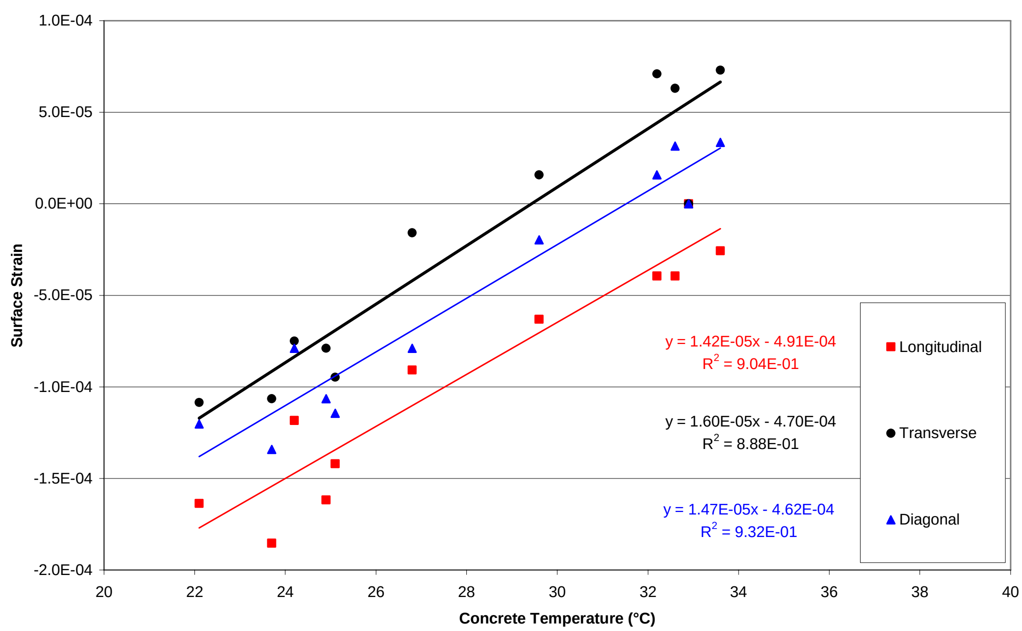


Figure 25. Burlington site—estimation of CTE from surface strains

Monitoring Early-Age Behavior of Concrete Pavements

As in the Platteville Pilot site, the project team selected two test sections, generally following the diagram in Figure 14. The test sections were constructed on the afternoon of June 7, 2005, and morning of June 8, 2005. The project team documented the diurnal cycles by continuously recording the environmental conditions before, during, and after construction, as shown in Figure 26. The project team also measured surface profiles and relative joint movements to capture the extreme points within the diurnal cycle. The revised instrumentation layout for Phase II is provided in Figure 27.

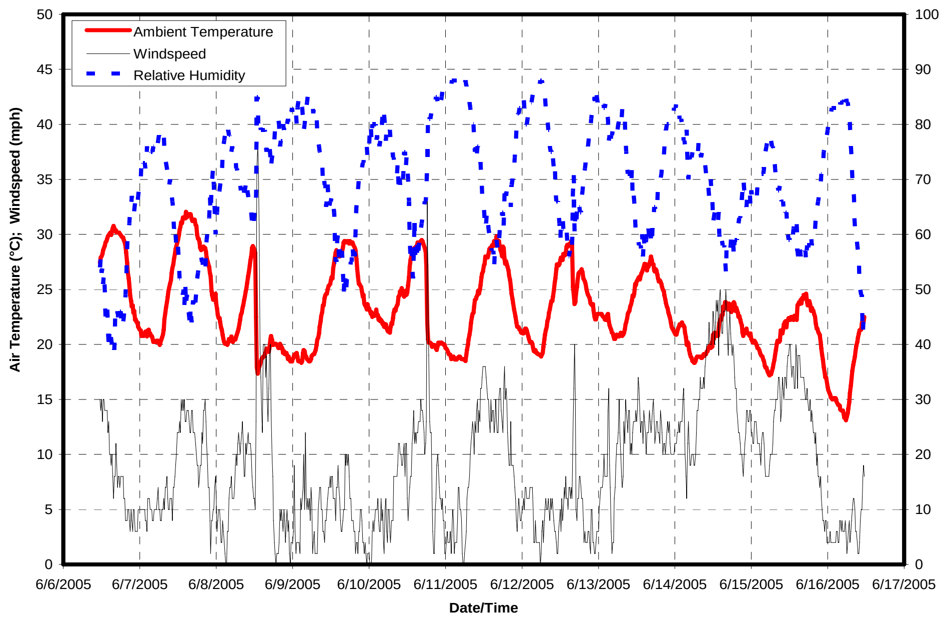


Figure 26. Burlington site—recorded environmental conditions

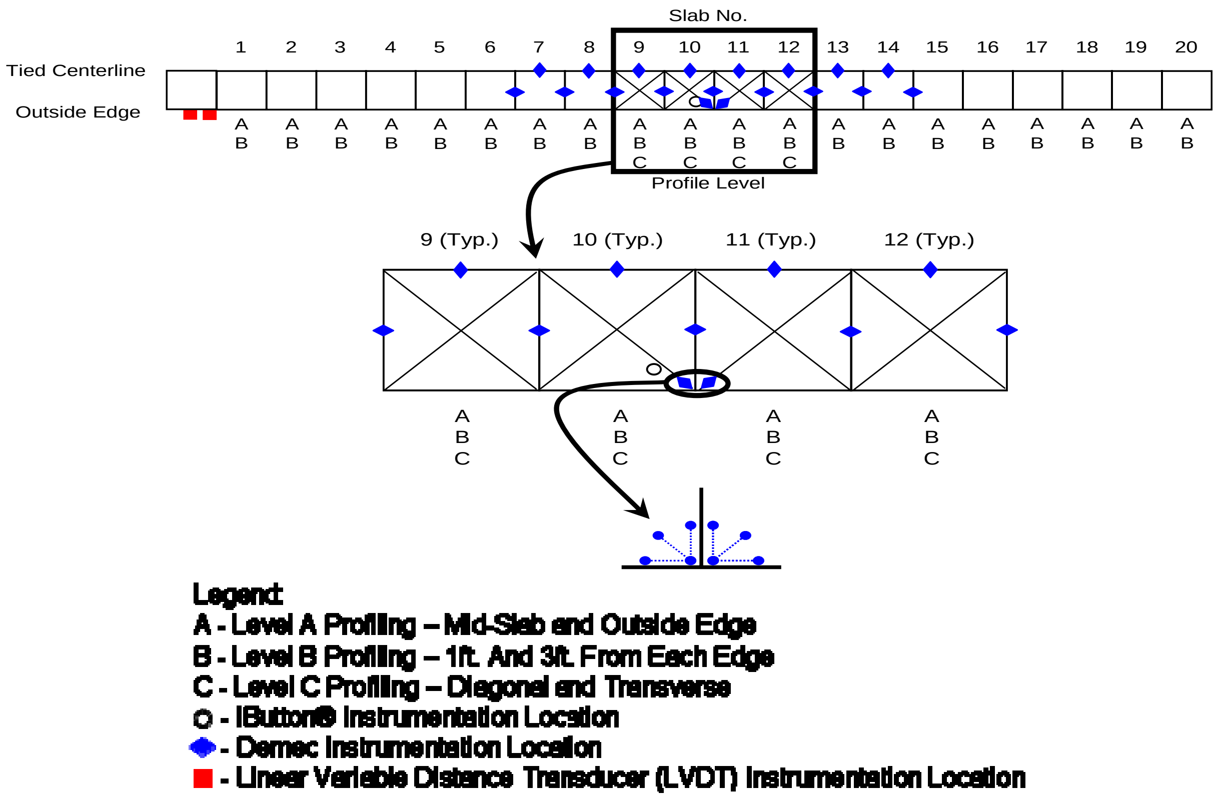


Figure 27. Phase II—typical instrumentation layout

Slab Temperature Gradient

The project team instrumented one location within each test section with Thermochron iButtons® at various depths within the concrete, as diagrammed in Figure 18. Slab temperature data were logged at five-minute intervals throughout the field-evaluation period. Appendices E and F contain the temperature and maturity records at various depths for the two test sections. Figures 28 and 29 present the temperature variations—ambient temperature and slab temperature at top, middle, and bottom—for two test sections. From these figures, pavement temperature is generally higher than ambient temperature and follows a pattern that is similar to that of ambient temperature, as reported by previous research studies (Armaghani 1987).

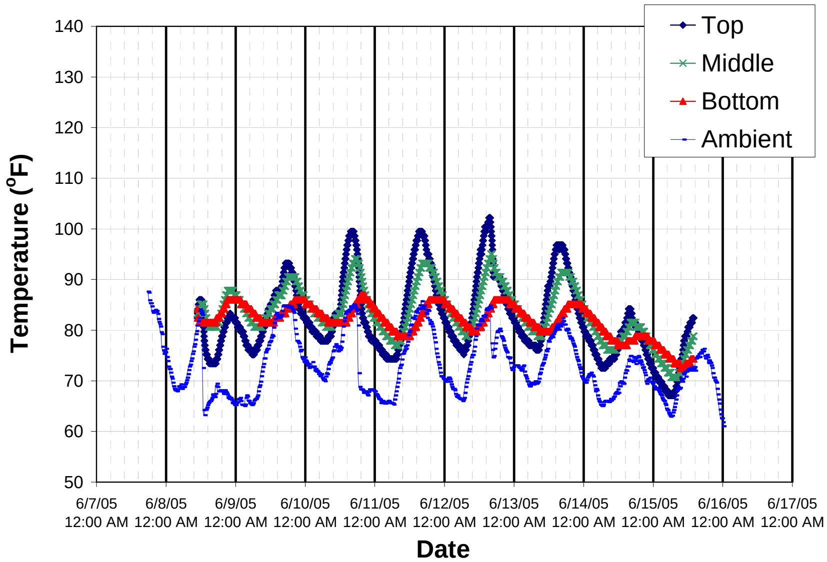


Figure 28. Burlington site—morning paving field temperature variations

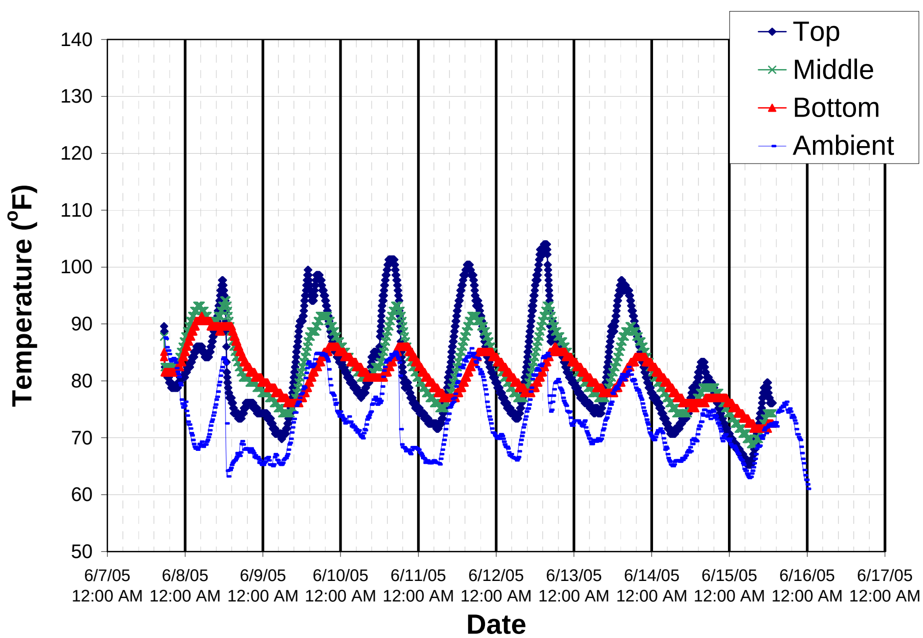


Figure 29. Burlington site—afternoon paving field temperature variations

As in the Platteville Pilot site, this information was used to determine the slab temperature profile during diurnal tests, as well as maturity-estimated strengths. In addition, the project team reset the iButtons® to log at 3-hour intervals for seasonal monitoring, allowing up to 256 days before downloading is necessary, and then extended the leadwires beyond the shoulder in a buried pipe to facilitate future access.

To assess the variation and gradient of moisture within the concrete slab, the project team experimented with installing Hygrochron iButtons® at various depths during construction. Since this instrumentation is unable to be cast into the slab and make measurements, the project team installed them in PVC housings with vent holes at various depths within the slab. The installation process was facilitated with Air Void Analyzer (AVA) sampling, as documented in Appendix D. The results from this instrumentation are provided in Figure 30. As shown in Figure 30, the moisture variations at the top of the slab are more sensitive to ambient moisture variations than at the middle of the slab.

Since the variations in PCC slab curling were directly influenced by temperature difference between the top and the bottom of the slab surface, the variations in temperature differences with time are plotted in Figure 31. In general, temperature differences are positive during daytime and early nighttime and negative during late nighttime and early morning. However, both test sections show the negative gradient at afternoon of June 8, 2005, because top surface of slabs in test sections experienced rapid cooling down during this period due to thunderstorm.

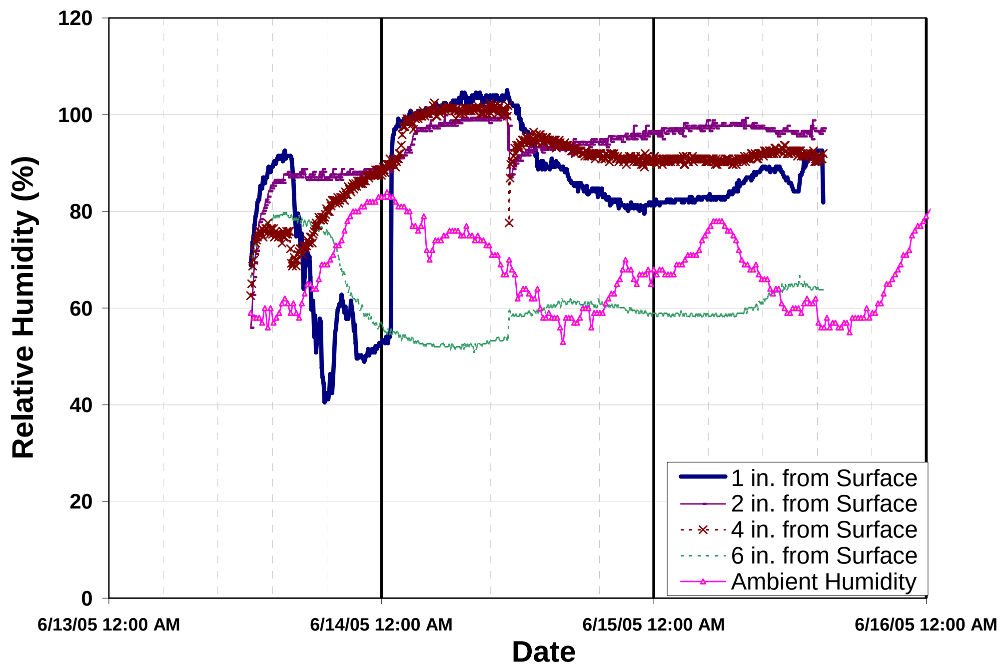


Figure 30. Burlington site—hygrochron relative humidity measurements

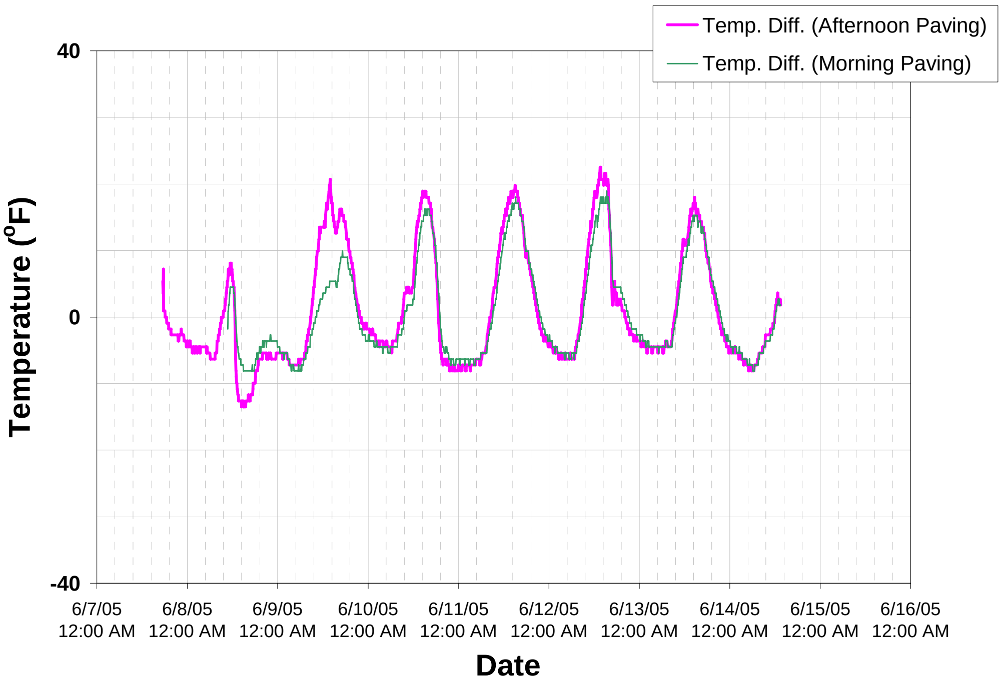


Figure 31. Burlington site—pavement temperature difference between the top and the bottom of slab with time

Relative and Absolute Joint Opening

Following the same procedure as in the Platteville Pilot site, the project team attached stainless steel discs to the pavement surface to reference DEMEC caliper measurements. These points were installed at 9 successive transverse joints, 8 successive longitudinal joints, and 2 "peacock" patterns at slab corners within each test section. Figure 25 and Table 28 provide the cumulative results for surface strains observed in the "peacock" patterns. It is an allowed practice in Iowa to "smooth" the surface with a motor grader prior to taking official profile measurements. This practice, documented with photos in Appendix D, removed some DEMEC discs, which had to be reinstalled. Cumulative results for relative joint movements are provided in Appendices E and F for the morning and afternoon paving test sections, respectively

Vertical Slab Movement

The project team was requested to deviate from the procedure used to install Linear Variable Distance Transducers (LVDT) at the Platteville Pilot site to facilitate additional modeling initiatives. Specifically, the project team instrumented two adjacent slabs within the afternoon paving test section. These measurements are used by the project team as a reference to the absolute slab movement due to curling and warping. LVDT installations on the slab edge and interior slab areas are depicted in Figure 23. The data record for free edge measurements at the mid-slab and corner for the afternoon test section is provided in Appendix F.

Pavement Surface Profiling

Due to the inability to complete all profiling patterns for both test sections within the diurnal cycles with Dipstick® profiler at the Platteville Pilot site, the project team used a SurPRO 2000 from International Cybernetics Corporation for a faster production rate. The SurPRO is a rolling profiler, also an inclinometer-based device, which is capable of collecting longitudinal profiles much faster than the Dipstick®. Besides the faster production rate, the SurPro profiler outputs profiles at one-inch intervals, versus 12-inch intervals by the Dipstick®. This allowed the project team to collect Level B profiles along the entire test section length during the morning and afternoon diurnal cycles. However, due to the fact that the SurPRO is a rolling profiler, it makes collecting a profile loop impractical. Therefore, revised profile patterns (shown in Figure 32) were used to accommodate the data collection. For this site, the paving direction was against the direction of future traffic. All measured profiles are in the direction of future traffic.

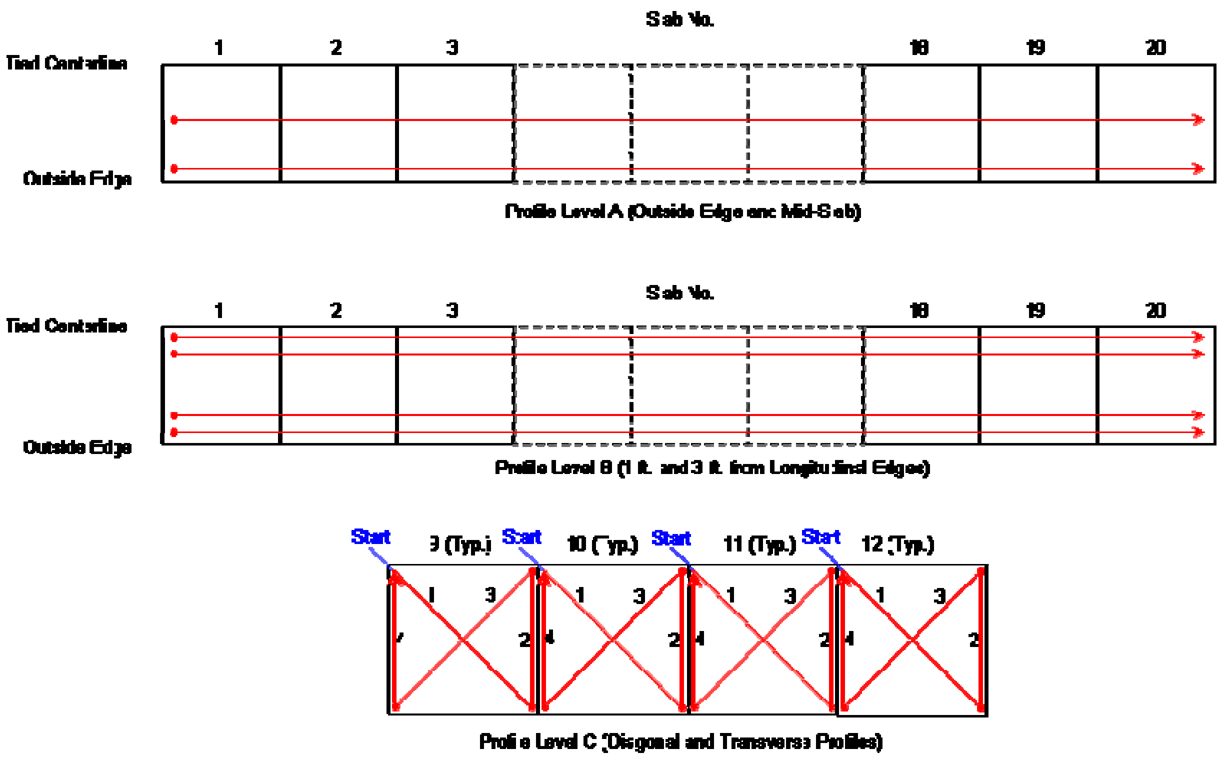


Figure 32. Phase II—profiling levels and paths

The data processing and analysis were performed following the same procedure as for the Platteville Pilot site. The calculated ride statistics and other measured parameters are summarized in the following tables:

- Tables 29 and 30—Level A—Morning Paving Test Section
- Tables 31, 32, 33, and 34—Level B—Morning Paving Test Section
- Tables 35 and 36—Level A—Afternoon Paving Test Section
- Tables 37, 38, 39 and 40—Level B—Afternoon Paving Test

Plots of filtered profiles from Levels A and B are provided in Appendices E and F for the morning and afternoon paving test sections, respectively. Following the same procedure as for the Platteville Pilot site, the individual segments within the Level C "butterfly" pattern were processed and are also reported in Appendices E and F.

Table 29. Burlington site, morning paving—level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1643	6/10/2005 16:43	54.00	92.3	84.9	110.8	250.7	2.65
11JN0645	6/11/2005 6:45	68.00	77.2	67.1	106.2	230.7	2.79
11JN1324	6/11/2005 13:24	74.67	86.9	82.8	103.7	234.8	2.76
12JN0744	6/12/2005 7:44	93.00	78.8	70.9	112.7	231.3	2.79
12JN1438	6/12/2005 14:38	99.92	91.6	84.4	112.6	241.0	2.72
13JN0958	6/13/2005 9:58	119.25	79.7	74.1	101.8	202.0	3.00
13JN1435	6/13/2005 14:35	123.83	88.5	81.1	106.6	223.1	2.85
14JN0642	6/14/2005 6:42	139.92	76.6	65.8	111.6	222.3	2.85
14JN1449	6/14/2005 14:49	148.08	79.2	72.9	107.1	228.9	2.81
15JN0633	6/15/2005 6:33	163.83	70.5	63.7	106.4	232.7	2.78
15JN1244	6/15/2005 12:44	170.00	77.0	72.5	96.6	220.0	2.87

Table 30. Burlington site, morning paving—level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1651	6/10/2005 16:51	54.08	92.1	84.9	75.1	167.0	3.28
11JN0652	6/11/2005 6:52	68.08	77.2	67.1	71.3	166.3	3.29
11JN1332	6/11/2005 13:32	74.75	87.4	82.8	68.0	155.1	3.38
12JN0752	6/12/2005 7:52	93.08	79.0	70.9	63.3	147.4	3.45
12JN1446	6/12/2005 14:46	100.00	91.8	84.4	65.6	150.8	3.42
13JN0906	6/13/2005 9:06	118.33	78.6	72.3	72.0	168.1	3.27
13JN1443	6/13/2005 14:43	124.00	88.9	80.4	65.9	140.1	3.51
14JN0650	6/14/2005 6:50	140.08	76.6	65.8	67.4	160.3	3.34
14JN1456	6/14/2005 14:56	148.17	79.5	72.9	64.7	151.8	3.41
15JN0640	6/15/2005 6:40	163.92	70.5	64.2	71.4	161.5	3.33
15JN1255	6/15/2005 12:55	170.17	77.2	72.3	67.6	154.3	3.39

Table 31. Burlington site, morning paving—level B profile summary (2 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1659	6/10/2005 16:59	54.25	92.3	84.6	86.6	172.4	3.24
11JN1340	6/11/2005 13:40	74.92	87.6	83.7	84.2	161.4	3.33
12JN1454	6/12/2005 14:54	100.17	92.1	84.6	83.0	165.9	3.29
13JN0913	6/13/2005 9:13	118.50	78.6	73.0	86.4	172.6	3.23
13JN1450	6/13/2005 14:50	124.08	88.9	80.4	89.1	173.0	3.23
14JN0656	6/14/2005 6:56	140.17	76.6	66.0	86.6	169.2	3.26
14JN1504	6/14/2005 15:04	148.33	79.7	72.9	85.7	162.3	3.32
15JN0648	6/15/2005 6:48	164.08	70.5	64.2	84.0	166.2	3.29
15JN1305	6/15/2005 13:05	170.33	77.5	72.3	83.8	174.1	3.22

Table 32. Burlington site, morning paving—level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1706	6/10/2005 17:06	54.33	92.3	84.6	68.3	163.6	3.31
11JN1347	6/11/2005 13:47	75.08	88.0	83.7	66.5	148.3	3.44
12JN1501	6/12/2005 15:01	100.25	92.3	84.6	68.3	158.9	3.35
13JN0920	6/13/2005 9:20	118.58	78.6	73.0	69.1	169.6	3.26
13JN1457	6/13/2005 14:57	124.25	89.1	81.1	77.9	174.6	3.22
14JN0703	6/14/2005 7:03	140.33	76.5	66.0	69.3	171.1	3.25
14JN1511	6/14/2005 15:11	148.42	79.7	74.1	67.9	155.7	3.37
15JN0654	6/15/2005 6:54	164.17	70.5	64.8	67.8	152.9	3.4
15JN1312	6/15/2005 13:12	170.50	77.7	72.0	69.9	154.4	3.39

Table 33. Burlington site, morning paving—level B profile summary (3 ft. from long joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1714	6/10/2005 17:14	54.50	92.5	84.0	79.5	173.9	3.22
11JN1355	6/11/2005 13:55	75.17	88.0	83.8	75.1	162.7	3.32
12JN1508	6/12/2005 15:08	100.42	92.3	84.6	70.3	182.2	3.16
13JN0928	6/13/2005 9:28	118.75	79.0	73.2	71.9	144.1	3.48
13JN1503	6/13/2005 15:03	124.33	89.2	81.1	73.7	167.1	3.28
14JN0710	6/14/2005 7:10	140.42	76.6	66.0	79.9	173.1	3.23
14JN1518	6/14/2005 15:18	148.58	79.9	74.1	75.2	165.8	3.29
15JN0701	6/15/2005 7:01	164.25	70.5	64.8	82.6	173.0	3.23

Table 34. Burlington site, morning paving—level B profile summary (1 ft. from long joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1721	6/10/2005 17:21	54.58	92.5	84.0	93.3	210.9	2.94
11JN1404	6/11/2005 14:04	75.33	88.3	83.8	89.2	204.8	2.98
12JN1515	6/12/2005 15:15	100.50	92.5	84.6	93.0	233.3	2.77
13JN0935	6/13/2005 9:35	118.83	79.0	73.2	84.7	196.9	3.04
13JN1510	6/13/2005 15:10	124.42	89.2	80.1	90.9	211.8	2.93
14JN0718	6/14/2005 7:18	140.58	76.5	66.0	73.8	165.2	3.29
14JN1525	6/14/2005 15:25	148.67	80.4	73.9	85.2	184.8	3.14
15JN0708	6/15/2005 7:08	164.42	70.5	65.5	83.8	191.7	3.08

Table 35. Burlington site, afternoon paving—level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
08JN1814	6/8/2005 18:14	24.75	80.2	68.2	78.9	166.0	3.29
09JN0803	6/9/2005 8:03	38.58	74.7	69.1	75.8	161.9	3.32
09JN1446	6/9/2005 14:46	45.25	88.2	82.4	80.8	181.7	3.16
10JN0733	6/10/2005 7:33	62.08	80.1	72.3	79.8	170.4	3.25
10JN1429	6/10/2005 14:29	69.00	89.8	83.7	86.4	210.1	2.94
11JN0734	6/11/2005 7:34	86.08	75.6	69.6	79.0	172.9	3.23
11JN1459	6/11/2005 14:59	93.50	89.8	84.0	74.4	173.0	3.23
12JN0702	6/12/2005 7:02	109.50	76.8	68.7	80.2	182.4	3.15
12JN1315	6/12/2005 13:15	115.75	89.4	82.8	75.4	177.5	3.19
13JN0716	6/13/2005 7:16	133.75	77.4	69.8	78.9	173.1	3.23
13JN1310	6/13/2005 13:10	139.67	84.4	79.2	77.9	181.9	3.16
14JN0754	6/14/2005 7:54	158.42	74.7	66.0	82.6	194.6	3.06
14JN1615	6/14/2005 16:15	166.75	79.5	73.9	92.3	211.0	2.93
15JN0855	6/15/2005 8:55	183.42	70.9	68.5	75.8	174.0	3.22

Table 36. Burlington site, afternoon paving—level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
08JN1836	6/8/2005 18:36	25.08	80.1	68.2	79.0	153.5	3.39
09JN0814	6/9/2005 8:14	38.75	75.0	69.8	70.9	162.0	3.32
09JN1456	6/9/2005 14:56	45.42	88.2	82.6	58.8	144.8	3.47
10JN0744	6/10/2005 7:44	62.25	80.4	73.2	67.1	159.5	3.34
10JN1436	6/10/2005 14:36	69.08	90.0	83.7	68.1	162.4	3.32
11JN0742	6/11/2005 7:42	86.17	75.6	70.3	64.8	161.9	3.32
11JN1508	6/11/2005 15:08	93.67	90.1	84.9	67.2	153.4	3.39
12JN0653	6/12/2005 6:53	109.42	77.0	68.7	66.3	174.8	3.22
12JN1323	6/12/2005 13:23	115.92	89.8	82.6	67.0	166.6	3.28
13JN0724	6/13/2005 7:24	133.92	77.2	69.4	64.1	134.6	3.56
13JN1318	6/13/2005 13:18	139.83	84.7	79.2	63.3	158.8	3.35
14JN0801	6/14/2005 8:01	158.50	74.7	66.0	67.6	169.6	3.26
14JN1622	6/14/2005 16:22	166.83	79.5	73.9	73.8	165.0	3.30
15JN0902	6/15/2005 9:02	183.50	70.9	68.5	62.3	161.4	3.33

Table 37. Burlington site, afternoon paving—level B profile summary (2 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
09JN0843	6/9/2005 8:43	39.25	75.6	71.8	94.2	195.4	3.05
09JN1509	6/9/2005 15:09	45.67	88.2	82.8	95.9	198.4	3.03
10JN0754	6/10/2005 7:54	62.42	80.6	73.8	96.2	220.0	2.87
10JN1443	6/10/2005 14:43	69.25	90.3	84.0	107.7	226.7	2.82
11JN1516	6/11/2005 15:16	93.75	90.1	84.9	104.1	231.1	2.79
12JN1333	6/12/2005 13:33	116.08	90.1	82.6	107.6	237.6	2.74
13JN0733	6/13/2005 7:33	134.08	77.2	69.4	98.5	174.9	3.21
13JN1326	6/13/2005 13:26	140.00	85.3	79.5	107.3	219.1	2.88
14JN0807	6/14/2005 8:07	158.67	74.8	66.0	102.0	231.4	2.79
14JN1629	6/14/2005 16:29	167.00	79.2	73.9	99.4	211.8	2.93
15JN0909	6/15/2005 9:09	183.67	71.4	70.3	96.1	203.0	2.99

Table 38. Burlington site, afternoon paving—level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
09JN0849	6/9/2005 8:49	39.33	75.6	71.8	86.4	219.4	2.87
09JN1519	6/9/2005 15:19	45.83	88.2	82.8	77.7	183.8	3.14
10JN0811	6/10/2005 8:11	62.67	80.4	73.6	75.2	190.2	3.09
10JN1450	6/10/2005 14:50	69.33	90.7	84.0	74.1	173.9	3.22
11JN1525	6/11/2005 15:25	93.92	90.3	84.9	81.2	197.6	3.04
12JN1339	6/12/2005 13:39	116.17	90.3	82.9	72.4	179.6	3.18
13JN0742	6/13/2005 7:42	134.17	77.2	69.6	69.7	154.3	3.39
13JN1333	6/13/2005 13:33	140.08	85.3	79.5	78.8	186.4	3.12
14JN0814	6/14/2005 8:14	158.75	74.8	65.8	80	197.3	3.04
14JN1641	6/14/2005 16:41	167.17	79.3	73.8	76.6	188.7	3.10
15JN0917	6/15/2005 9:17	183.83	71.8	70.3	67.5	160.2	3.34

Table 39. Burlington site, afternoon paving—level B profile summary (3 ft. from long joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
09JN0915	6/9/2005 9:15	39.75	76.5	73.2	76.6	168	3.27
09JN1531	6/9/2005 15:31	46.00	88.2	82.9	73.8	154.6	3.38
10JN0825	6/10/2005 8:25	62.92	80.4	73.9	68.8	152.0	3.41
10JN1458	6/10/2005 14:58	69.50	90.7	84.0	64.1	124.6	3.65
11JN1533	6/11/2005 15:33	94.08	90.7	84.9	66.0	139.2	3.52
12JN1349	6/12/2005 13:49	116.33	90.7	82.9	57.5	129.8	3.60
13JN0750	6/13/2005 7:50	134.33	77.0	69.6	59.9	113.6	3.75
13JN1341	6/13/2005 13:41	140.17	85.8	79.9	77.2	146.9	3.45
14JN0821	6/14/2005 8:21	158.83	74.8	65.8	65.0	150.1	3.42
14JN1650	6/14/2005 16:50	167.33	79.0	73.8	62.7	138.8	3.52
15JN0925	6/15/2005 9:25	183.92	71.8	70.2	58.4	124	3.66

Table 40. Burlington site, afternoon paving—level B profile summary (1 ft. from long joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
09JN0920	6/9/2005 9:20	39.83	76.5	73.2	71.6	192.2	3.08
09JN1543	6/9/2005 15:43	46.25	88.5	83.8	68.6	181.8	3.16
10JN0834	6/10/2005 8:34	63.08	80.4	73.9	57.3	174.9	3.21
10JN1507	6/10/2005 15:07	69.67	91.0	84.0	56.7	160.0	3.34
11JN1546	6/11/2005 15:46	94.25	90.9	84.4	61.9	154.0	3.39
12JN1355	6/12/2005 13:55	116.42	90.7	84.0	62.4	163.8	3.31
13JN0758	6/13/2005 7:58	134.50	77.0	69.8	60.2	161.3	3.33
13JN1348	6/13/2005 13:48	140.33	86.0	79.9	68.8	178.2	3.19
14JN0826	6/14/2005 8:26	158.92	74.8	65.8	74.8	186.2	3.12
14JN1656	6/14/2005 16:56	167.42	79.0	74.7	69.1	159.7	3.34
15JN0932	6/15/2005 9:32	184.00	71.8	70.2	59.0	145.8	3.46

As can be seen in Tables 29 to 40 and in plots of filtered profiles from Levels A and B provided in Appendices E and F, there are variations with respect to measurement locations in both test sections, as reported by Karamihas et al. (1999). These results indicate that profiling measurement for quality control should be conducted along the actual traffic wheel-path of pavement to obtain consistent measurements. Although the measured IRI and RN showed some apparent variations with respect to measurement times (morning and afternoon), they may not be significant. To examine if these variations were statistically significant, a statistical test, Analysis of Variance (ANOVA), was conducted and the results are summarized in Table 41.

Table 41. Burlington site—ANOVA for the measured smoothness indices at different times

Test section	IRI (in/mi)			PTRN (in/mi)			RN		
	Mean @ morning (- temp. diff.)	Mean @ afternoon (+ temp. diff.)	p-value	Mean @ morning (- temp. diff.)	Mean @ afternoon (+ temp. diff.)	p-value	Mean @ morning (- temp. diff.)	Mean @ afternoon (+ temp. diff.)	p-value
Morning paving	82.9	82.8	0.98	180.4	182.6	0.78	3.18	3.16	0.81
Afternoon paving	74.5	76.6	0.51	172.6	176.4	0.55	3.24	3.21	0.55

ANOVA results can be expressed in terms of p-values, which represent the weight of evidence for rejecting the null hypothesis (Ott and Longnecker 2001). The null hypothesis of sample equality cannot be rejected if p-value is greater than the selected significance level. From Table 41, all p-values are higher than 0.05 (95% significance level), which indicates that the measured smoothness indices with respect to measurement times (morning vs. afternoon) may not be different.

However, this comparison combines the smoothness metrics calculated from profiles collected at various locations on the slabs and for each of the "morning" and "afternoon" events (recognizing that the slabs during these early ages are undergoing irreversible changes). It is also noted that a small difference in the smoothness indices can change the grade of pavement from "full pay range" to "penalty range," for instance, based on State smoothness specifications. The measured IRI ranges at different locations during the field evaluation periods are summarized in Table 42 for the Burlington site and assigned the corresponding smoothness specification grade (i.e., "full pay," "penalty," or "correction") based on Table 22. From this table, it is clear that changes in IRI during the early age can influence the smoothness specification grade of new concrete pavements. Note that similar conclusions were reached for the Platteville pilot site discussed previously.

Table 42. Summary of the measured IRI ranges at different locations—Burlington site

Test section	Location	IRI (in/mi) Maximum / Pavement grade	IRI (in/mi) Minimum / Pavement grade
Morning paving	Edge	112.7 / Correction	96.6 / Penalty
	2ft from shoulder	89.1 / Penalty	83.0 / Penalty
	3ft from shoulder	77.9 / Full pay	67.8 / Full pay
	Mid - slab	72.0 / Full pay	63.3 / Full pay
	3ft from longitudinal joint	82.6 / Penalty	70.3 / Full pay
	2ft from longitudinal joint	93.0 / Penalty	73.8 / Full pay
Afternoon paving	Edge	92.3 / Penalty	74.4 / Full pay
	2ft from shoulder	107.7 / Correction	94.2 / Penalty
	3ft from shoulder	86.4 / Penalty	69.7 / Full pay
	Mid - slab	73.8 / Full pay	58.8 / Bonus
	3ft from longitudinal joint	77.2 / Full pay	57.5 / Bonus
	2ft from longitudinal joint	74.8 / Full pay	56.7 / Bonus

It is anticipated that a more detailed analysis would be performed based on results from a related ongoing FHWA project entitled "Inertial Profile Data for Pavement Performance Analysis." As part of this effort, more relevant means to quantify slab curvature have been developed which will be applied to this database.

Finite Element Simulation

The FE simulation was conducted to understand the early-age behavior of concrete pavement systems in more detail. ISLAB 2000 and EverFE 2.24 were primarily selected as FE programs because of special advantages over other FE programs. Both programs are specially made for rigid pavement analysis. The ISLAB 2000 two-dimensional (2-D) FE program is a key component in the next generation mechanistic-empirical pavement design guide. EverFE 2.24 is the only available three-dimensional (3-D) FE program among the ready-made FE software.

Based on the actual geometric proportions and the material properties collected from the test sections, the unknown input parameters required in FE simulations were assumed based on the results of the parametric study. For example, it has been observed that the slab deformation increases for increasing modulus of subgrade reaction (*k*) from 30 psi/in to 130 psi/in, but for *k* values greater than 130 psi/in, the slab deformation does not increase much. The value 130 psi/in is a typical minimum value for subgrade reaction in Iowa; therefore, 230 psi/in was assumed as the modulus of subgrade reaction (*k*) for FE simulation. Three consecutive slabs in each lane were used, as shown in Figure 33, and middle slab in the travel lane was selected to represent field measurements. Although the slab temperature profiles with depth have been recognized as non-linear distributions, the observed temperature profiles under which the pavement profile data were collected in this study showed nearly a linear temperature distribution, so the linear temperature distributions were used in this simulation.

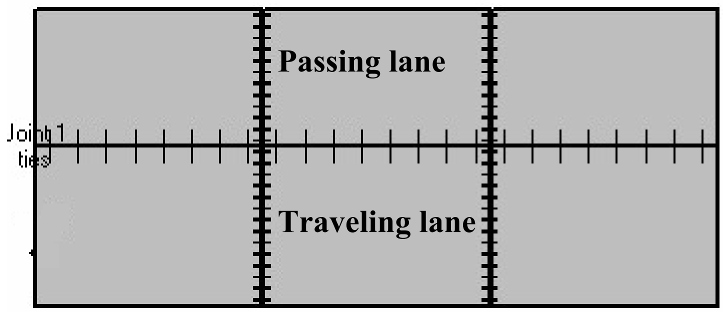


Figure 33. Three consecutive slab systems in each lane used in FE simulation

Even though ISLAB 2000 and EverFE 2.24 can simulate the slab deformation due to temperature changes, it cannot directly simulate the slab deformation due to moisture variations and permanent deformation at zero temperature difference and zero moisture difference which can be apparent during early age. Therefore, if FE simulation were conducted using the actual material inputs and the actual linear/non-linear temperature distributions, still the calculated deflection would not match the actual deflection due to environmental effects (Rao et al. 2001). However, it is believed that this limitation could be circumvented if the effects of other environmental loadings could be converted into an equivalent temperature difference (Korovesis 1990; Davids 2003).

Since all the environmental effects are highly correlated with each other, it is quite difficult to quantify each of these effects in terms of temperature differences; therefore, the concept of combining all of the active effects into an equivalent temperature difference has been used by previous researchers (Rao et al. 2001; Yu and Khazanovich 2001; Jeong and Zollinger 2004; Rao and Roesler 2005). Using this concept, the relation between actual measured temperature difference and equivalent temperature difference associated with actual pavement behavior could be established. Similar to the approach used by previous researchers (Rao et al. 2001; Yu and Khazanovich 2001; Jeong and Zollinger 2004), equivalent temperature differences of both FE programs were back-estimated to generate the relative corner deflection to center of the measured slab curvature profiles from diagonal direction. This was done so because these profiles represent the longest segments along the slab and include the internal center in slab. Once the equivalent temperature difference on given measured temperature difference was estimated, the equivalent temperature difference values were plotted with measured temperature differences, as shown in Figure 34. From Figure 34, the equivalent temperature differences and the measured temperature differences show a linear relation.

Linear regression equations from Figure 34 show the difference between ISLAB 2000 and EverFE 2.24 approaches since the basic elements constituting the meshes in these programs (thin plate element for ISLAB 2000 and solid element for EverFE 2.24) have different nodes and degrees of freedom. It is interesting to note that the coefficient of linear regression equation is less than unity. It is possible to relate the coefficient and the independent variable of the linear regression equation to the transient component of equivalent temperature difference (temperature and moisture gradient variation) and the intercept of the regression equation to the permanent component of equivalent temperature difference (unrecoverable shrinkage, temperature condition during construction, and creep).

It is interesting to note that approximately –8°F (–4°C) for ISLAB 2000 and –11°F (–6°C) for EverFE 2.24 were obtained as intercepts for the linear regression equations in this study, which is similar to a value of –10°F (–5.6°C) defined as permanent curl/warp effective temperature difference in the MEPDG through national calibration results. Based on linear regression equations from Figure 34, equivalent temperature differences during pavement profile data collection were calculated and used as inputs for both FE programs.

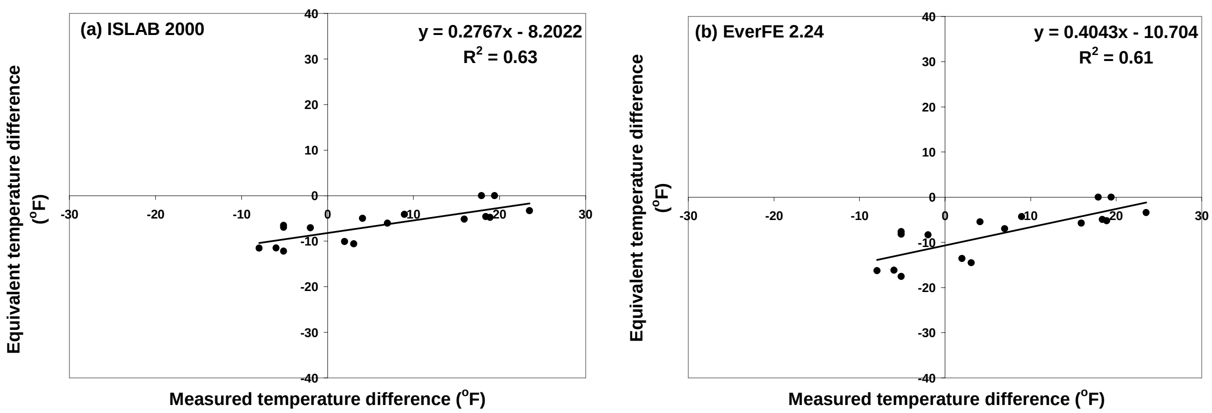


Figure 34. Burlington site—equivalent temperature differences versus measured temperature differences

FE simulated results were compared with the measured slab curl behaviors in diurnal cycles obtained from the average level C profile of slabs and provided in Appendices E and F for the morning and afternoon paving test sections. In addition, FE simulated results were quantified with the numerical values in order to identify the difference. If the slab behavior could be characterized in terms of total amount of deflection and the slab shape, the total amount of deflection could be quantified using the relative deflection of corner to center in the measured direction (*Rc*), and the slab shape could be quantified by the curvature of slab profile (*k*). The quantitative comparisons between the measured profiles and the FE simulated profiles for morning paving section and afternoon paving section are presented in Figures 35, 36, 37, and 38.

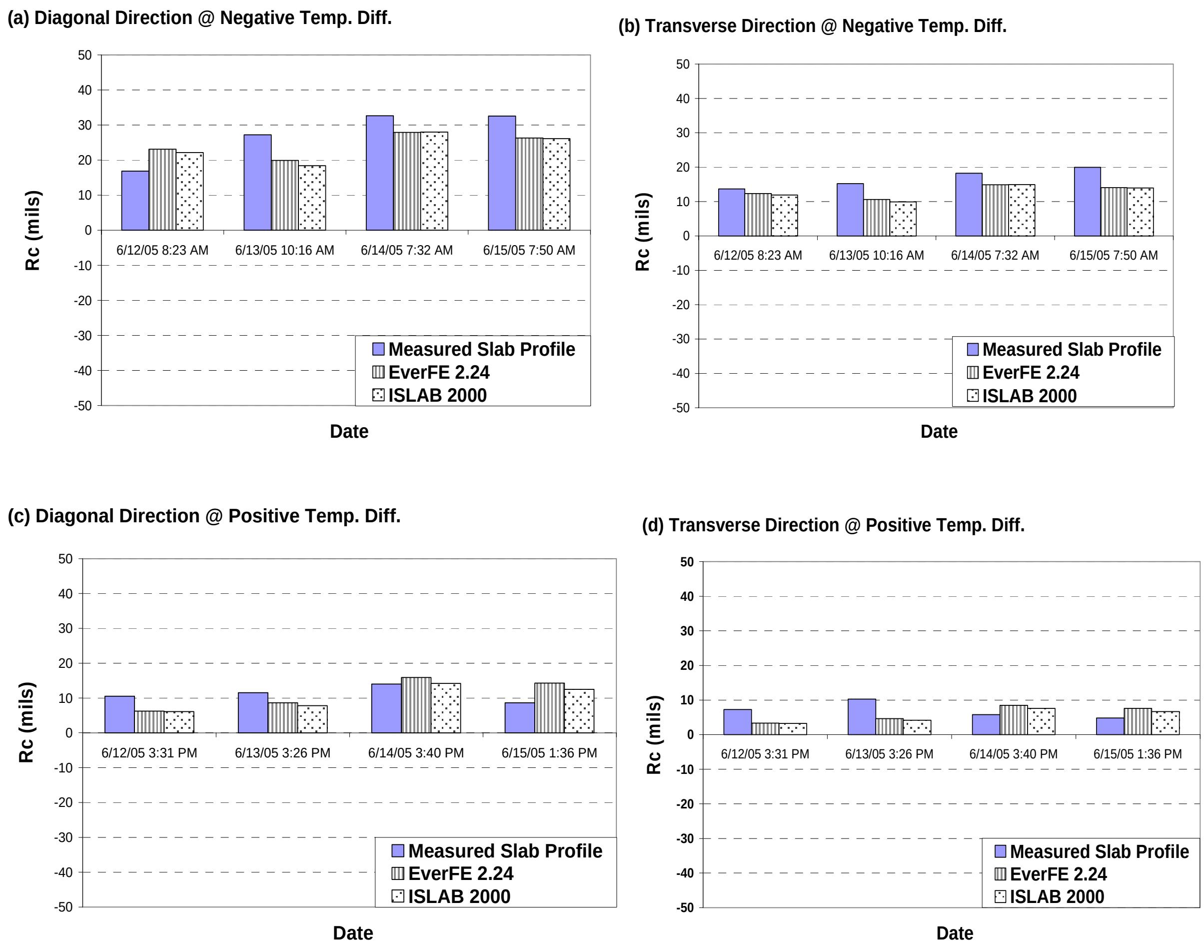


Figure 35. Burlington site, morning paving—comparisons of relative corner deflection (*Rc*) between measured and FE-predicted slab curvature profiles

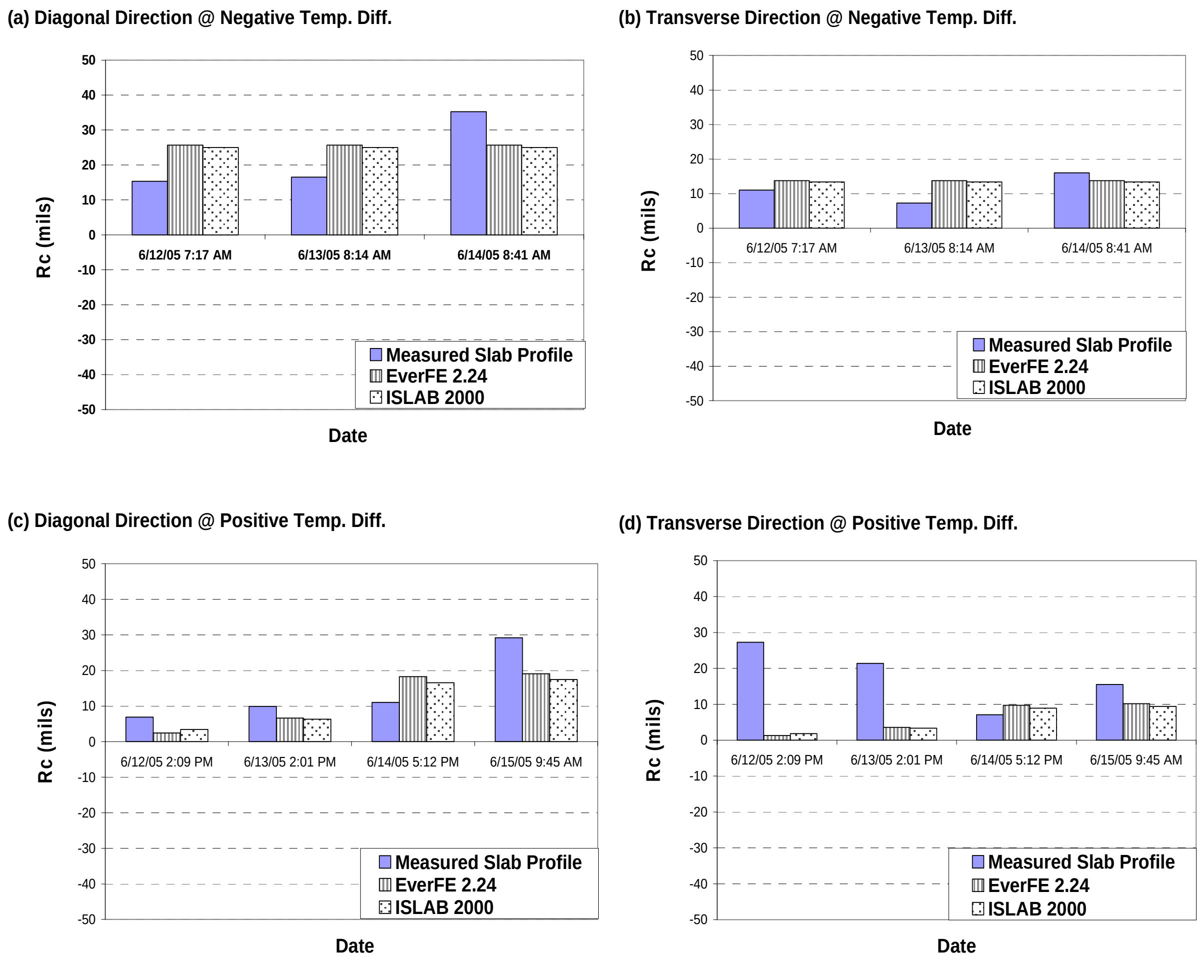


Figure 36. Burlington site, afternoon paving—comparisons of relative corner deflection (*Rc*) between measured and FE-predicted slab curvature profiles

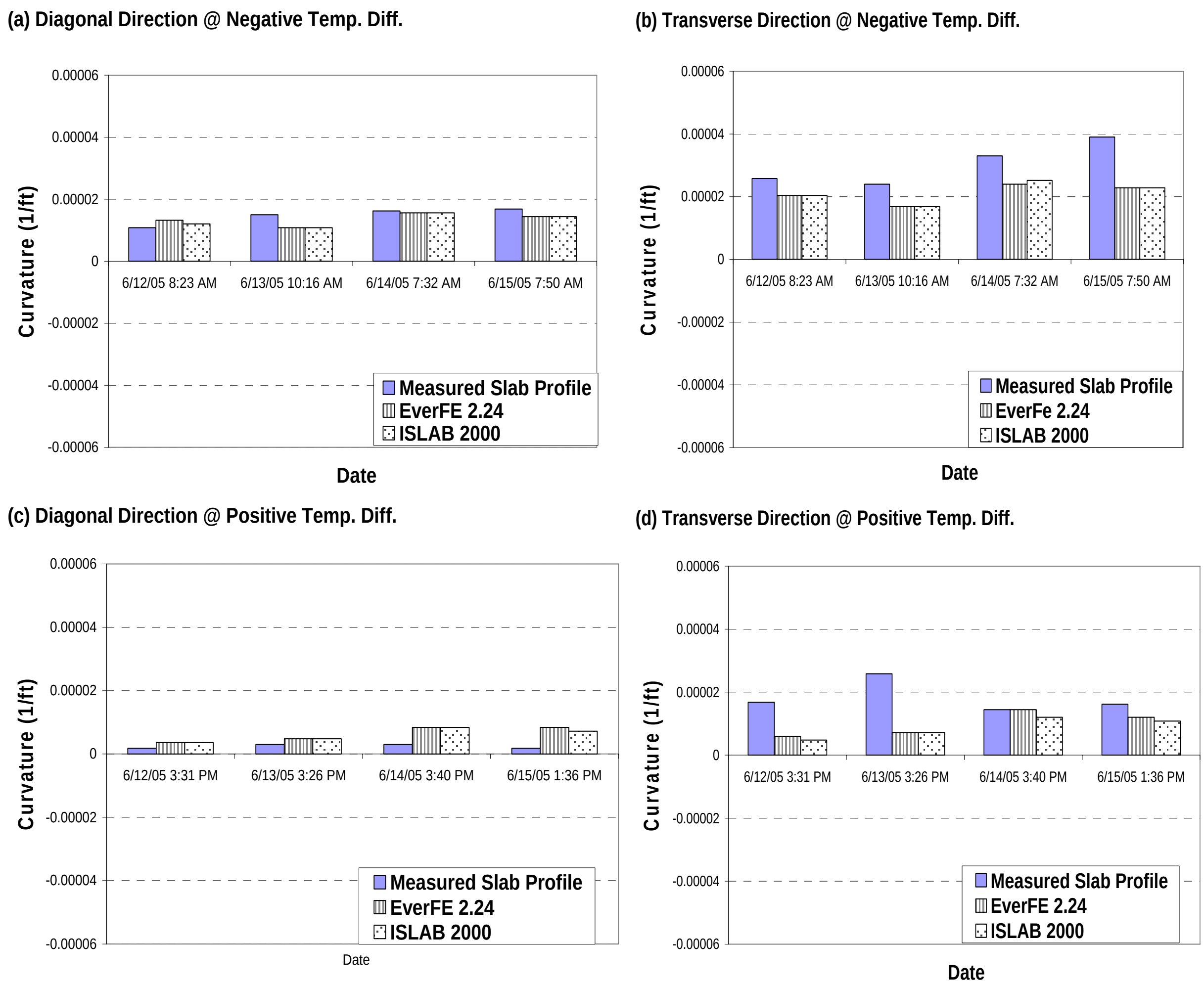


Figure 37. Burlington site, morning paving—comparisons of curvature (*k*) between measured and FE-predicted slab curvature profiles

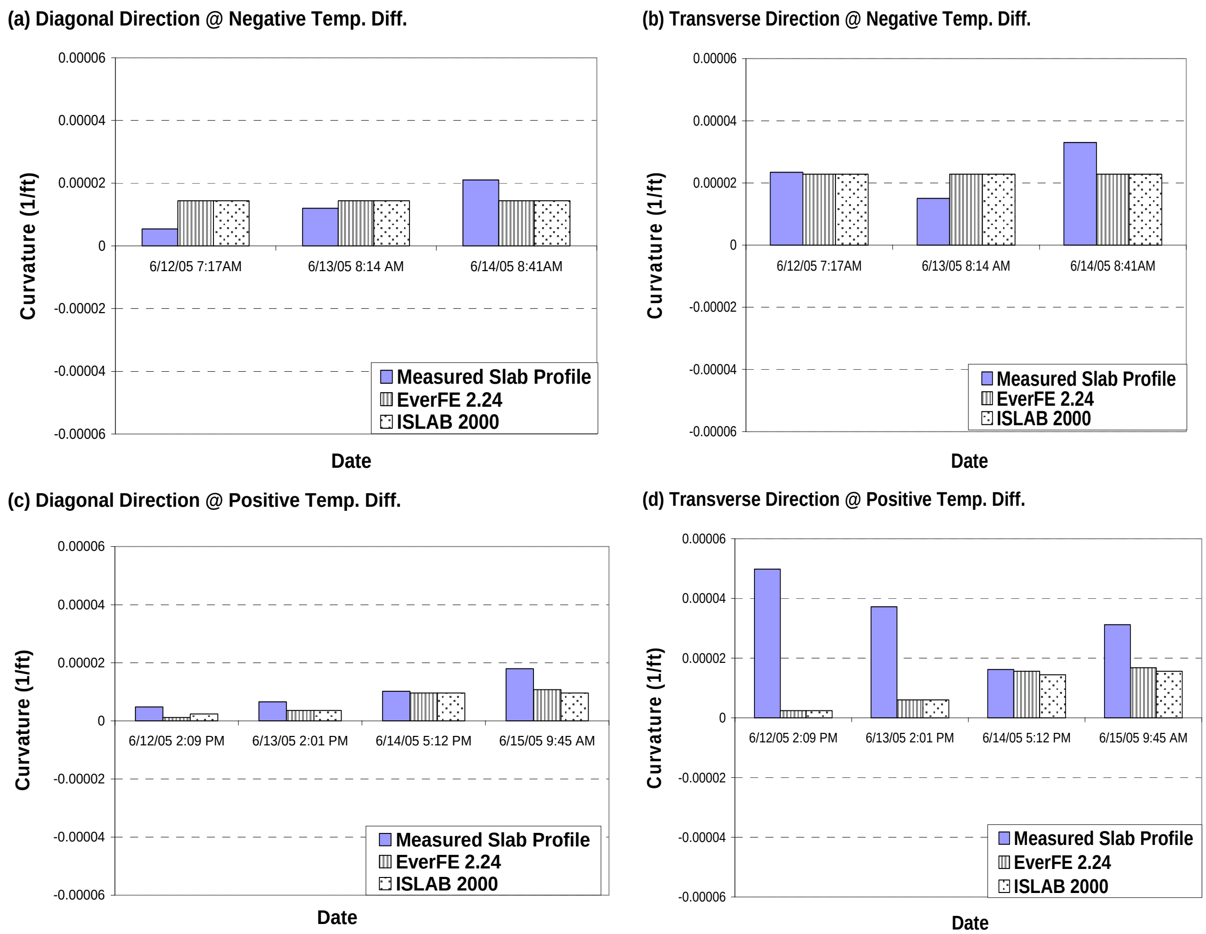


Figure 38. Burlington site, afternoon paving—comparisons of curvature (*k*) between measured and FE-predicted slab curvature profiles

PHASE II—MARSHALLTOWN, IOWA SITE

The final monitoring project for Phase II took place during the construction of U.S. 30 near Marshalltown, Iowa. This evaluation generally followed the same activities as for the Burlington site, including the use of a SurPRO rolling inclinometer profiler, one temperature instrumentation location per test section, installation of LVDTs in adjacent slabs from only one of the two test sections, and the installation of Hygrochron® relative humidity sensors.

Pavement Design

This evaluation took place during the construction of a 10.2 in. (260 mm) JPCP. The pavement was constructed upon a 6 to 10 in. (152 to 260 mm) open-graded granular base. The concrete haul trucks traveled adjacent to the grade and fed the concrete into a spreader, which placed the concrete before the paver. The transverse joint spacing was approximately 19.7 ft. (6.0 m). The passing lane was approximately 11.8 ft. (3.6 m) wide, and the travel lane was approximately 13.8

ft. (4.2 m) wide, which includes a 2 ft. (0.6 m) widened lane. An open-graded granular shoulder was added after construction.

Across the longitudinal joints, 35 in. (900 mm) tie-bars (size #5, 0.63 in. or 15.9 mm) were inserted approximately every 29.5 in. (750 mm). Dowel baskets were placed before the paver at transverse joints. The basket held smooth dowels of 18.1 in. (460 mm) in length, 1.5 in. (38 mm) in diameter, and spaced at approximately 11.8 in. (300 mm) intervals. The sawcut joints were cleaned and sealed with a hot asphalt sealant.

Early-age saws were used to cut transverse joints to a depth of approximately 1.25 in. (32 mm). Conventional saws were used to cut the longitudinal joint to a depth of approximately 3.4 in. (87 mm). Appendix G contains photos of typical construction operations, including concrete delivery, paving, texturing, curing, and sawing.

Pavement Materials

The concrete mixture design is provided in Table 43. The strengths of the subbase and subgrade layers were not reported to the project team. The splitting tensile (ASTM C 496 1996) and compressive (ASTM C 39 2001) strengths are reported in Tables 44 and 45, respectively. The Elastic Modulus test (ASTM C 469 1994) was also conducted at various ages and is reported in Table 46. The CTE measured from field-fabricated samples tested following AASHTO TP-60 (2000) was reported to be 5.35×10^{-6} ε/°F (9.63×10^{-6} ε/°C). As in the previous sites, the project team also made estimates of the CTE from measured surface strains in three directions. These results are provided in Table 47 and Figure 39.

Table 43. Marshalltown site—concrete mixture design

Component	Description	Batch Weight
Portland Cement	Ash Grove (Louisville, NE) - Type I/II	448 lbs/yd^3
GGBFS		
Fly Ash	Ottumwa Generating Station - Type C (Spec. Grav. = 2.61)	112 lbs/yd^3
Silica Fume		
Coarse Aggregate 1	Wendling - Montour #86002 (Spec. Grav = 2.61)	1,539 lbs/yd^3
Coarse Aggregate 2	Wendling - Montour #86002 (Spec. Grav = 2.61)	273 lbs/yd^3
Fine Aggregate 1	Manatt - Flint #86502 (Spec. Grav. = 2.66)	1,272 lbs/yd^3
Fine Aggregate 2		
Water		224 lbs/yd^3
Admixture 1	WR Grace - Daravair 1400 - Air Entrainer	3.92 oz/yd^3
Admixture 2	WR Grace - WRDA 82 - Water Reducer	19.61 oz/yd^3
Water/Cementitious Materials Ratio		**0.40**
Air Content		**6.0%**

Table 44. Marshalltown site—splitting tensile strength results

Age (hrs)	Splitting Tensile Strength	
	psi	MPa
12	397	2.74
24	333	2.30
48	437	3.02
96	338	2.33
168	355	2.45

Table 45. Marshalltown site—compressive strength results

Age (hrs)	Compressive Strength	
	psi	MPa
12	3,260	22.48
24	3,750	25.86
48	4,770	32.89
96	5,036	34.72
168	5,303	36.56

Table 46. Marshalltown site—elastic modulus results

Age (hrs)	Elastic Modulus	
	psi	MPa
12	4,081,588	28,142
24	4,117,468	28,389
48	4,449,651	30,679
96	4,781,834	32,970
168	4,363,452	30,085
672	5,024,031	34,639

Table 47. Marshalltown site—cumulative results for estimating CTE from surface strains

Direction	Estimated CTE	
	(ε/°F)	(ε/°C)
Longitudinal	4.0×10^{-06}	7.28×10^{-06}
Diagonal	7.9×10^{-06}	1.43×10^{-05}
Transverse	6.1×10^{-06}	1.09×10^{-05}
Average	6.0×10^{-06}	1.08×10^{-05}

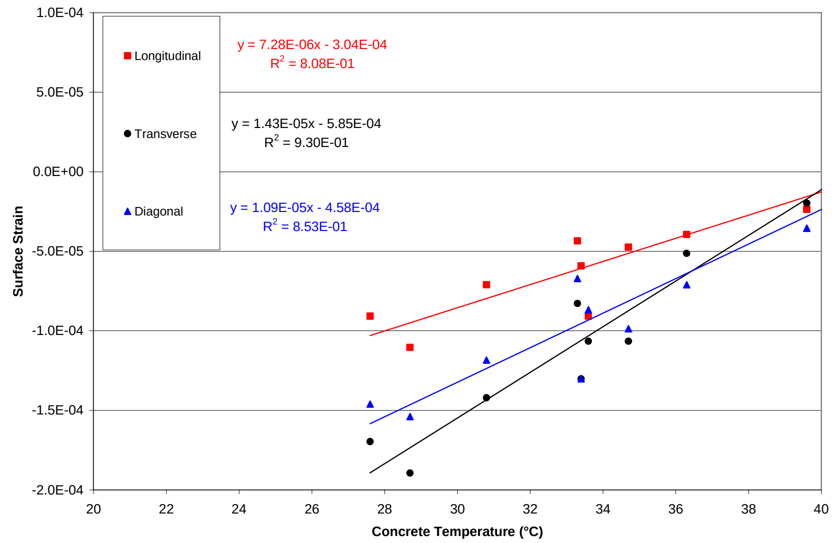


Figure 39. Marshalltown site—estimation of CTE from surface strains

Monitoring Early-Age Behavior of Concrete Pavements

As in the previous evaluations, the project team selected two test sections, generally following the diagram in Figure 14. The test sections were constructed on the afternoon of July 13, 2005, and morning of July 14, 2005. The project team documented the diurnal cycles by continuously recording the environmental conditions before, during, and after construction, as shown in Figure 40. The project team also measured surface profiles and relative joint movements to capture the extreme points within the diurnal cycle generally following the diagrams in Figure 27.

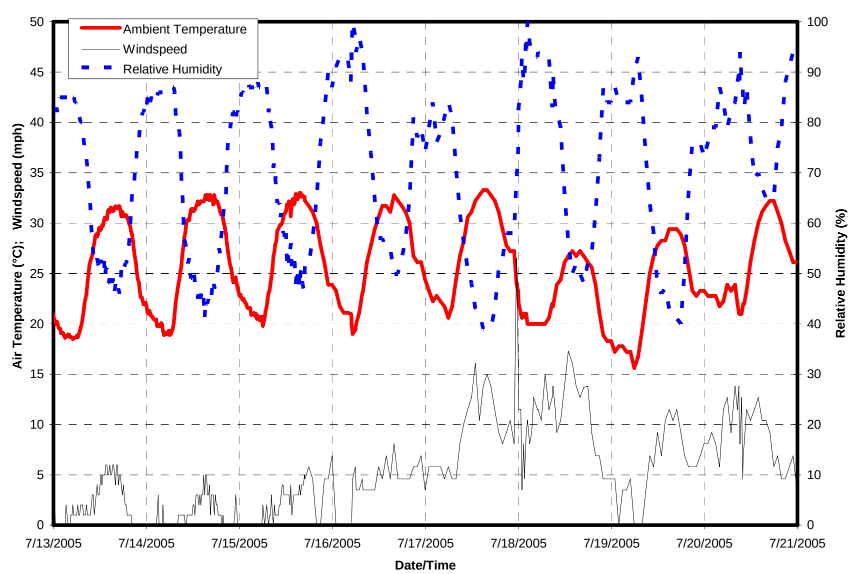


Figure 40. Marshalltown site—recorded environmental conditions

Slab Temperature Gradient

The project team instrumented one location within each test section with Thermochron iButtons® at various depths within the concrete, as diagrammed in Figure 18, including a sensor placed into the base layer. In addition, one sensor was buried 40 in. (1.0 m) beneath the pavement for seasonal monitoring after construction. Appendices H and I contain the temperature and maturity records for the two test sections. Figures 41 and 42 presents the temperature variations—ambient temperature and slab temperature at top, middle, and bottom—for two test sections. As in the Burlington site, pavement reached its maximum and minimum temperatures one to two hours after air temperature did.

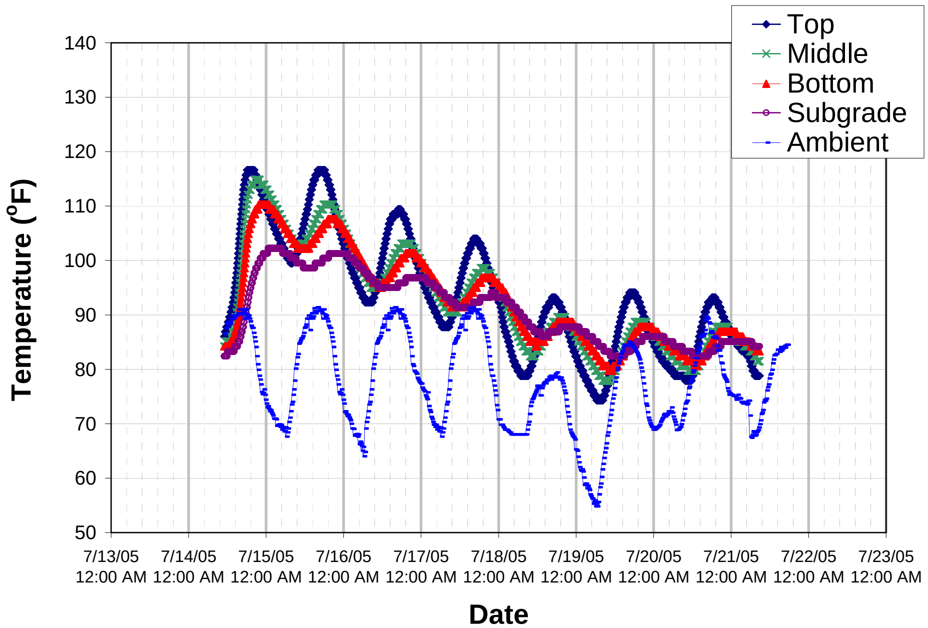


Figure 41. Marshalltown site, morning paving—field temperature variations

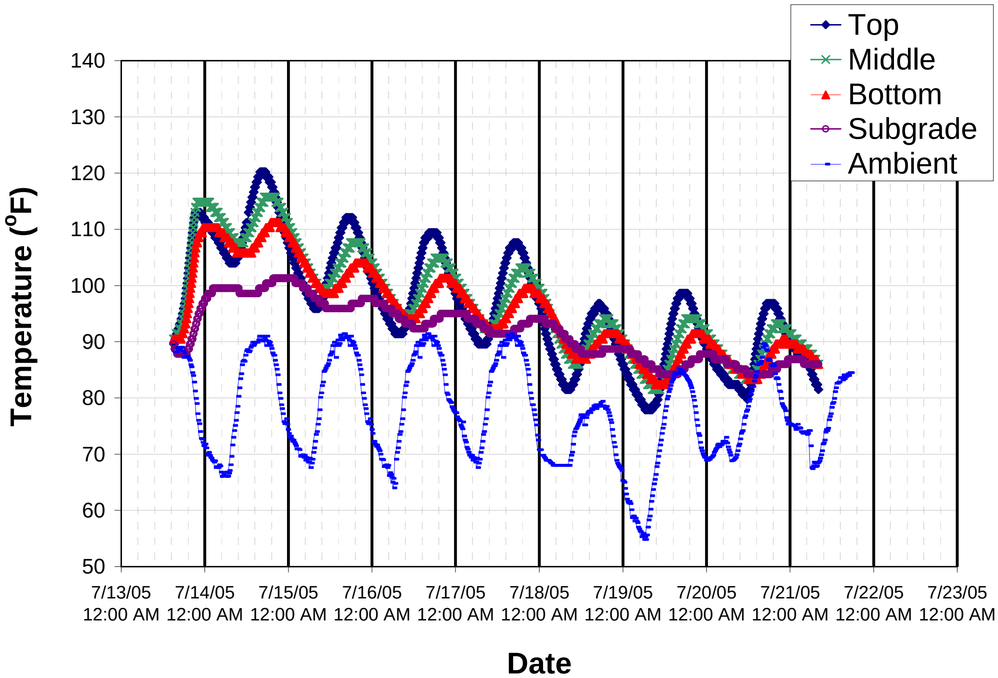


Figure 42. Marshalltown site, afternoon paving—field temperature variations

These data were used to determine the temperature profile during diurnal tests, as well as maturity-estimated strengths. In addition, the project team reset the iButtons® to log at 3-hour intervals for seasonal monitoring, allowing up to 256 days before downloading is necessary, and then extended the leadwires beyond the shoulder in a buried pipe to facilitate future access.

As in the Burlington site, the project team installed Hygrochron iButtons® at various depths during construction. This instrumentation was installed adjacent to the slabs containing LVDTs. The results from this instrumentation are reported in Figure 43.

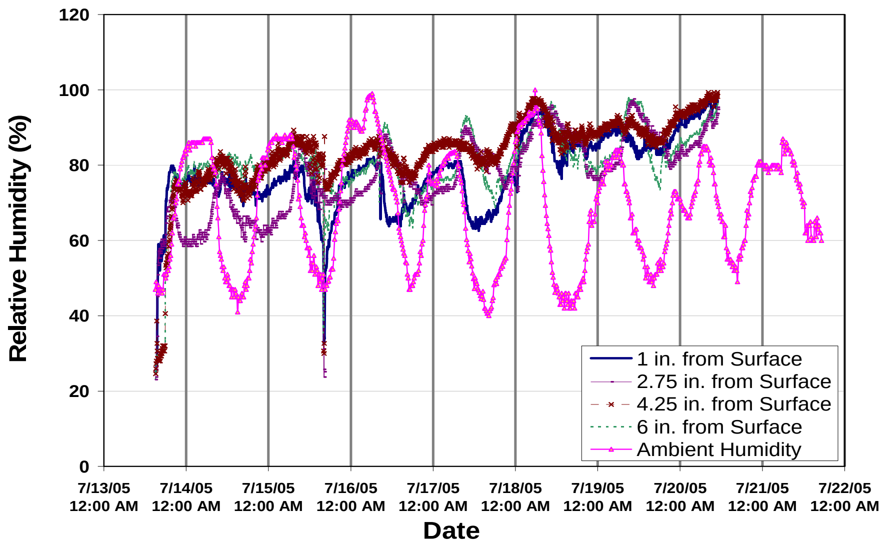


Figure 43. Marshalltown site—hygrochron relative humidity measurements

The variations in PCC slab curling and warping were influenced not only by temperature difference but also by moisture difference between the top and the bottom of the slab surface. The variations in temperature and moisture differences with time are plotted in Figure 44. In general, temperature differences are positive during daytime and early nighttime and negative during late nighttime and early morning. In contrast, moisture differences presented as "RH Diff" in Figure 44 show the reverse trend. Especially until the day 2 of paving, moisture differences are negative for most part, i.e., higher moisture at the bottom of the slab compared to the top. This indicates higher drying shrinkage of concrete near the top of the slab causing the slab corner to warp upward until the day 2 of paving.

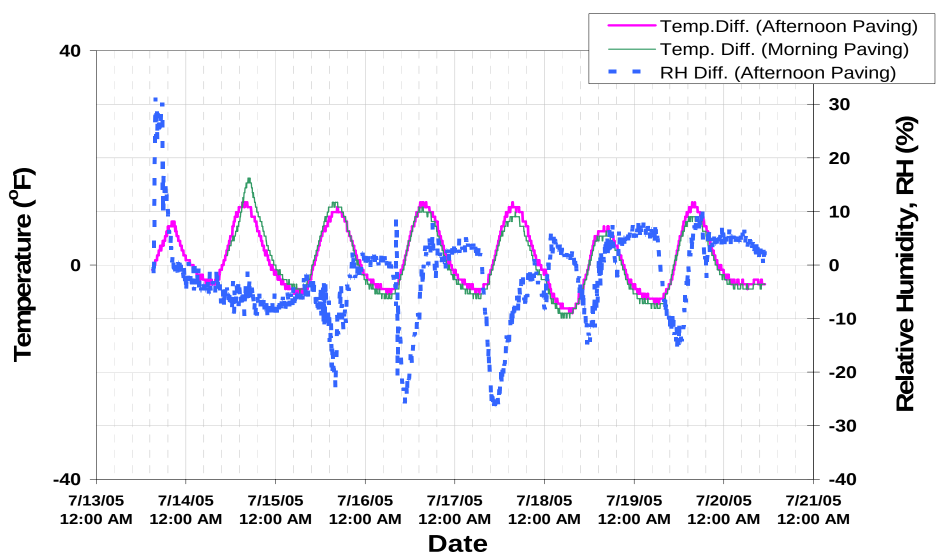


Figure 44. Marshalltown site—hygrochron relative humidity measurements

Relative and Absolute Joint Opening

The project team attached stainless steel discs to the pavement surface for DEMEC measurements as in the previous evaluations. These points were installed at 9 successive transverse joints, 4 successive longitudinal joints, and 2 "peacock" patterns at slab corners within each test section. The reduction in number of longitudinal joints measured is in response to data analysis and observations from previous sites that showed that tied joints do not move as much as doweled joints and therefore do not show a large amount of variability between slabs. Figure 39 and Table 47 provide the cumulative results for surface strains observed in the "peacock" patterns. Cumulative results for relative joint movements are provided in Appendices H and I for the two test sections.

Vertical Slab Movement

The project team instrumented two adjacent slabs within the afternoon paving test section with LVDTs. These measurements are used by the project team as a reference to the absolute slab movement due to curling and warping. The data record for free edge measurements at the mid-slab and corner for the afternoon test section is provided in Appendix I.

Inclinometer Profiling

The project team used a SurPRO 2000 to facilitate a greater efficiency in profile data collection following the revised profile patterns in Figure 32. For this site, the paving direction was with the direction of future traffic. All measured profiles are in the direction of future traffic.

The data processing and analysis were performed following the same procedure as for the previous sites. The calculated ride statistics, as well as other measured parameters, such as pavement temperature, are summarized in the following tables:

- Tables 48 and 49—Level A—Morning Paving Test Section
- Tables 50, 51, 52, and 53—Level B—Morning Paving Test Section
- Tables 54 and 55—Level A—Afternoon Paving Test Section
- Tables 56, 57, 58, and 59—Level B—Afternoon Paving Test

Plots of filtered profiles from Levels A and B are provided in Appendices H and I for the morning and afternoon paving test sections, respectively. Following the same procedure as for the Platteville Pilot site, the individual segments within the Level C "butterfly" pattern were processed and are also reported in Appendices H and I.

Table 48. Marshalltown site, morning paving—level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1029	7/15/2005 10:29	24.67	103.1	85.8	73.3	165.3	3.29
15JL1635	7/15/2005 16:35	30.75	110.8	90.9	67.5	154.0	3.39
16JL0922	7/16/2005 9:22	47.50	94.8	82.0	80.6	182.5	3.15
16JL1658	7/16/2005 16:58	55.17	104.0	90.0	75.5	171.1	3.25
17JL0827	7/17/2005 8:27	70.67	90.1	80.1	80.3	169.7	3.26
17JL1427	7/17/2005 14:47	76.92	97.0	91.9	77.5	186.3	3.12
18JL0738	7/18/2015 7:38	93.83	83.3	69.1	74.9	174.4	3.22
18JL1636	7/18/2005 16:36	102.75	89.6	80.1	77.7	173.1	3.23
19JL0938	7/19/2005 9:38	119.83	78.4	77.0	76.3	163.2	3.31
19JL1719	7/19/2005 17:19	127.50	89.6	84.0	73.3	148.8	3.43
20JL0616	7/20/2005 6:16	140.42	82.0	73.9	78.1	176.8	3.20
20JL1448	7/20/2005 14:48	149.00	83.8	88.0	74.7	169.9	3.26

Table 49. Marshalltown site, morning paving—level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1037	7/15/2005 10:37	24.75	103.1	85.8	68.6	115.0	3.74
15JL1645	7/15/2005 16:45	30.92	111.0	90.7	68.2	123.3	3.66
16JL0933	7/16/2005 9:33	47.75	95.0	82.0	66.1	108.0	3.81
16JL1707	7/16/2005 17:07	55.25	104.0	90.0	66.9	114.3	3.75
17JL0840	7/17/2005 8:40	70.83	90.1	80.1	65.9	111.8	3.77
17JL1455	7/17/2005 14:55	77.08	97.2	91.9	67.1	110.5	3.78
18JL0746	7/18/2015 7:46	93.92	83.3	69.1	67.4	117.3	3.72
18JL1646	7/18/2005 16:46	102.92	90.0	80.1	66.2	111.2	3.78
19JL0946	7/19/2005 9:46	119.92	78.4	77.0	67.8	111.3	3.78
19JL1729	7/19/2005 17:29	127.67	89.8	84.0	65.6	109.4	3.79
20JL0625	7/20/2005 6:25	140.58	81.9	73.9	68.9	119.5	3.70
20JL1456	7/20/2005 14:56	149.08	84.0	88.0	65.8	115.8	3.73

Table 50. Marshalltown site, morning paving—level B profile summary (2 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1652	7/15/2005 16:52	31.00	111.4	90.0	79.7	148.8	3.43
16JL0942	7/16/2005 9:42	47.83	95.0	82.0	75.5	136.2	3.54
16JL1715	7/16/2005 17:15	55.42	104.2	90.0	76.1	135.9	3.55
17JL0848	7/17/2005 8:48	71.00	90.3	80.1	73.2	133.3	3.57
17JL1503	7/17/2005 15:03	77.25	97.3	91.9	75.0	138.1	3.53
18JL0755	7/18/2015 7:55	94.08	83.3	69.1	77.5	130.8	3.59
18JL1654	7/18/2005 16:54	103.08	90.1	80.1	74.6	135.3	3.55
19JL0955	7/19/2005 9:55	120.08	78.8	77.0	75.6	132.6	3.58
19JL1738	7/19/2005 17:38	127.83	89.8	84.0	73.0	130.0	3.60
20JL0632	7/20/2005 6:32	140.67	81.7	73.9	76.2	143.1	3.48
20JL1504	7/20/2005 15:04	149.25	84.4	88.0	79.8	146.3	3.46

Table 51. Marshalltown site, morning paving—level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1659	7/15/2005 16:59	31.17	111.4	90.0	75.6	142.7	3.49
16JL0950	7/16/2005 9:50	48.00	95.0	82.0	75.4	127.1	3.63
16JL1723	7/16/2005 17:23	55.58	104.4	90.0	75.4	137.3	3.53
17JL0856	7/17/2005 8:56	71.08	90.3	80.1	75.2	134.3	3.56
17JL1511	7/17/2005 15:11	77.33	97.3	91.9	74.6	134.5	3.56
18JL0802	7/18/2015 8:02	94.17	83.3	69.1	73.7	136.1	3.55
18JL1702	7/18/2005 17:02	103.17	90.1	80.1	70.4	138	3.53
19JL1003	7/19/2005 10:03	120.25	78.6	77.0	72.1	126.9	3.63
19JL1745	7/19/2005 17:45	127.92	89.8	84.0	72.6	128.1	3.62
20JL0639	7/20/2005 6:39	140.83	81.5	73.9	73.1	131.2	3.59
20JL1513	7/20/2005 15:13	149.42	84.7	88.0	74.3	134.2	3.56

Table 52. Marshalltown site, morning paving—level B profile summary (3 ft. from long joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1706	7/15/2005 17:06	31.25	111.4	90.0	70.8	140.7	3.50
16JL1006	7/16/2005 10:06	48.25	95.4	82.0	66.3	121.5	3.68
16JL1738	7/16/2005 17:38	55.83	104.5	89.1	67.6	120.4	3.69
17JL0912	7/17/2005 9:12	71.33	90.5	80.1	67.9	119.1	3.70
17JL1527	7/17/2005 15:27	77.58	98.1	91.9	67.9	121.3	3.68
18JL0817	7/18/2015 8:17	94.42	83.1	69.1	65.6	115.1	3.74
18JL1720	7/18/2005 17:20	103.50	90.1	80.1	64.7	114.4	3.75
19JL1021	7/19/2005 10:21	120.50	78.8	77.0	65.6	112.1	3.77
19JL1802	7/19/2005 18:02	128.17	89.8	84.0	66.9	117.5	3.72
20JL0655	7/20/2005 6:55	141.08	81.1	73.9	63.3	113.5	3.75
20JL1528	7/20/2005 15:28	149.67	85.1	88.0	66.8	121.9	3.67

Table 53. Marshalltown site, morning paving—level B profile summary (1 ft. from long joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1714	7/15/2005 17:14	31.42	111.4	90.0	49.3	127.4	3.62
16JL0959	7/16/2005 9:59	48.17	95.0	82.0	44.7	107.4	3.81
16JL1731	7/16/2005 17:31	55.67	104.4	89.1	52.2	128.4	3.62
17JL0905	7/17/2005 9:05	71.25	90.5	80.1	51.8	125.4	3.64
17JL1519	7/17/2005 15:19	77.50	97.7	91.9	47.7	116.7	3.72
18JL0810	7/18/2015 8:10	94.33	83.1	69.1	55.8	129.2	3.61
18JL1713	7/18/2005 17:13	103.42	90.1	80.1	45.6	107.1	3.81
19JL1012	7/19/2005 10:12	120.33	78.6	77.0	44.6	100.5	3.88
19JL1755	7/19/2005 17:55	128.08	89.8	84.0	44.6	118.0	3.71
20JL0647	7/20/2005 6:47	140.92	81.3	73.9	50.4	119.8	3.69
20JL1521	7/20/2005 15:21	149.50	84.7	88.0	50.4	122.3	3.67

Table 54. Marshalltown site, afternoon paving—level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1011	7/14/2005 10:11	20.25	106.5	85.8	83.1	189.8	3.10
14JL1614	7/14/2005 16:14	26.33	115.0	90.1	95.9	210.7	2.94
15JL0623	7/15/2005 6:23	40.50	100.0	68.7	84.7	183.6	3.14
15JL1430	7/15/2005 14:30	48.58	104.0	91.2	94.5	212.7	2.92
16JL0633	7/16/2005 6:33	64.67	94.5	70.0	94.9	202.1	3.00
16JL1519	7/16/2005 15:19	73.42	102.6	91.0	86.0	196.8	3.04
17JL0643	7/17/2005 6:43	88.83	92.1	71.1	97.7	215.9	2.90
17JL1315	7/17/2005 13:15	95.33	96.8	91.0	90.7	200.9	3.01
18JL0605	7/18/2005 6:05	112.17	88.0	68.0	94.1	199.3	3.02
18JL1458	7/18/2005 14:58	121.08	91.4	80.6	91.3	192.8	3.07
19JL0606	7/19/2005 6:06	136.17	81.9	61.2	96.9	211.1	2.93
19JL1544	7/19/2005 15:44	145.83	91.9	84.9	87.7	194.6	3.06
20JL0743	7/20/2005 7:43	161.83	84.2	75.0	85.7	185.8	3.13

Table 55. Marshalltown site, afternoon paving—level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1027	7/14/2005 10:27	20.58	106.9	86.5	99.3	150.8	3.42
14JL1623	7/14/2005 16:23	26.50	115.3	90.5	102.5	152.4	3.40
15JL0632	7/15/2005 6:32	40.58	100.0	69.1	98.3	146.8	3.45
15JL1440	7/15/2005 14:40	48.75	104.5	90.7	100.4	149.5	3.43
16JL0641	7/16/2005 6:41	64.75	94.5	70.0	98.3	149.2	3.43
16JL1528	7/16/2005 15:28	73.58	102.6	91.0	96.2	136.9	3.54
17JL0650	7/17/2005 6:50	88.92	92.1	71.1	102.5	169.3	3.26
17JL1324	7/17/2005 13:24	95.50	97.2	91.0	96.5	142.8	3.49
18JL0617	7/18/2005 6:17	112.33	87.4	68.0	103.6	150.7	3.42
18JL1506	7/18/2005 15:06	121.17	91.4	80.6	105.6	157.0	3.36
19JL0613	7/19/2005 6:13	136.33	81.9	61.2	104.2	152.5	3.40
19JL1555	7/19/2005 15:55	146.00	91.9	84.9	96.8	135.8	3.55
20JL0751	7/20/2005 7:51	161.92	84.2	75.0	98.2	137.0	3.54

Table 56. Marshalltown site, afternoon paving—level B profile summary (2 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1040	7/14/2005 10:40	20.75	107.1	86.7	118.1	222.5	2.85
14JL1634	7/14/2005 16:34	26.67	115.3	91.0	118.8	242.3	2.71
15JL0646	7/15/2005 6:46	40.83	99.9	70.3	125.7	224.3	2.84
15JL1449	7/15/2005 14:49	48.92	104.5	90.7	120.4	241.1	2.72
16JL0650	7/16/2005 6:50	64.92	94.5	70.0	121.5	245.3	2.69
16JL1537	7/16/2005 15:37	73.67	102.6	91.0	120.7	237.7	2.74
17JL0658	7/17/2005 6:58	89.08	92.1	71.1	118.3	233.4	2.77
17JL1333	7/17/2005 13:33	95.67	97.3	91.0	117.8	228.1	2.81
18JL0627	7/18/2005 6:27	112.50	87.4	68.0	116.6	239.7	2.73
18JL1514	7/18/2005 15:14	121.33	91.6	80.6	121.8	238.3	2.74
19JL0621	7/19/2005 6:21	136.42	81.7	61.2	116.4	233.2	2.77
19JL1604	7/19/2005 16:04	146.17	92.5	84.9	115.7	216.0	2.90
20JL0801	7/20/2005 8:01	162.08	84.0	75.0	116.4	219.1	2.88

Table 57. Marshalltown site, afternoon paving—level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1641	7/14/2005 16:41	26.75	115.3	90.7	106.0	187.4	3.12
15JL0658	7/15/2005 6:58	41.08	99.5	71.1	106.4	178.9	3.18
15JL1507	7/15/2005 15:07	49.17	104.7	90.3	101.1	173.9	3.22
16JL0657	7/16/2005 6:57	65.08	93.9	70.0	107.0	188.9	3.10
16JL1551	7/16/2005 15:51	73.92	103.3	91.0	104.0	186.4	3.12
17JL0705	7/17/2005 7:05	89.17	91.9	71.1	102.5	171.5	3.24
17JL1340	7/17/2005 13:40	95.75	97.5	91.0	100.9	168.8	3.27
18JL0635	7/18/2005 6:35	112.67	87.4	68.0	101.2	168.2	3.27
19JL0628	7/19/2005 6:28	136.58	81.7	61.2	107.5	174.7	3.22
19JL1613	7/19/2005 16:13	146.33	92.7	84.9	98.9	161.2	3.33
20JL0816	7/20/2005 8:16	162.33	83.8	75.0	106.4	174.2	3.22

Table 58. Marshalltown site, afternoon paving—level B profile summary (3 ft. from long joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1706	7/14/2005 17:06	27.17	115.5	90.3	107.5	167.9	3.27
15JL0716	7/15/2005 7:16	41.33	99.1	72.3	104.4	167.5	3.28
15JL1526	7/15/2005 15:26	49.50	105.4	91.4	103.2	167.3	3.28
16JL0712	7/16/2005 7:12	65.25	93.9	70.0	108.3	176.6	3.20
16JL1607	7/16/2005 16:07	74.17	103.3	91.0	103.5	157	3.36
17JL0720	7/17/2005 7:20	89.42	91.9	71.1	106.3	167.2	3.28
17JL1356	7/17/2005 13:56	96.00	98.1	91.0	103.9	159.6	3.34
18JL0652	7/18/2005 6:52	112.92	86.7	68.0	105.8	157.5	3.36
18JL1539	7/18/2005 15:39	121.75	91.9	80.6	97.9	148.0	3.44
19JL0644	7/19/2005 6:44	136.83	81.3	61.2	102.1	154.8	3.38
19JL1629	7/19/2005 16:29	146.58	93.0	84.9	99.3	146.9	3.45
20JL0831	7/20/2005 8:31	162.58	83.7	75.0	102.8	151.1	3.41

Table 59. Marshalltown site, afternoon paving—level B profile summary (1 ft. from long joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temp. (°F)	Ambient Temp. (°F)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1657	7/14/2005 16:57	27.00	115.3	90.3	95.0	186.7	3.12
15JL0708	7/15/2005 7:08	41.25	99.1	72.3	87.2	155.2	3.38
15JL1518	7/15/2005 15:18	49.42	105.3	90.7	89.5	168.4	3.27
16JL1558	7/16/2005 15:58	74.08	103.3	91.0	88.9	172.2	3.24
17JL0712	7/17/2005 7:12	89.25	91.9	71.1	88.0	163.6	3.31
17JL1349	7/17/2005 13:49	95.92	97.9	91.0	86.0	165.5	3.29
18JL0644	7/18/2005 6:44	112.83	87.3	68.0	87.5	158.2	3.35
18JL1531	7/18/2005 15:31	121.58	91.8	80.6	84.3	152.6	3.40
19JL0637	7/19/2005 6:37	136.67	81.5	61.2	92.7	164.7	3.30
19JL1620	7/19/2005 16:20	146.42	92.8	84.9	84.0	153.9	3.39
20JL0824	7/20/2005 8:24	162.50	83.7	75.0	87.4	159.3	3.34

As in Burlington site, it was observed from Tables 48 to 59 and from plots of filtered profiles from Levels A and B provided in Appendices H and I that there are variations with respect to measurement locations and measurement times (morning and afternoon) in both test sections. Analysis of Variance (ANOVA) test was conducted to examine if these variations were statistically significant, and the results are summarized in Table 60.

As can be seen in Table 60, all p-values are higher than 0.05 (95% significance level), which indicates that the measured smoothness indices with respect to measurement times (morning vs. afternoon) may not be different.

Table 60. Marshalltown site—ANOVA for the measured smoothness indices at different times

Test section	IRI (in/mi)			PTRN (in/mi)			RN		
	Mean @ morning (- temp. diff.)	Mean @ afternoon (+ temp. diff.)	p-value	Mean @ morning (- temp. diff.)	Mean @ afternoon (+ temp. diff.)	p-value	Mean @ morning (- temp. diff.)	Mean @ afternoon (+ temp. diff.)	p-value
Morning paving	68.5	67.8	0.77	131.6	133.1	0.77	3.59	3.57	0.73
Afternoon paving	102.0	101.1	0.72	180.5	182.7	0.76	3.18	3.16	0.80

However, this comparison combines the smoothness metrics calculated from profiles collected at various locations on the slabs and for each of the "morning" and "afternoon" events (recognizing that the slabs during these early ages are undergoing irreversible changes). It is also noted that a small difference in the smoothness indices can change the grade of pavement from "full pay range" to "penalty range," for instance, based on State smoothness specifications. The measured IRI ranges at different locations during the field evaluation periods are summarized in Table 61 for the Marshalltown site and assigned the corresponding smoothness specification grade (i.e., "full pay," "penalty," or "correction") based on Table 22. From this table, it is clear that changes in IRI during the early age can influence the smoothness specification grade of new concrete pavements. Note that similar conclusions were reached for the Platteville and Burlington sites discussed previously.

Table 61. Marshalltown site—summary of the measured IRI range at different locations

Test section	Location	IRI (in/mi)	
		Maximum / Pavement grade	Minimum / Pavement grade
Morning paving	Edge	80.6 / Penalty	67.5 / Full pay
	2ft from shoulder	79.8 / Full pay	73.0 / Full pay
	3ft from shoulder	75.6 / Full pay	70.4 / Full pay
	Mid - slab	68.9 / Full pay	65.6 / Full pay
	3ft from longitudinal joint	70.8 / Full pay	63.3 / Full pay
	2ft from longitudinal joint	55.8 / Bonus	44.6 / Bonus
Afternoon paving	Edge	97.7 / Penalty	83.1 / Penalty
	2ft from shoulder	125.7 / Correction	115.7 / Correction
	3ft from shoulder	107.5 / Correction	98.9 / Penalty
	Mid - slab	105.6 / Correction	96.2 / Penalty
	3ft from longitudinal joint	108.3 / Correction	97.9 / Penalty
	2ft from longitudinal joint	95.0 / Penalty	84.0 / Penalty

It is anticipated that a more detailed analysis would be performed based on results from a related ongoing FHWA project entitled "Inertial Profile Data for Pavement Performance Analysis." As part of this effort, more relevant means to quantify slab curvature have been developed which will be applied to this database.

Finite Element Simulation

Following the same procedure as in the Burlington site, FE simulations were undertaken from the actual geometric proportion, the colleted material properties, and assumed input parameter values. Three consecutive slab systems in each lane were used, as shown in Figure 33, and middle slab in travel lane was selected for representing the field measurement.

The relation between the actual measured temperature differences and the equivalent temperature differences associated with actual pavement behavior could be also established using the same procedure as in the Burlington site. The equivalent temperature differences were plotted with the measured temperature differences, as shown in Figure 45, for the Marshalltown site simulations using ISLAB 2000 and EverFE 2.24. As seen in this figure, the equivalent temperature differences and the measured temperature differences in Marshalltown site show linear relation similar to Burlington site test results. As in Burlington site, approximately –8°F (–4°C) for ISLAB 2000 and –12°F (–6.6°C) for EverFE 2.24 were obtained as intercepts for the linear regression equations related to the permanent component of equivalent temperature difference. Based on linear regression equations from this figure, equivalent temperature differences corresponding to temperature differences under which pavement profile data were collected were calculated and used as input for both FEM programs.

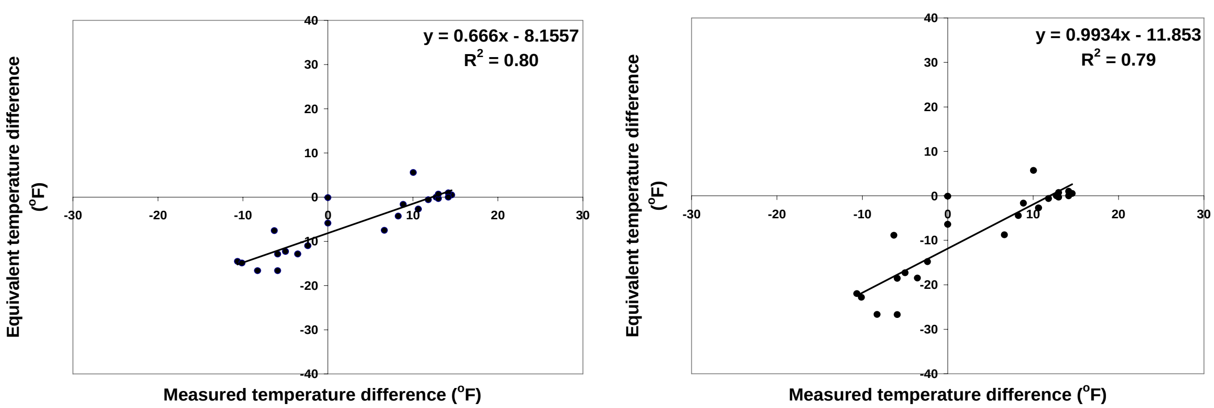


Figure 45. Marshalltown site—equivalent temperature differences versus measured temperature differences

FE simulated results were compared with the measured slab curl behaviors in diurnal cycles obtained from the average level C profile of slabs and provided in Appendices H and I for the morning and afternoon paving test sections. In addition, FE simulated results were quantified with the numerical values in order to identify the difference. If the slab behavior could be characterized in terms of total amount of deflection and the slab shape, the total amount of deflection could be quantified using the relative deflection of corner to center in the measured direction (*Rc*), and the slab shape could be quantified by the curvature of slab profile (*k*). The quantitative comparisons between the measured profiles and the FE simulated profiles for morning paving section and afternoon paving section are presented in Figures 46, 47, 48, and 49.

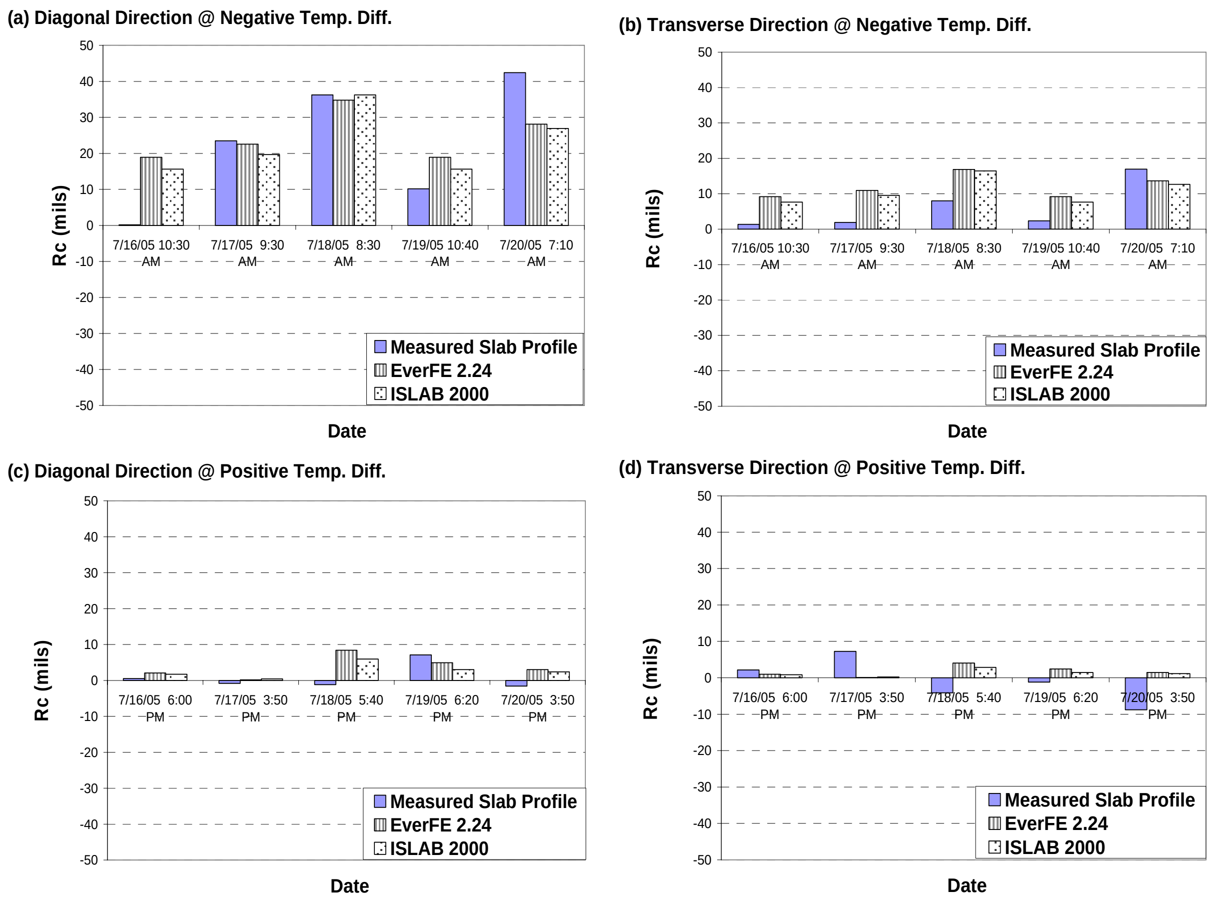


Figure 46. Marshalltown site, morning paving—comparisons of relative corner deflection (*Rc*) between measured and FE-predicted slab curvature profiles

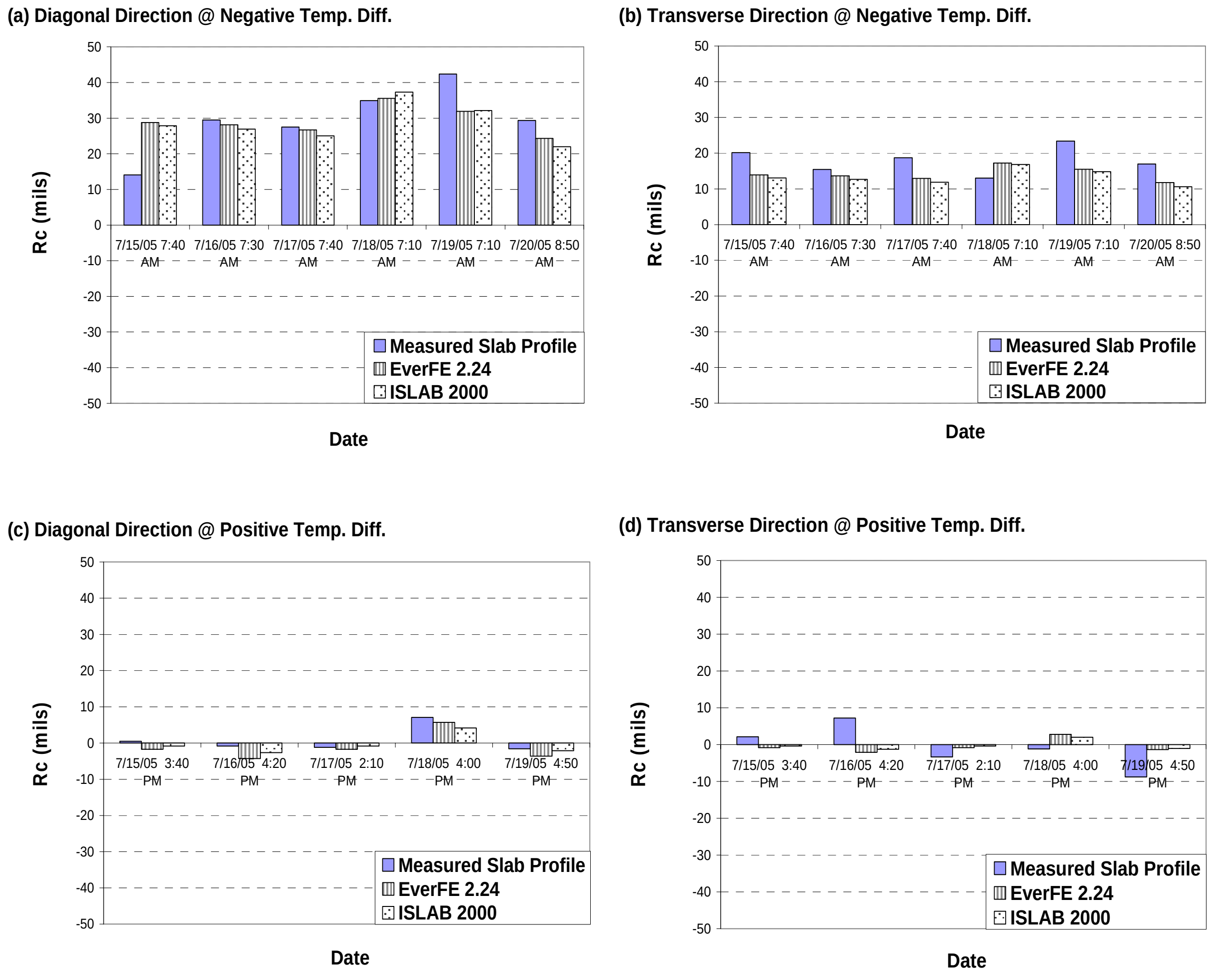


Figure 47. Marshalltown site, afternoon paving—comparisons of relative corner deflection (*Rc*) between measured and FE-predicted slab curvature profiles

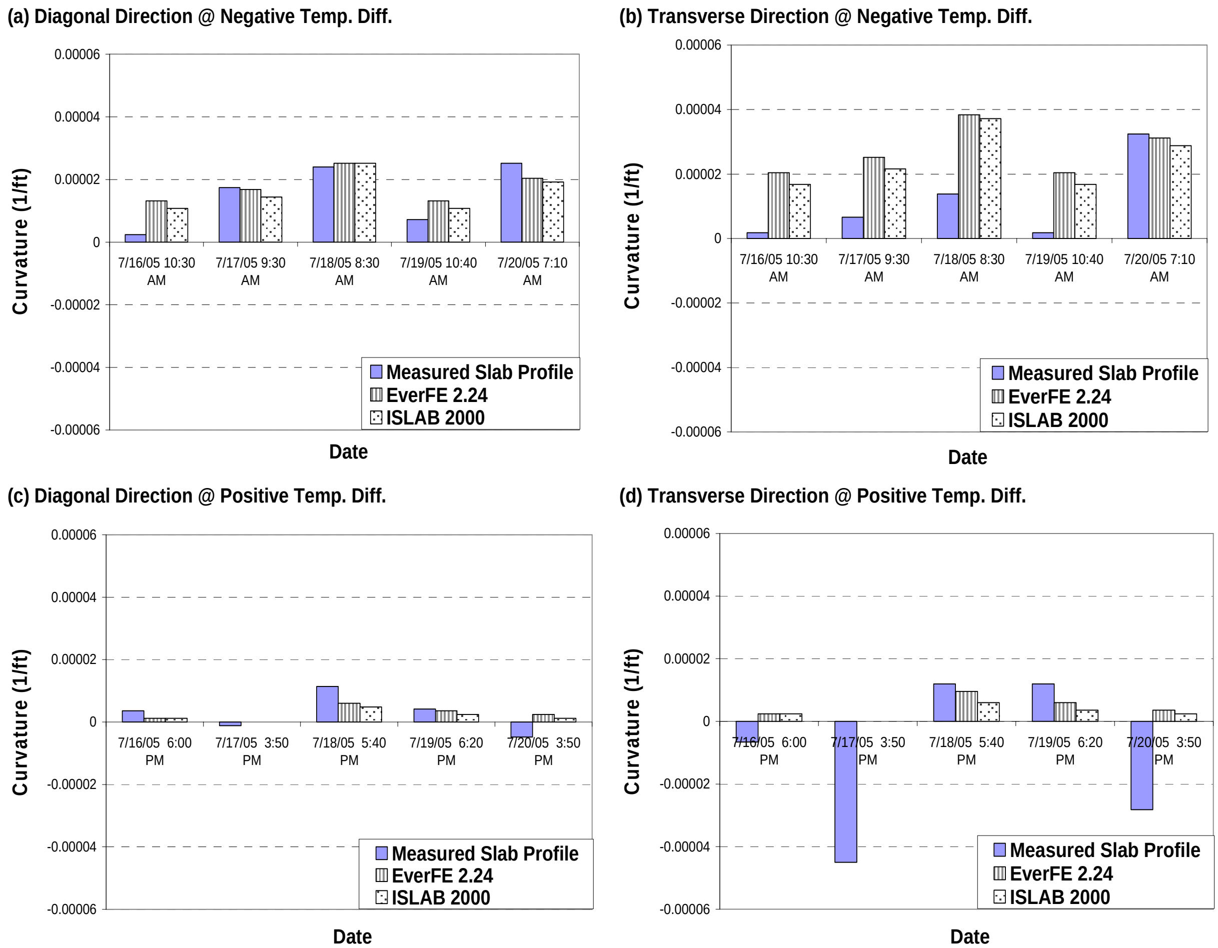


Figure 48. Marshalltown site, morning paving—comparisons of curvature (*k*) between measured and FE-predicted slab curvature profiles

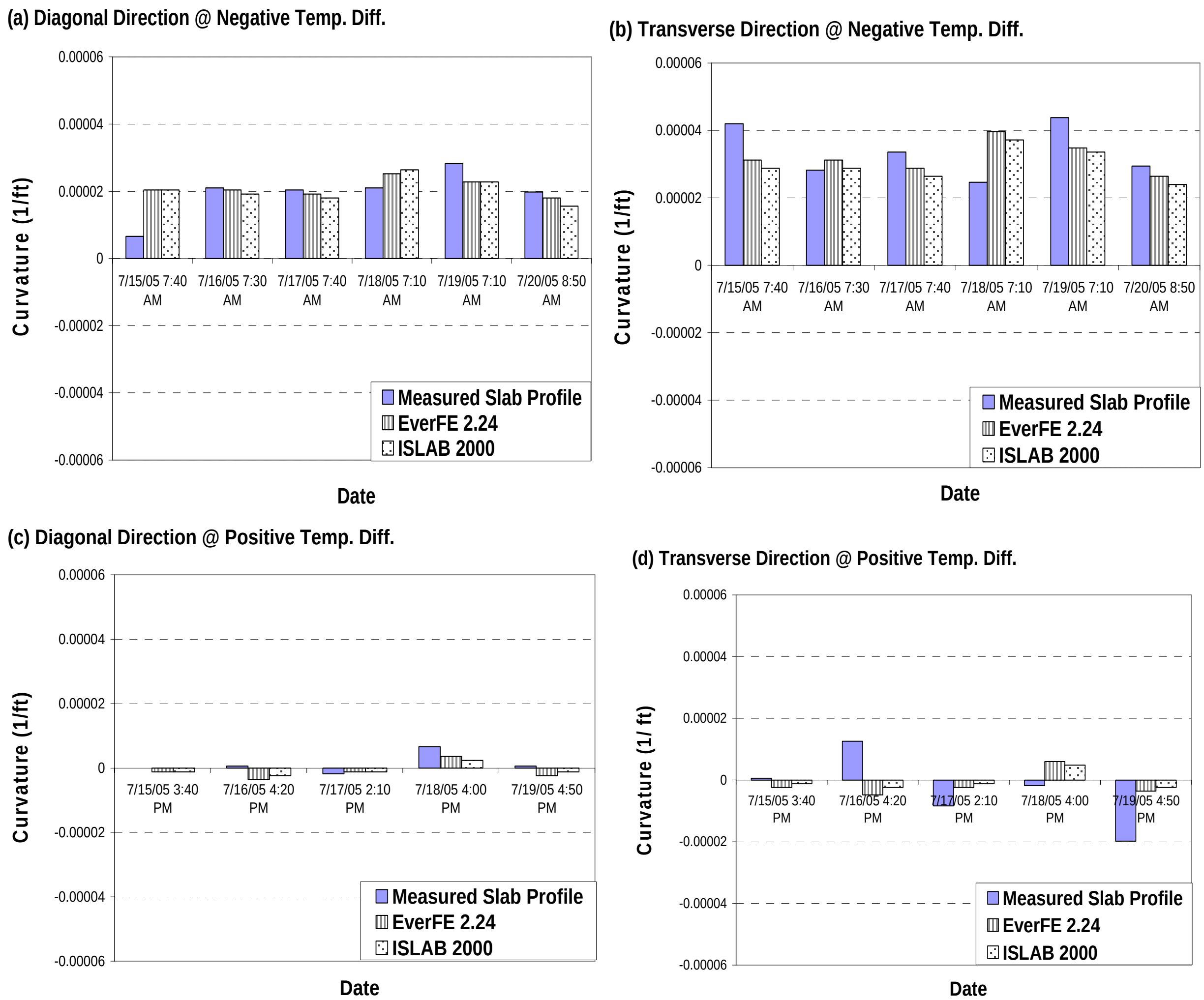


Figure 49. Marshalltown site, afternoon paving—comparisons of curvature (*k*) between measured and FE-predicted slab curvature profiles

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary of Findings and Conclusions

This study intentionally evaluated pavements experiencing a variety of climatic conditions. The Platteville pilot site was constructed late in the year (October) and experienced only modest daily diurnal cycles. The Burlington site was constructed early in the paving season (June) and experienced multiple rainfall events during the evaluation period. The Marshalltown site was built towards the middle of the construction season (July) and experienced relatively higher ambient temperatures. This variability in site selection only adds to the value of the collected data.

The comparison between measured and FE-simulated slab deformation in this study showed that the curling and warping behaviors at early ages are influenced not only by temperature variation but also by other environmental effects such as the moisture variation, drying shrinkage, and temperature and wind conditions during pavement construction.

The three evaluations reported in this document show a unique and detailed data collection effort that enhances our understanding of changes in pavement smoothness that occur during the critical time following construction. Each evaluation included both field and laboratory tests, as well as detailed records which will allow each site to be included in future research. Specifically, temperature instrumentation embedded into the pavements is currently monitoring seasonal variations and are intended to be reused for future studies. The major study findings are as follows:

- Based on the limited field data, it appears that morning paving produces smoother JPCP pavements (in terms of measured smoothness indices) compared to afternoon paving.
- The measured smoothness index values between morning and afternoon measurement times showed some variations.
- The measured smoothness index values were different at different measurement locations within a pavement test section.
- Within the scope of this project, it can be concluded that measurable changes of early-age pavement smoothness do occur over time from the standpoint of smoothness specifications.
- The changing slab curvature conditions at early ages are influenced not only by temperature variation but also by other environmental effects, such as the moisture variation, drying shrinkage, and wind conditions during pavement construction.
- The permanent curling/warping effective temperature difference identified from this study ranged approximately from -8^{o}F to -12^{o}F on different sites, measurement methods, and FE-programs (Note that -10^{o}F (-5.6^{o}C) is defined as permanent curl/warp effective temperature difference in the newly released MEPDG through national calibration results).
- A linear relation was observed between the actual measured temperature difference and the equivalent temperature difference associated with actual slab displacement

under pure environmental loading.
- Pavement temperature differences are usually positive at daytime and early nighttime and negative at late nighttime and early morning.
- Pavement temperature is generally higher than ambient temperature and follows a pattern that is similar to that of ambient temperature with one- to two-hour lag.

Significance of Research Findings

This project serves to fill an important gap in concrete pavement engineering. It has developed a database that contains a wealth of information related to early-age behavior of concrete pavements under pure environmental loading. While databases like LTPP provide information on the structural response and long-term performance of select pavement sections, the database developed here includes data that are more critical—collected in the early hours of the pavement life. With the recognition that the early-age response significantly affects the long-term performance, having this information available in such detail will allow researchers to help solidify this connection in years to come.

Underscoring the importance of this project is the connection to at least two other significant research efforts, both benefiting from the data collected during this effort.

The first research effort is an FHWA project “Inertial Profile Data for Pavement Performance Analysis,” which is entering the final analysis stages. As part of this effort, numerous models describing pavement response are being developed and validated. Among these are more accurate and relevant ways to quantify slab curvature. To date, these models have been validated on older concrete pavement sections and have resulted in a better understanding of the diurnal and seasonal responses of concrete pavements. The database collected in this ISU effort has allowed the researchers to extrapolate this assessment to the critical early ages. As a result, a bridge is being formed between the understanding and modeling early-age and long-term concrete pavement behavior. More specifically, factors such as so-called “built-in curling” found in newer pavement design methodologies can be better quantified.

A second important national effort that will benefit from this project is the Concrete Pavement Surface Characteristics Program (CPSCP) that has been co-sponsored by ISU, FHWA, and ACPA. During this project, the Marshalltown test site was selected so as to coincide with what is termed a “Type 1” site in the CPSCP. The objective of a “Type 1” site is to assess the impact that materials and construction operations have on various pavement surface characteristics, including smoothness, friction, and noise among others. The intent is to evaluate these surface characteristics in the early days and months, as well as in the years to come. Having a direct connection to the early age vis-à-vis the data collected herein will be vital to understanding these relationships. The results of this ISU effort will continue to be reviewed to help solidify understanding of the connection between design, construction, environment, and the functional response of concrete pavements.

The findings of this research can also provide the following benefits to the pavement researchers and practitioners:

- Documentation of pavement temperature variation and moisture variation for seven days after paving which are the important quality control periods for agencies and contractors.
- Documentation of the slab curvature behavior without traffic loading for seven days after paving.
- Verification of the environmental loading factors resulting in permanent curling and warping, which will be an important contribution to advance the state of the art in mechanistic-empirical rigid pavement analysis and design.
- Examination of different test techniques for measuring the early age slab deformation.
- Use of 2-D and 3-D FEM models for studying the early slab behavior due to environmental loads.
- Simulation of actual slab curvature behavior considering the permanent curling and warping with 3-D FEM models (EverFE 2.24).
- Investigation of the effect of environmental loads on initial smoothness.
- Simulation of initial smoothness variations in diurnal cycles due to environmental loads.
- Insight into PCC thermal properties input for the implementation of Mechanistic-Empirical Pavement Design Guide (MEPDG) by State Department of Transportations (DOTs).

Recommendations

Based on the research findings in this study, the followings recommendations are suggested for JPCP construction, smoothness evaluation, and future research.

Recommendations for JPCP Construction

The following recommendations are suggested for JPCP construction to reduce curling and warping behavior of JPCP:

- Many factors must be considered in the day-to-day scheduling of a paving operation. Many of the factors affecting the operation change day by day and even hour by hour. But, if minimizing curling and warping is a priority and can be accommodated in conjunction with the other project restraints, schedule the paving time to maintain minimal temperature gradient change during the concrete hardening. JPCP placed during the daytime shows positive temperature gradient prior to hardening and experiences cooling at top surface after hardening, usually during the nighttime. This changing temperature gradient before and after hardening of concrete could result in permanent curling and warping, which can influence the JPCP performance. Since nighttime paving seems to reduce the permanent curling and warping by preventing the temperature gradient change before and after concrete hardening, nighttime paving could be considered as an alternative in view of JPCP performance. However, nighttime paving can increase construction cost (productivity tends to be lower) and cause safety issues. To decide upon the paving time, a pavement engineer should find a balance between the JPCP performance and construction issues by considering the pros and cons. The predictive tool HIPERPAV should be used to analyze the daily project conditions that would affect these parameters. As conditions change, night paving may not have significant advantages under certain conditions compared to normal paving schedules.

- The limited field data from this study showed that morning paving produces smoother JPCP pavements (in terms of measured smoothness indices) compared to afternoon paving. Therefore, in situations where paving schedules can accommodate consideration of minimizing curling and warping, nighttime paving would be preferable, but paving during morning time would be next best in order to minimize the effects of curling and warping of PCC slab. Again, the predictive tool HIPERPAV should be used to analyze the daily project conditions that would affect these parameters before schedule changes are made.
- Avoid the use of aggregates having high CTE value. Aggregate type is one of the most significant factors influencing the PCC curling behavior. Aggregates with higher CTE values can increase slab curling. In general, the CTE value of quartz and gravel (11.9 × 10-6 ε/ °C to 10.8 × 10-6 ε/ °C) is approximately twice that compared to limestone (6.8 × 10-6 ε/ °C); therefore, limestone aggregate may be more preferable for JPCP construction in this context.
- Apply curing method with uniform and adequate coverage over entire surface to prevent the loss of mixing water from the surface of concrete. The rapid drying of moisture in an exposed slab surface can result in the drying shrinkage of concrete near the top of a slab and a higher saturated condition at the bottom of a slab. This moisture difference through the slab depth can cause non-uniform concrete shrinkage and non-uniform volume change as function of depth. Caution is necessary when curing is being done.

Recommendations for JPCP Smoothness Testing

Agencies should consider the following when judging and monitoring JPCP smoothness condition:

- Conducting profile measurements along the actual traffic wheel path of pavement best measures the true effect on the driver and provides consistent measurements.
- The slab curvature behavior, due to environmental loads, can possibly influence the profile measurements.

Recommendations for Future Research

The followings recommendations are proposed for the future research:

- Examine the effects of seasonal and climatic changes on smoothness of rigid pavement and identify the periods when climatic changes can significantly influence the smoothness.
- Develop laboratory and field test protocols for determining the shrinkage gradient in early-age PCC pavements.
- Investigate the rigid pavement response and curling and warping behavior associated with simultaneous traffic and environmental loading through experimental research.
- Implement studies focusing on the effects of parameters such as material properties (aggregate type, cementitious materials, etc), different curing techniques and compounds, slab thickness and geometry, and base type on permanent curling and warping.
- Identify the significance of internal stresses induced from slab deflection under environmental loading on early-age cracking.

REFERENCES

AASHTO.TP60. 2000. Standard test method for coefficient of thermal expansion of hydraulic cement concrete, *AASHOTO'S Standard Specification for Transportation Materials and Methods of Sample and Testing,* 2000.

Akhter, M., Hussain, M., Boyer, J., and Parcells, W. J. 2002. Factors affecting rapid roughness progression on portland cement concrete pavements in Kansas. *Transportation Research Record*, Vol. 1809, Transportation Research Board, Washington, D.C., pp. 74-84.

Armaghani, J. M., Lybas, J. M., Tia, M., and Ruth, B. E. 1986. Concrete pavement joint stiffness evaluation. *Transportation Research Record*, Vol.1099, Transportation Research Board, Washington, D.C., pp. 22-36.

Armaghani, J. M., Larsen, T. J., and Smith, L. L.1987. Temperature response of concrete pavement. *Transportation Research Record*, Vol. 1121, Transportation Research Board, Washington, D.C., pp. 23-33.

ASTM. C39. 2001. Standard test method for compressive strength of cylindrical concrete specimens, *Annual Book of ASTM stand*ards, Vol. 04. 02, ASTM International, West Conshohocken, PA, 2001.

ASTM. C469. 1994. Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression, *Annual Book of ASTM stand*ards, Vol. 04. 02, ASTM International, West Conshohocken, PA, 2001.

ASTM. C496. 1996. Standard test method for splitting tensile strength of cylindrical concrete specimens, *Annual Book of ASTM stand*ards, Vol. 04. 02, ASTM International, West Conshohocken, PA, 2001.

ASTM E867. 1997. Terminology relating to vehicle –pavement systems, *Annual Book of ASTM stand*ards, Vol. 04. 03., ASTM International, West Conshohocken, PA, 1998.

Beckemeyer, C. A., Khazanovich, L., and Yu, H. T. 2002. Determining amount of built-in curling in jointed plain concrete pavement: case study of Pennsylvania I-80. *Transportation Research Record*, Vol. 1809, Transportation Research Board, Washington, D.C., pp. 85-92.

Bradbury, R.D. 1938. *Reinforced Concrete Pavements.* Wire Reinforcement Institute, Washington, D.C.

Chatti, K., Lysmer, J., and Monismith, C. L. 1994. Dynamic finite element analysis of jointed concrete pavement. *Transportation Research Record*, Vol. 1449, Transportation Research Board, Washington, D.C., pp. 79-90.

Chou, Y. T. 1981. *Structural Analysis Computer Programs for Rigid Multi-Component Pavement Structures with Discontinuities: WESLIQID and WESLAYER*, Technical Report GL 81-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Chou, S. F. and Pellinen, T. K. 2005. Assessment of constriction smoothness specification pay factor limits using artificial neural network modeling. *Journal of Transportation Engineering*, Vol. 131, No.7, American Society of Civil Engineering, pp.563-570.

Choubane, B. and Tia, M. 1992. Nonlinear temperature gradient effect on maximum warping stresses in rigid pavements. *Transportation Research Board*, Vol. 1370, Washington, D.C., pp. 14-24.

Davids, W. G. 2001. 3D finite element study on load transfer at doweled joints in flat and curled rigid pavements. *The International Journal of Geomechanics*, American Society of Civil Engineering, Vol.1, No.3, pp. 309-323.

Davids, W. G. and Mahoney, J. P. 1999. Experimental verification of rigid pavements joint load transfer modeling with EverFE. *Transportation Research Record*, Vol. 1684, Transportation Research Board, Washington, D.C., pp. 81-89.
Davids, W. G., Turkiyyah, G. M., and Mahoney, J. P. 1998. EverFE: rigid pavement three – dimensional finite element analysis tool. *Transportation Research Record*. Vol. 1629, Transportation Research Board, Washington, D.C., pp. 41-49.
Davids, W.G., Wang, Z., Turkiyyah, G. M., Mahoney, J. P., and Bush, D. 2003. Three-dimensional finite element analysis of jointed plan concrete pavement with EverFE2.2. *Transportation Research Record*, Vol. 1853, Transportation Research Board, Washington, D.C., pp. 92-99.
Davids, W.G. 2003. *EverFE Theory Manual*, University of Maine, Civil Engineering Department, Orono, Main, pp.1-18.
Hammons, M. I. and Ioannides, A. M. 1997. *Advanced Pavement Design: Finite Element Modeling for Rigid Pavement Joints Report I: Background Investigation*, Technical Report DOT- FAA- AR-95-85, Federal Aviation Administration, U.S. Department of Transportation.
Holt, E. and Janssen, D. 1998. Influence of early age volume changes on long term concrete shrinkage. *Transportation Research Record*, Vol. 1610, Transportation Research Board, Washington, D.C., pp. 28-32.
Harik, I. E., Jianping, P., Southgate, H., and Allen, D. 1994. Temperature effects on rigid pavements. *Journal of Transportation Engineering*, Vol. 120, No.1, American Society of Civil Engineering, pp.127-143.
Hrennikoff, A. 1941. Solution of problems in elasticity by the frame work method. *Journal of Applied Mechanics*, Vol. 8, No. 4, pp.169 – 175.
Huang, Y. H. 1993. *Pavement Design and Analysis*, 1st edition, Prentice Hall, Englewood Cliffs, NJ.
Hveem, F. N. 1951. Slap warping affects pavement joint performance. *Proceedings of the American Concrete Institute*, Vol. 47, pp.797-808.
Ioannides, A. M. and Korovesis, G. T. 1990. Aggregate interlock: a pure-shear load transfer mechanism. *Transportation Research Record*, Vol.1286, Transportation Research Board, Washington, D.C., pp. 14-24.
Ioannides, A. M. and Korovesis, G. T. 1992. Analysis and design of doweled slab-on-grade pavement systems. *Journal of Transportation Engineering*, Vol. 118, No. 6, American Society of Civil Engineering, pp. 745-768.
Ioannides, A. M. and Salsili-Murua, R. A. 1989. Temperature curling in rigid pavements: an application of dimensional analysis. *Transportation Research Record*, Vol. 1227, Transportation Research Board, Washington, D.C., pp. 1-10.
Ioannides, A. M. and Khazanovich, L. 1998. Nonlinear temperature effects on multilayered concrete pavements. *Journal of Transportation Engineering*, Vol.124, No.2, American Society of Civil Engineering, pp.128-136.
Janssen, D.J. 1987. Moisture in portland cement concrete. *Transportation Research Record*, Vol. 1121, Transportation Research Board, Washington, D.C., pp. 40-44.
Janoff, M. S. 1990. The prediction of pavement ride quality from profile measurements of pavement roughness. *Surface Characteristic of Roadways: International Research Technologies*, ASTM STP 1031, American Society of Testing and Materials, Philadelphia, Pennsylvania, pp.259-267.

Jeong, J. H. and Zollinger, D. G. 2004. Insights on early age curling and warping behavior from fully instrumented test slab system. *CD-ROM Proceedings of the 83rd Annual Meeting of the Transportation Research Board*, Transportation Research Board, Washington, D.C.

Jeong., J. H. and Zollinger, D. G. 2005 Environmental effects on the behavior of jointed plain concrete. *Journal of Transportation Engineering*, Vol.131, No.2, American Society of Civil Engineering, pp. 140-148.

Karamihas, S. M., Gillespie, T. D., Perera, R. W., and Kohn, S. D. 1999. *Guidelines for Longitudinal Pavement Profile Measurement*, National Cooperative Highway Research Program Report 434, Transportation Research Board, Washington. D.C.

Ksaibati, K., Staigle, R. and Adkins, T. M. 1995. Pavement construction smoothness specification in the United States. *Transportation Research Record*, Vol.1491, Transportation Research Board, Washington, D.C., pp. 27-32.

Khazanovich, L., Yu, H. T., Rao, S., Galasova, K., Shats, E., and Jones, R. 2000. *ISLAB2000-Finite Element Analysis Program for Rigid and Composite Pavements*, User's Guide, ERES Consultant, Champaign, Illinois.

Kim, J. and Hjelmstad, K. D. 2003. Three-dimensional finite element analysis of doweled joints for airport pavements. *Transportation Research Record*, Vol.1853, Transportation Research Board, Washington, D. C., pp. 100-109.

Korovesis, G. T. 1990. Analysis of slab on grade pavement systems subjected to wheel and temperature loadings, Ph.D. dissertation, University of Illinois, Urbana Champaign, Illinois.

Kosmatka, S. H., Kerkhoff, B., and Panarese, W. C. 2002. *Design and control of concrete mixtures*, 4th edition, Portland Cement Association, Skokie, Illinois.

Kuo, C. M., Hall, K. T., and Dater, M. I. 1995. Three dimensional finite element model for analysis of concrete pavement support. *Transportation Research Record*, Vol.1505, Transportation Research Board, Washington, D.C., pp. 119-127.

Lee, Y. H. and Dater, M. I. 1993. Mechanistic design models of loading and curling in concrete pavements. *Proceedings of Airport Pavement Innovations – Theory to Practice*, Vicksburg, MS.

Logan, D.L. 2002. *A First Course in the Finite Element Method*, 3rd edition, Thomson Learning, Inc., Pacific Grove, CA.

Ma, S. and Caprez, M. 1995. The pavement roughness requirement for WIM. *First European Conference on Weight –in –motion of Road Vehicle*, Switzerland.

Mahboub, K. C., Liu, Y., and Allen, D. L. 2004. Evaluation of temperature responses in concrete pavement. *Journal of Transportation Engineering*, Vol.130, No.3, American Society of Civil Engineering, pp. 395-401.

Massad, E. and Taha, R.1996. Finite-element analysis of temperature effects on plain - jointed concrete pavements. *Journal of Transportation Engineering*, Vol.122, No.5, American Society of Civil Engineering, pp. 388-398.

McHenry, D. 1943. A lattice analogy for the solution of plane stress problems. *Journal of Institution of Civil Engineers*, Vol. 21, pp. 59-82.

McCullough, B. F. and Rasmussen, R. O. 1999. *Fast-Track Paving: Concrete Temperature Control and Traffic Opening Criteria for Bonded Concrete Overlays*, Volume I: Final Report, FHWA-RD-98-167, Washington, D.C.

Mindess, S. and Young, J. F. 1981. *Concrete*. 1st edition, Prentice-Hall, Inc., Englewood Cliffs, NJ.

Mindess, S., Young, J. F. and Darwin, D. 2003. *Concrete*. 2nd edition, Prentice-Hall, Inc., Englewood Cliffs, NJ.

Mohamed, A. R. and Hansen, W. 1997. Effect of nonlinear temperature gradient on curling stress in concrete pavement. *Transportation Research Record*, Vol. 1568, Transportation Research Board, Washington, D. C., pp.65-71.

National Cooperative Highway Research Program (NCHRP). 2004. *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*, National Cooperative Highway Research Program 1-37A, Transportation Research Board, Washington, D.C. http://trb.org/mepdg.

Nevil, A.M.1996. *Properties of Concrete*, 4th edition, John Wiley & Sons, Inc., New York, NY.

Ott, L.R. and Longnecker, M. 2001. *An Introduction to Statistical Methods and Data Analysis*, 5th edition, Duxbury, Pacific Grove, California.

Perera. R. W and Kohn. S. D. 2002, *Issues in Pavement Smoothness*, National Cooperative Highway Research Program Web Document No. 42, Transportation Research Board, Washington, D.C.

Rao, C., Barenberg, E. J., Snyder, M. B., and Schmidt, S. 2001. Effects of temperature and moisture on the response of jointed concrete pavements. *Proceedings of 7th International Conference on Concrete Pavements*, Orlando, Florida.

Rao, S., and Roesler, J. R. 2005. Characterizing effective built in curling from concrete pavement field measurements. *Journal of Transportation Engineering*, Vol. 131, No.4, American Society of Civil Engineering, pp. 320-327.

Rasmussen, R. O. 1996. *Development of An Early Age Behavior Model for Portland Cement Concrete Pavements*, Ph.D. Thesis, University of Texas at Austin, Austin, Texas.

Rasmussen, R. O., Karamihas, S. K. and Chang, C. K. 2002. *Inertial Profile Data for Pavement Performance Analysis : Project Overview*, Tech Brief Number 1, Federal Highway Administration Contact DTFH 61-02-C-00077, Washington, D.C.

Rasmussen, R. O., Karamihas, S. K., Cape, W. R., Chang, C. K. and Guntert, R. M. 2004. Stringline effects on concrete pavement construction. *Transportation Research Record*, Vol. 1900, Transportation Research Board, Washington, D.C., pp. 3-11.

Sayers, M. W. and Karamihas, S. M. 1998. *The Little Book of Profiling*. University of Michigan, Ann Arbor. Michigan.

Siddique, Z. Q. 2004. Finite element simulation of curling on concrete pavement. Ph.D. dissertation, Kansas State University, Manhattan, Kansas.

Smith, K. L., Smith, K. D., Evans, L. D., Hoerner, T. E., Darter, M. I., and Woodstrom, J. H. 1997. *Smoothness Specifications for Pavements*. National Cooperative Highway Research Program Web Document No. 1, Transportation Research Board, Washington, D.C.

Smith, K. L., and Clover, L. T., Evans, L. D. 2002. *Pavement Smoothness Index Relationships*, Technical Report Feral Highway Administration- RD- 02-057, Federal Highway Administration, U.S. Department of Transportation.

Tabatabaie, A. M. and Barenberg, E. J. 1978. Finite element analysis of jointed or cracked concrete pavements. *Transportation Research Record*, Vol. 671, Transportation Research Board, Washington, D.C., pp. 11-17.

Tayabji, S. D. and Colley, B. E. 1986. *Analysis of Jointed Concrete Pavements*, Technical Report Federal Highway Administration- RD- 86-041, Federal Highway Administration, U.S. Department of Transportation.

Thomlinson, J. 1940. Temperature variations and consequence stress produced by daily and seasonal temperature cycles in concrete slabs. *Concrete Constructional Engineering*, Vol. 36, No. 6, pp.298-307 and No.7, pp. 352-360.

Tia, M., Armaghani, J. M., Wu, C. L., Lei, S., and Toye, K. L.1987. FEACONS Ш, computer program for analysis of jointed concrete pavements. *Transportation Research Record*, Vol. 1136, Transportation Research Board, Washington, D. C., pp. 12-22.

Vandenbossche, J. M. 2003. Interpreting falling weight deflectometer results for curled and warped portland cement concrete pavements, Ph.D. dissertation, University of Minnesota, Minneapolis, Minnesota.

Vandenbossche, J. M., Wells, S. A. and Phillips, B.M. 2006. Quantifying built-in construction gradients and early-age slab shape to environmental loads for jointed plain concrete pavements. *CD-ROM Proceedings of the 85rd Annual Meeting of the Transportation Research Board*, Washington, D.C.

Vepa, T. S. and George, K. P.1997. Deflection response model for cracked rigid pavements. *Journal of Transportation Engineering*, Vol. 123, No. 5, American Society of Civil Engineering, pp.377-384.

Wang, W., Basheer, I., and Petros, K. 2006. Jointed plain concrete pavement models evaluation. *CD-ROM Proceedings of the 85rd Annual Meeting of the Transportation Research Board*, Washington, D.C.

Westergaard, H. M.1926. Analysis of stressed in concrete pavements due to variations of temperature. *Proceedings of Highway Research Board*, Vol. 6, National Research Council, Washington, D.C., pp.201-217.

Yu, H. T., Khazanovich, L. Darter, M. I, and Ardani, A. 1998. Analysis of concrete pavement response to temperature and wheel loads measured from instrumented slab. *Transportation Research Record*, Vol. 1639, Transportation Research Board, Washington, D.C., pp.94-101.

Yu, H. T., Khazanovich, L. 2001. Effects of construction on concrete pavement behavior. *Proceedings of 7th International Conference on Concrete Pavements*, Orlando, Florida.

Yu, H. T., Khazanovich, L., and Darter, M. I. 2004. Consideration of JPCP curling and warping in the 2002 design guide. *CD-ROM Proceedings of the 83rd Annual Meeting of the Transportation Research Board*, Washington, D.C.

Zienkiewicz, O. C. and Taylor, R. L. 1987. *The Finite Element Method- Basic Formulation and Linear Problems*, Vol. 1, 4th edition, Mcgraw-Hill Book Company, London.

APPENDIX A: PLATTEVILLE SITE PHOTO LOG

Figure A.1. Base preparation and concrete delivery operations

Figure A.2. Concrete delivery operations

Figure A.3. Paver and dowel bar inserter operations

Figure A.4. Dowel bar inserter operations

Figure A.5. Paving operations

Figure A.6. Straightedge operations

Figure A.7. Texturing operations

Figure A.8. Curing operations

Figure A.9. Transverse sawcut operations

Figure A.10. Transverse sawcut operations

Figure A.11. Longitudinal sawcut operations

Figure A.12. Inclinometer profiling

Figure A.13. Inclinometer profiling

Figure A.14. Temperature instrumentation installation

Figure A.15. Temperature instrumentation installation

Figure A.16. Temperature instrumentation installation

Figure A.17. Temperature instrumentation installation

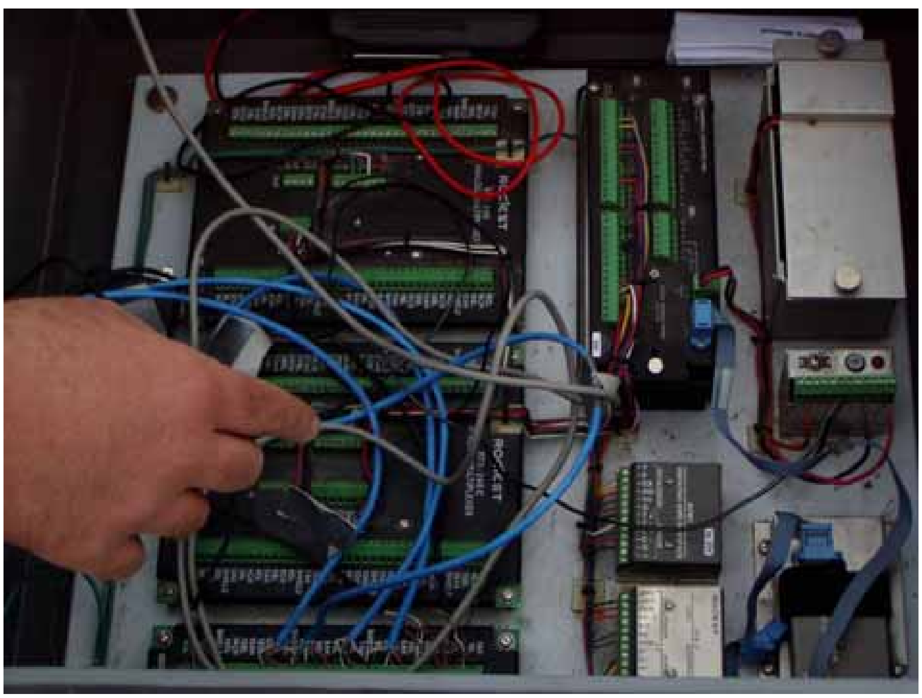


Figure A.18. LVDT datalogger

Figure A.19. LVDT installation (Iowa State)

Figure A.20. LVDT installation (Transtec)

Figure A.21. Pavement coring

Figure A.22. Corner DEMEC installation

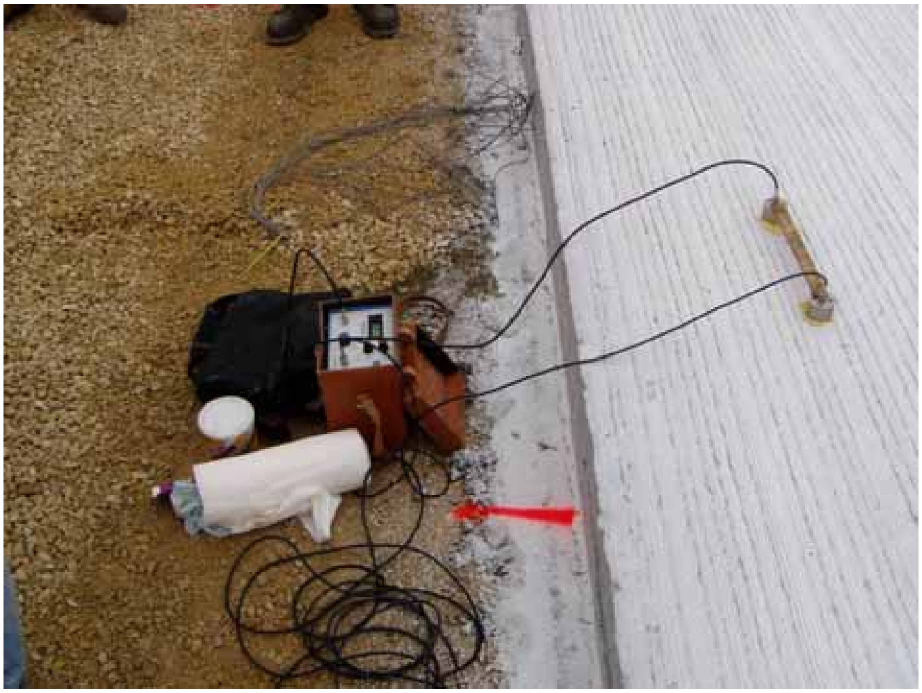


Figure A.23. Ultrasonic pulse velocity

APPENDIX B: PLATTEVILLE SITE MORNING PAVING TEST SECTION

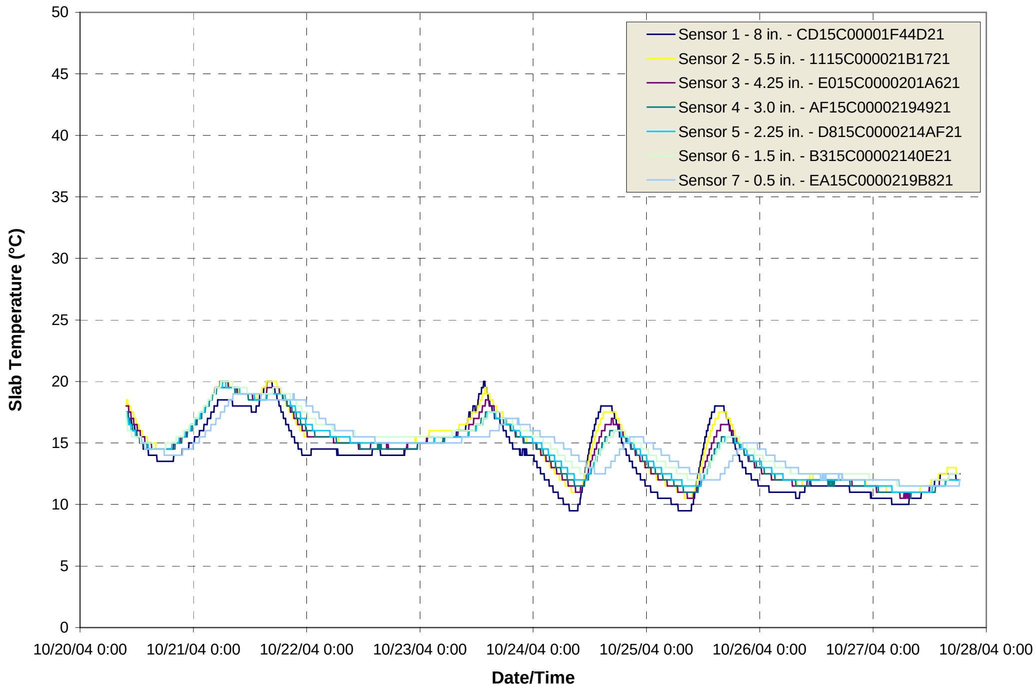


Figure B.1. Slab temperature data

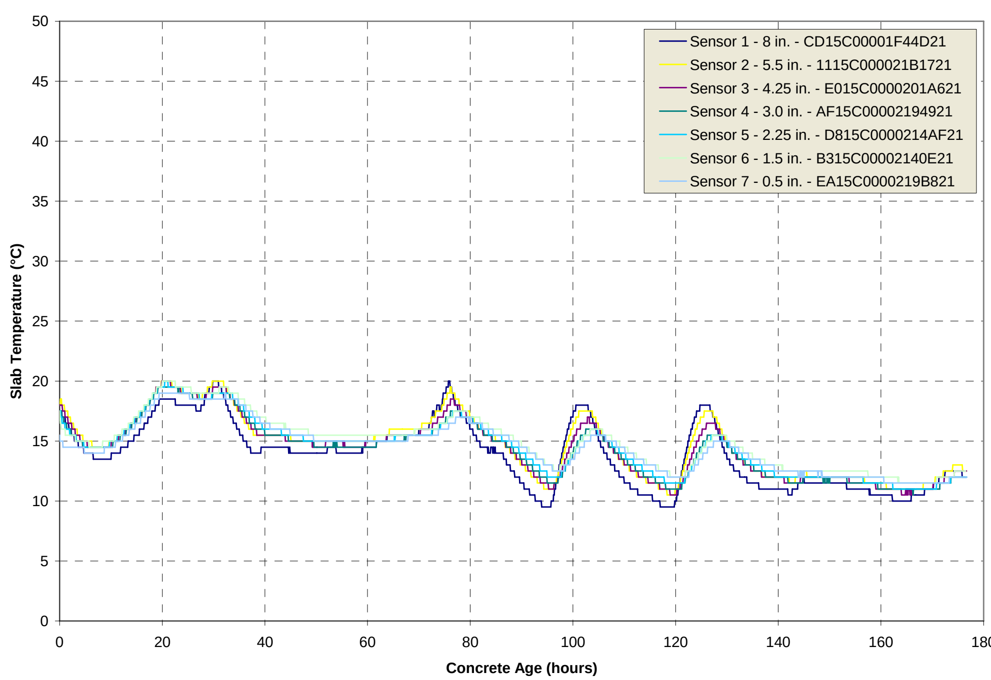


Figure B.2. Slab temperature data

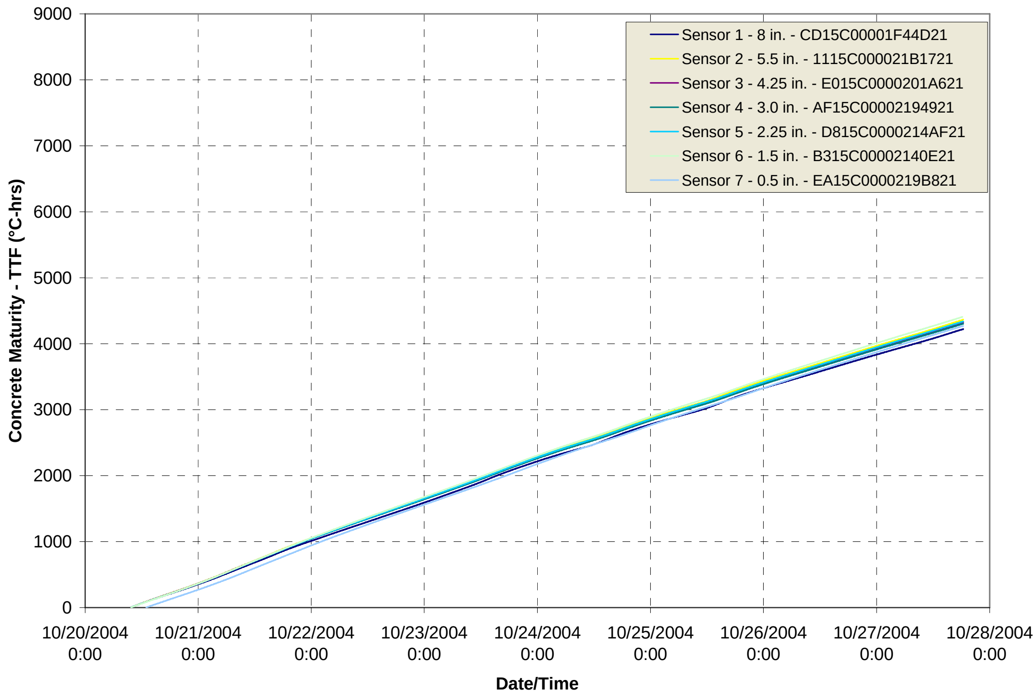


Figure B.3. Slab maturity data

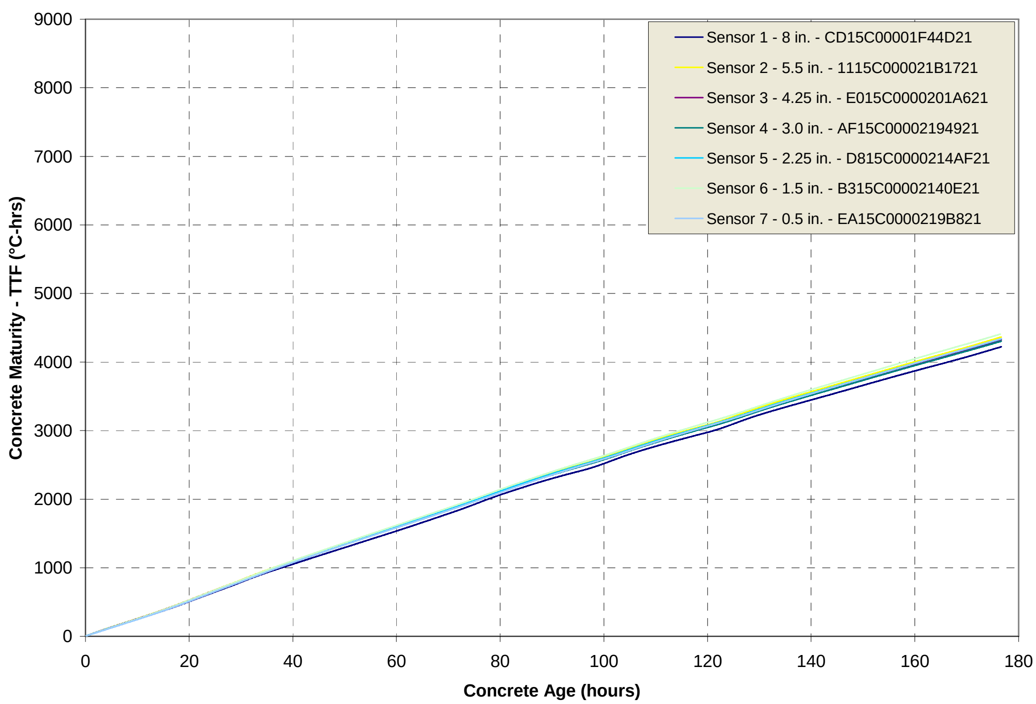


Figure B.4. Slab maturity data

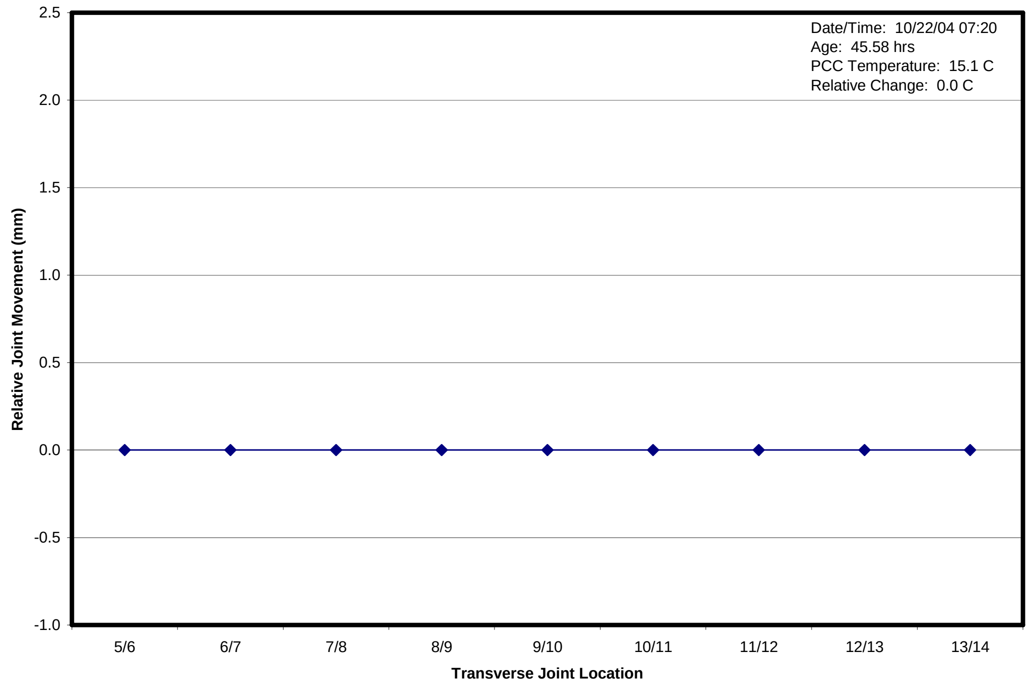


Figure B.5. Transverse joint relative opening

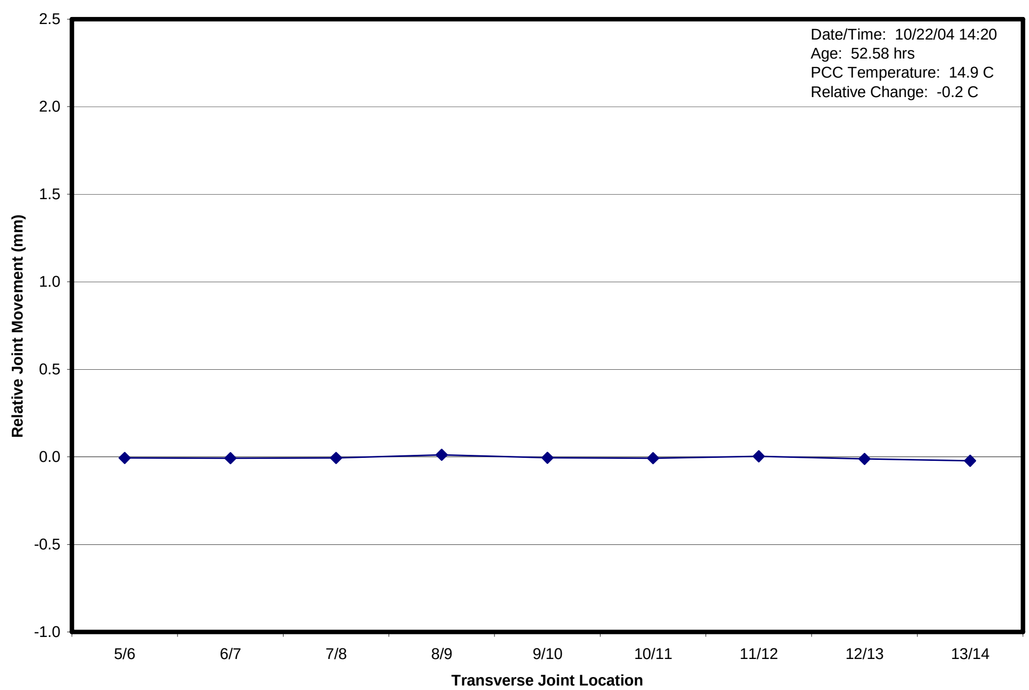


Figure B.6. Transverse joint relative opening

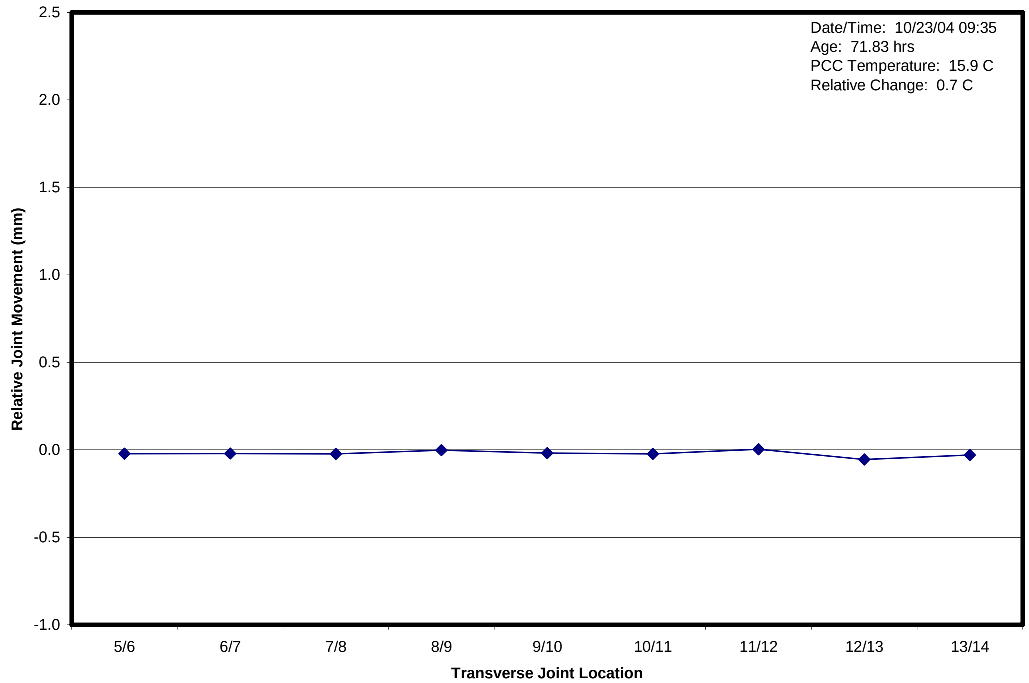


Figure B.7. Transverse joint relative opening

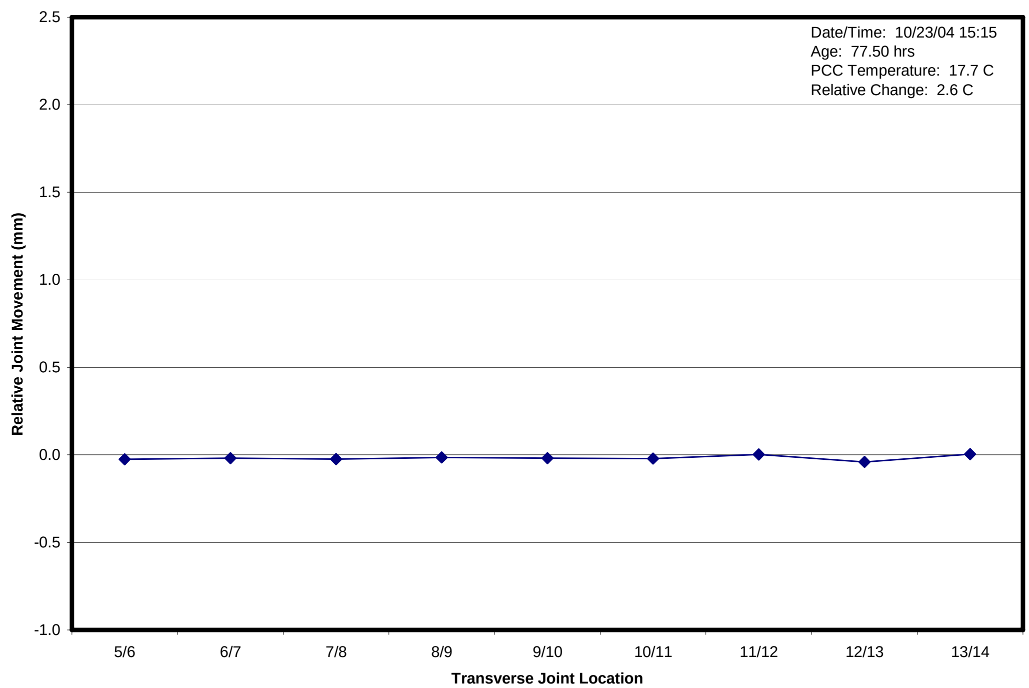


Figure B.8. Transverse joint relative opening

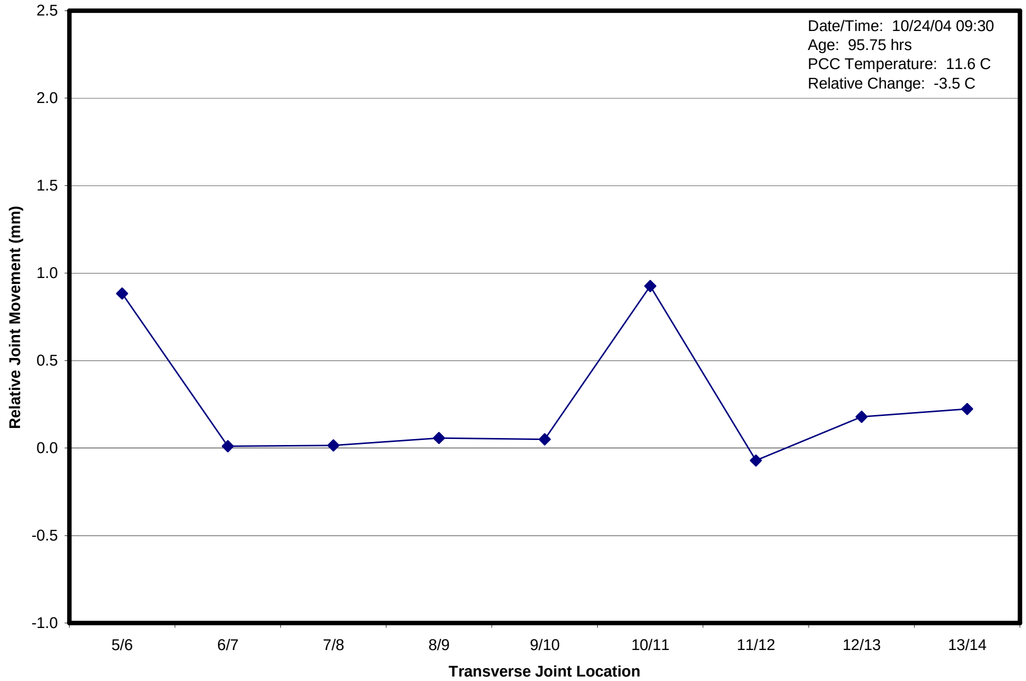


Figure B.9. Transverse joint relative opening

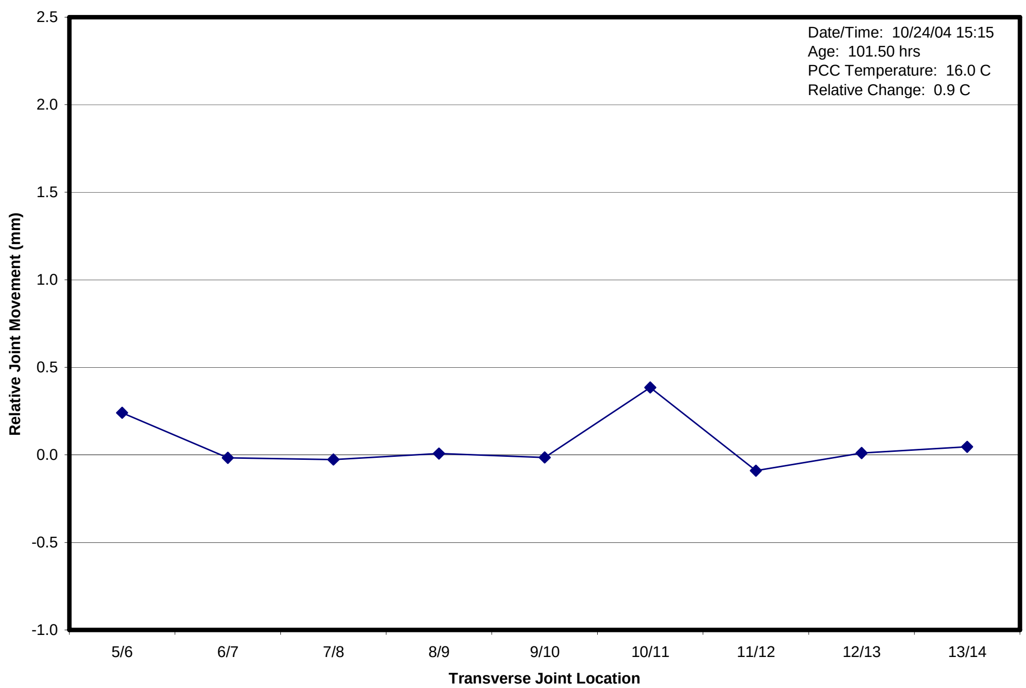


Figure B.10. Transverse joint relative opening

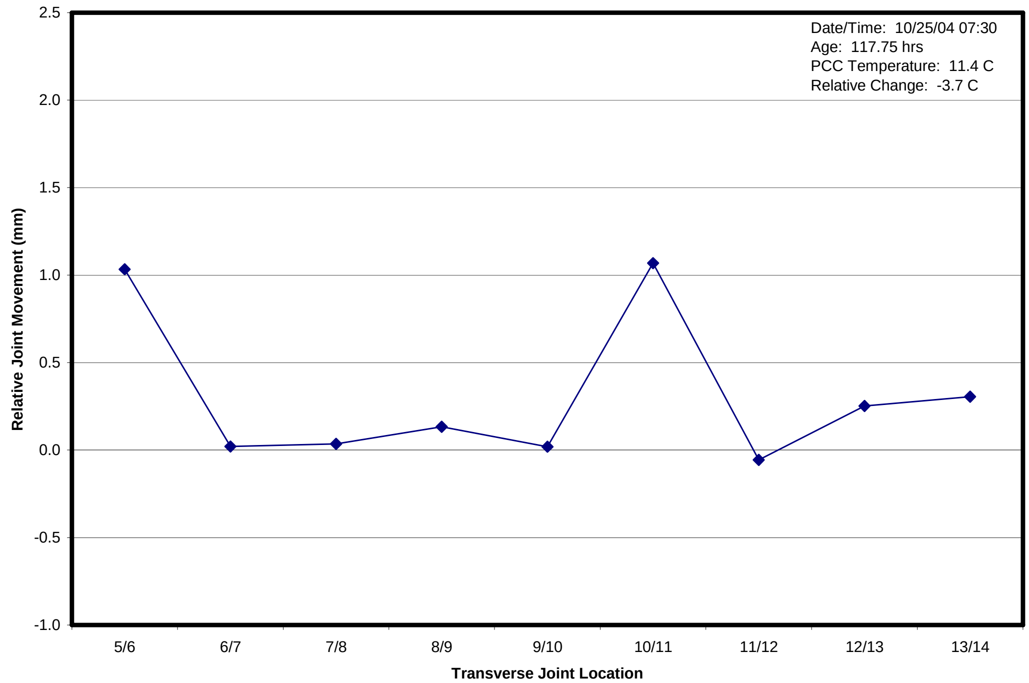


Figure B.11. Transverse joint relative opening

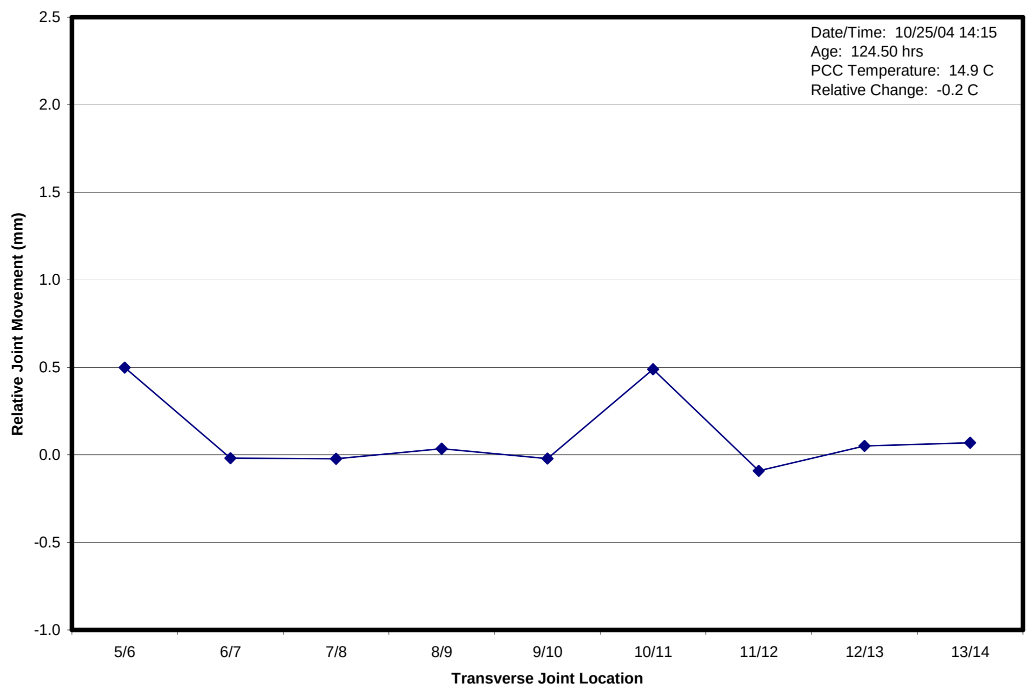


Figure B.12. Transverse joint relative opening

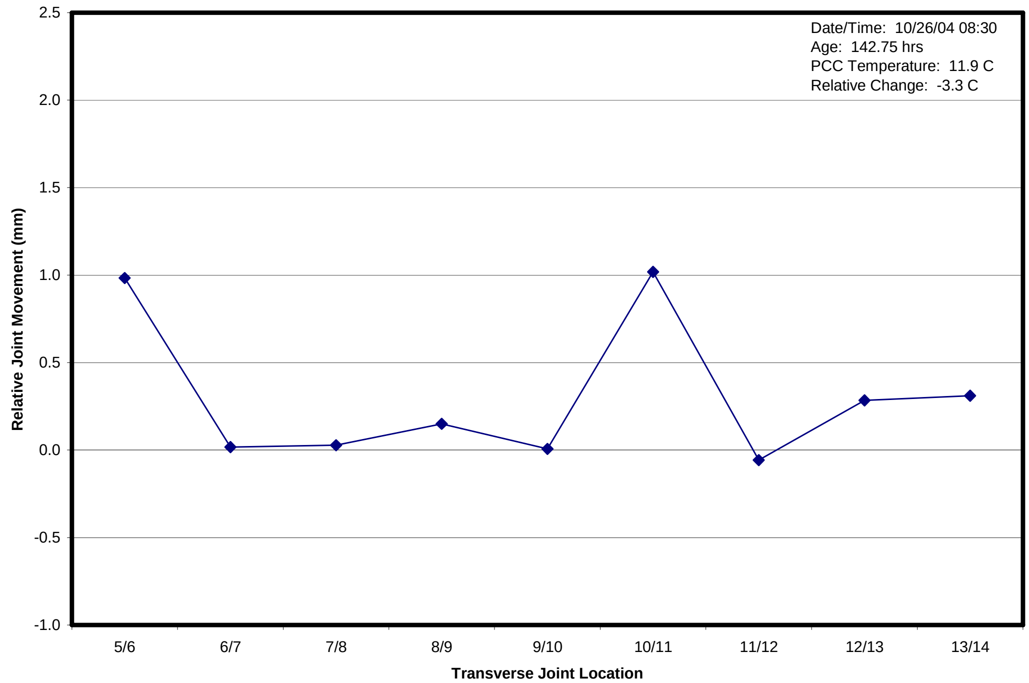


Figure B.13. Transverse joint relative opening

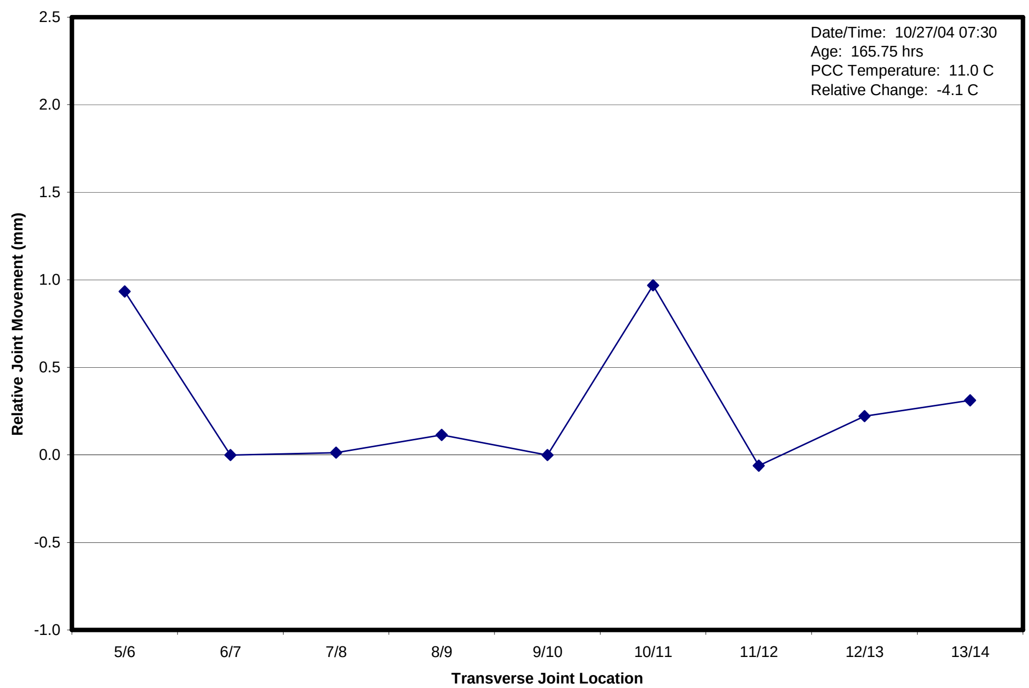


Figure B.14. Transverse joint relative opening

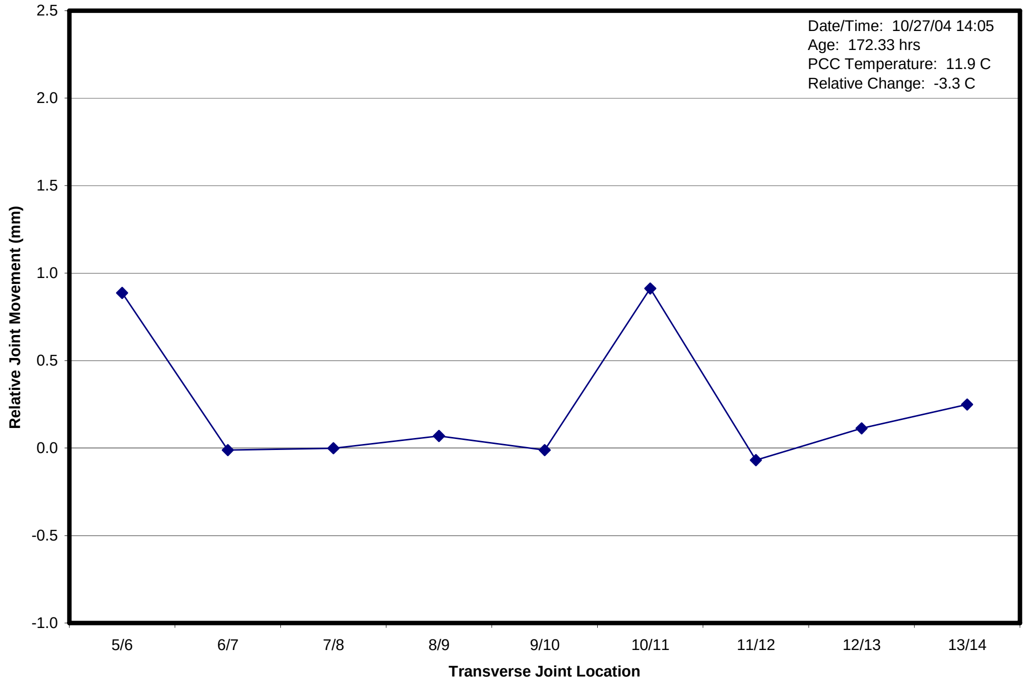


Figure B.15. Transverse joint relative opening

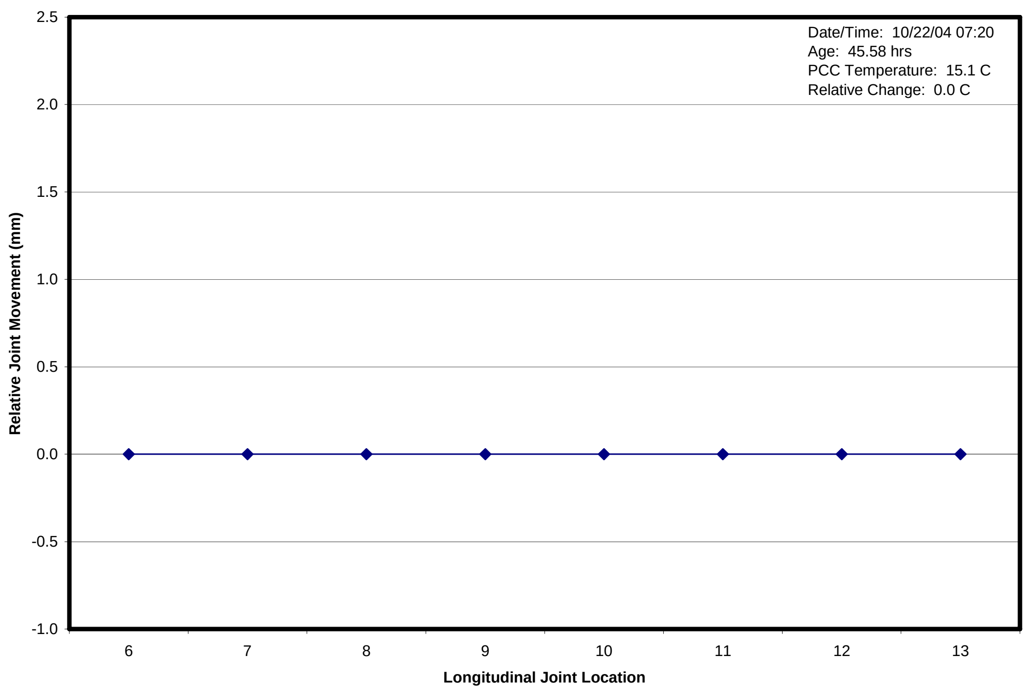


Figure B.16. Longitudinal joint relative opening

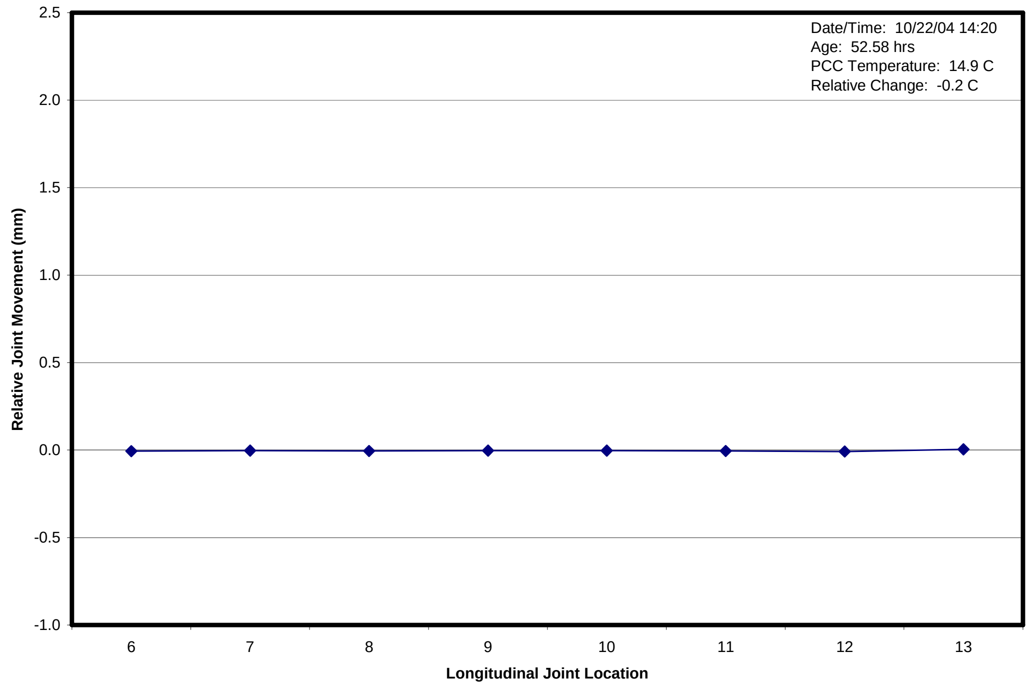


Figure B.17. Longitudinal joint relative opening

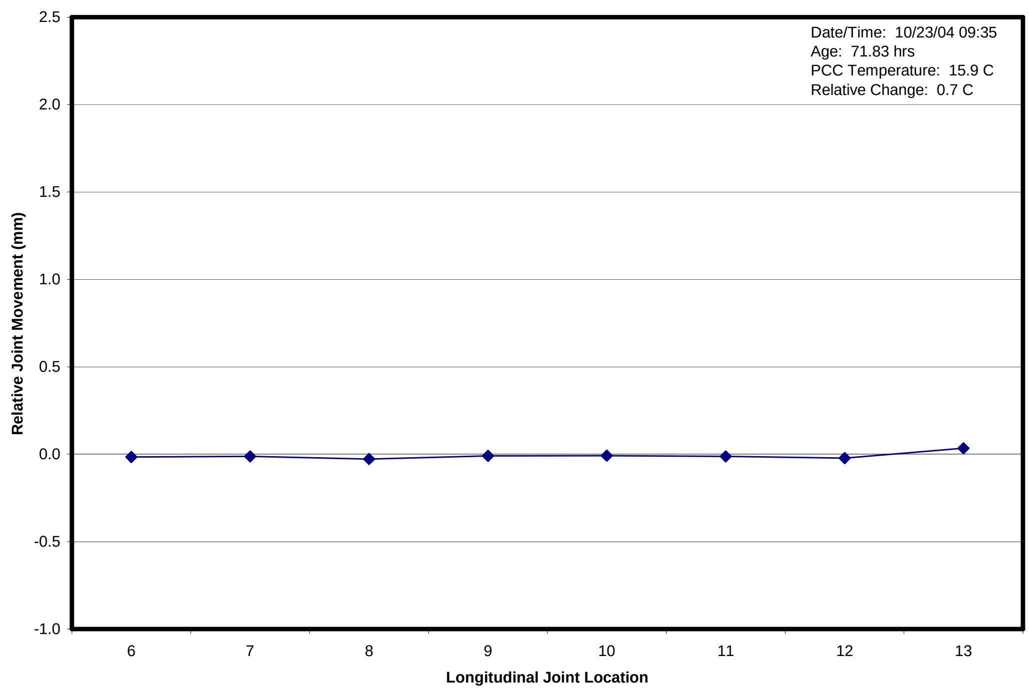


Figure B.18. Longitudinal joint relative opening

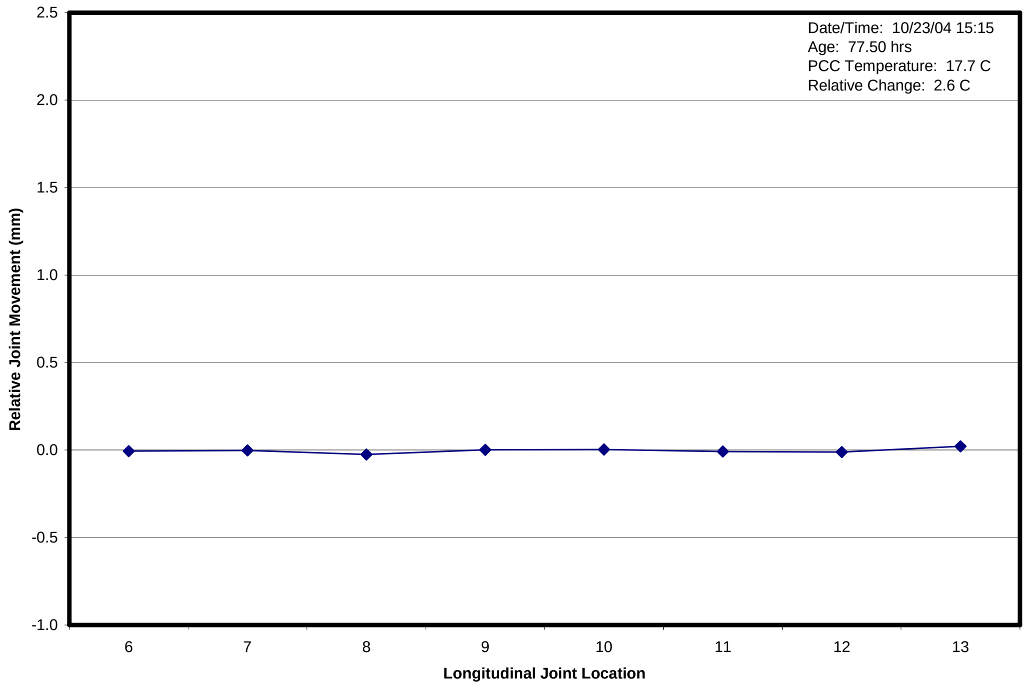


Figure B.19. Longitudinal joint relative opening

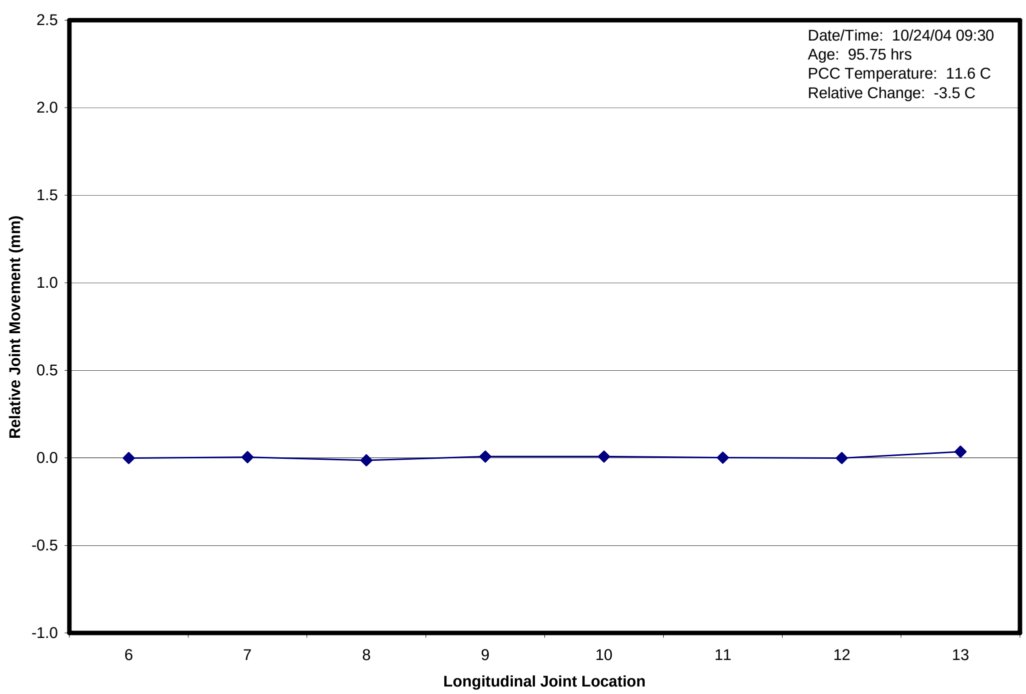


Figure B.20. Longitudinal joint relative opening

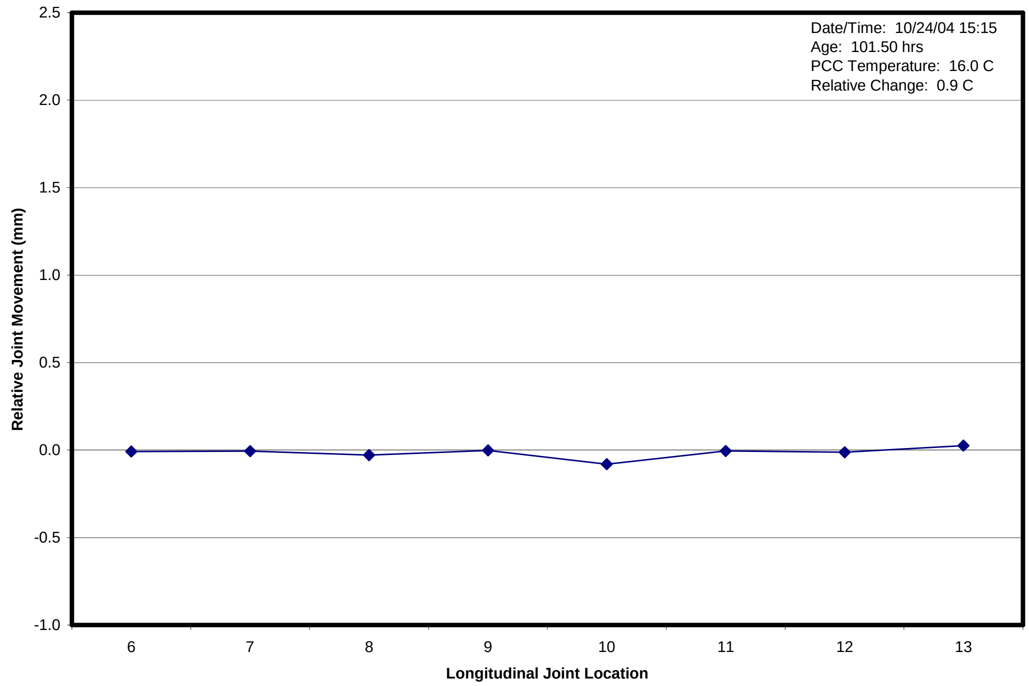


Figure B.21. Longitudinal joint relative opening

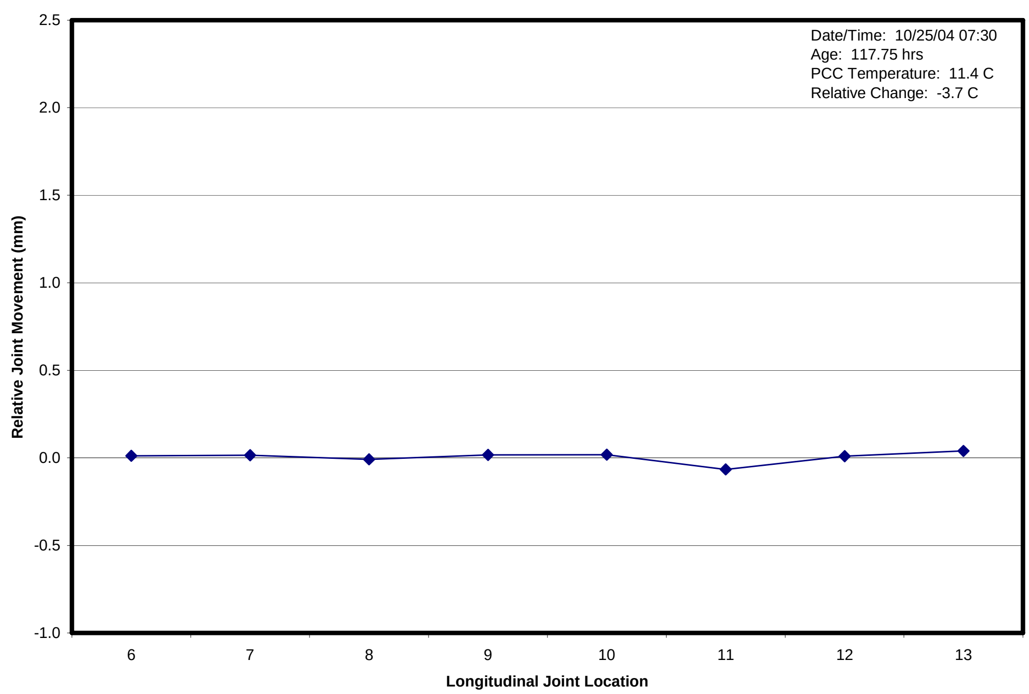


Figure B.22. Longitudinal joint relative opening

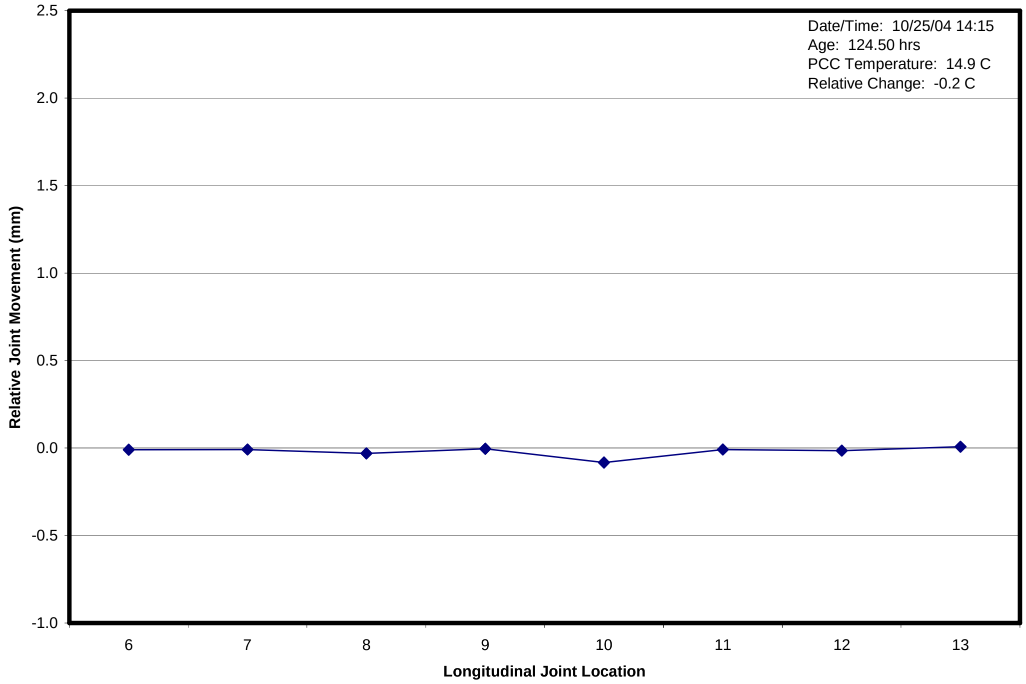


Figure B.23. Longitudinal joint relative opening

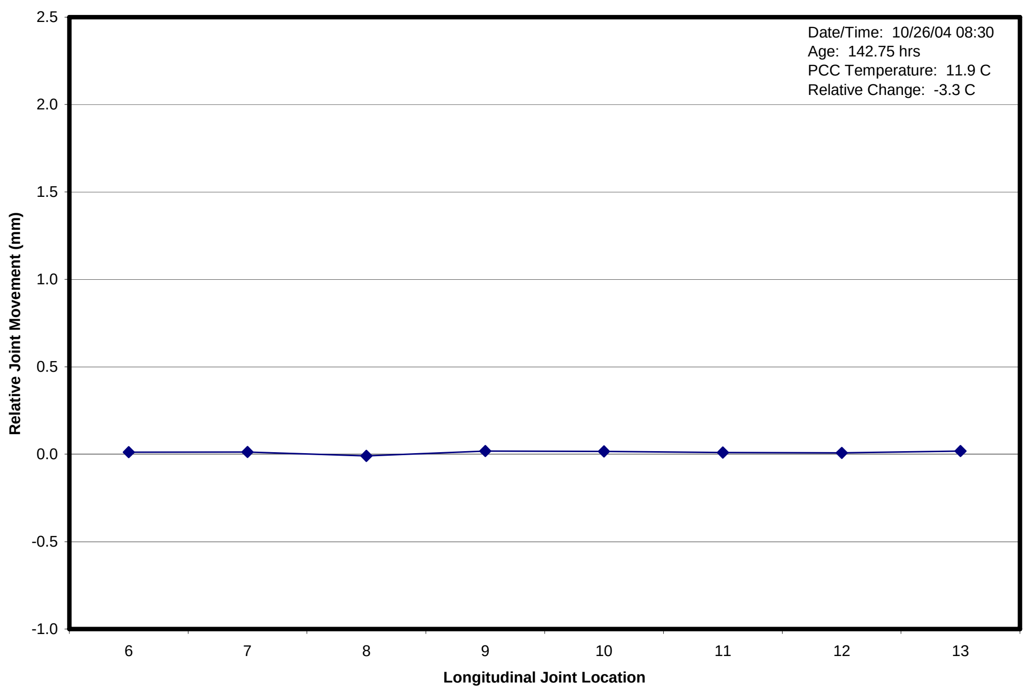


Figure B.24. Longitudinal joint relative opening

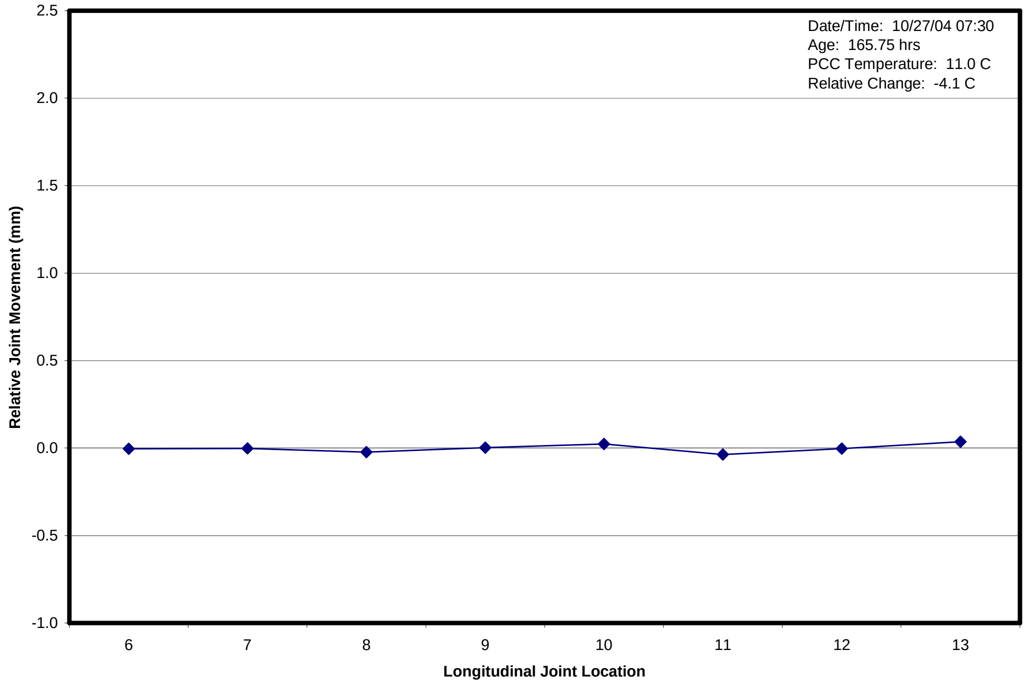


Figure B.25. Longitudinal joint relative opening

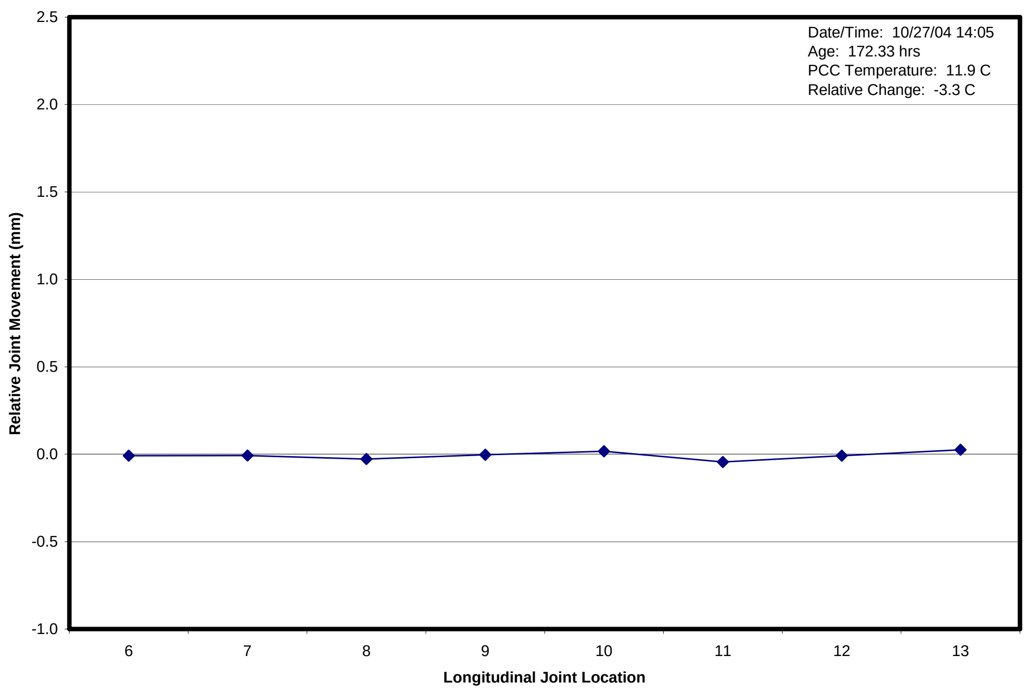


Figure B.26. Longitudinal joint relative opening

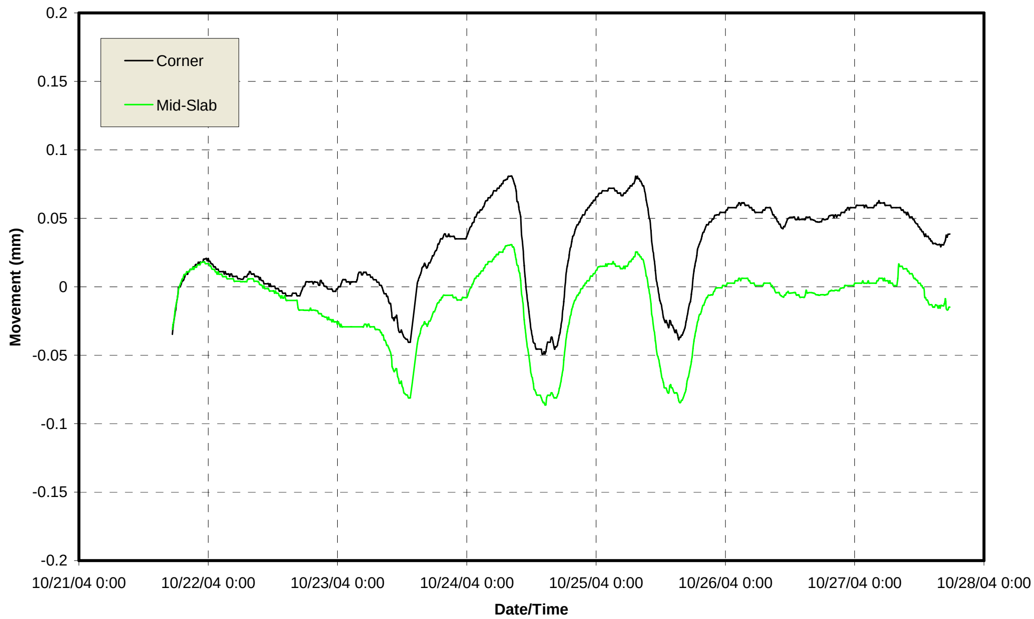


Figure B.27. LVDT record

Table B.1. Level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperatur e (°C)	IRI (in/mi)	PTRN (in/mi)	RN
1A121E	10/21/2004 7:00	21.25	19.5	8.0	93	151.4	3.41
1A122E	10/21/2004 10:30	24.75	18.9	10.2	96.1	172.7	3.23
1A31E	10/22/2004 6:00	44.25	15.4	10.4	94.8	175.6	3.21
1A33E	10/22/2004 13:00	51.25	14.8	11.6	92.9	172.8	3.23
1A41E	10/23/2004 7:30	69.75	15.6	16.9	100.6	145.3	3.46
1A43E	10/23/2004 13:00	75.25	17.3	18.4	98.4	149.8	3.43
1A51E	10/24/2004 9:00	95.25	11.6	7.6	97.2	150.4	3.42
1A53E	10/24/2004 14:00	100.2 5	15.1	16.7	98.6	150.6	3.42
1A61E	10/25/2004 6:30	116.7 5	11.6	8.2	96	143	3.48
1A63E	10/25/2004 13:10	123.4 2	13.9	16.1	96.5	146.9	3.45
1A71E	10/26/2004 8:30	142.7 5	11.8	9.5	93.3	148.2	3.44
1A81E	10/27/2004 6:45	165.0 0	10.9	9.2	94.5	144.4	3.47
1A83E	10/27/2004 13:00	171.2 5	11.6	10.9	94.4	147.1	3.45

Table B.2. Level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	RNPI (in/mi)	RN
1A122M	10/21/2004 10:30	24.75	18.9	10.2	70.7	120.9	3.68
1A41M	10/23/2004 7:30	69.75	15.6	16.9	83	127.3	3.63
1A43M	10/23/2004 13:00	75.25	17.3	18.4	73.8	114.3	3.75
1A51M	10/24/2004 9:00	95.25	11.6	7.6	76.5	116.9	3.72
1A53M	10/24/2004 14:00	100.25	15.1	16.7	78.1	114.7	3.74
1A61M	10/25/2004 6:30	116.75	11.6	8.2	73.3	117.7	3.71
1A63M	10/25/2004 13:10	123.42	13.9	16.1	73.3	106.4	3.82
1A71M	10/26/2004 8:30	142.75	11.8	9.5	72.4	108.3	3.8
1A81M	10/27/2004 6:45	165.00	10.9	9.2	78.7	111.4	3.77

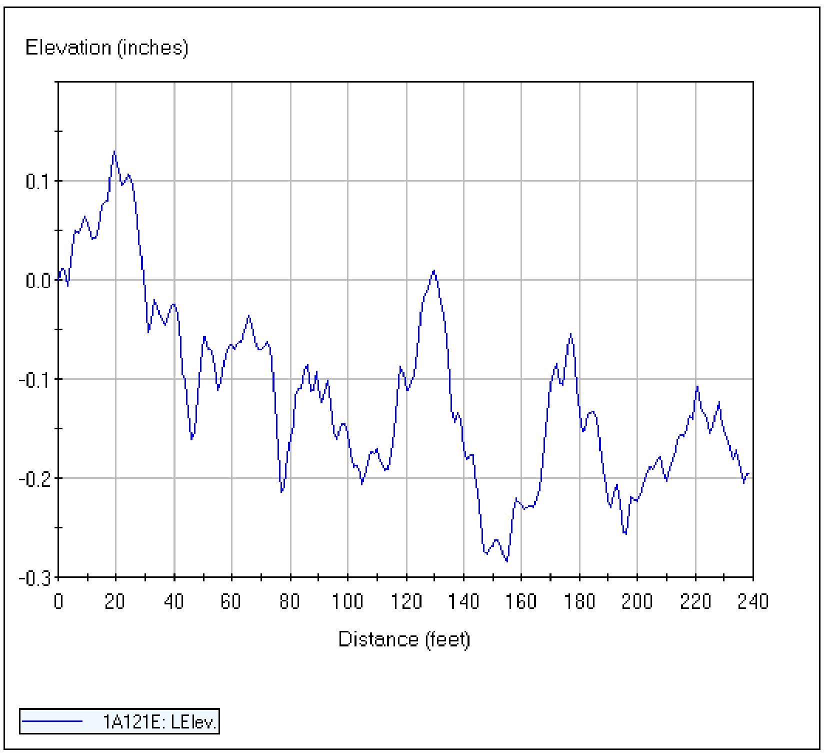


Figure B.28. Level A profile – edge only – Oct. 21, 2004 07:00

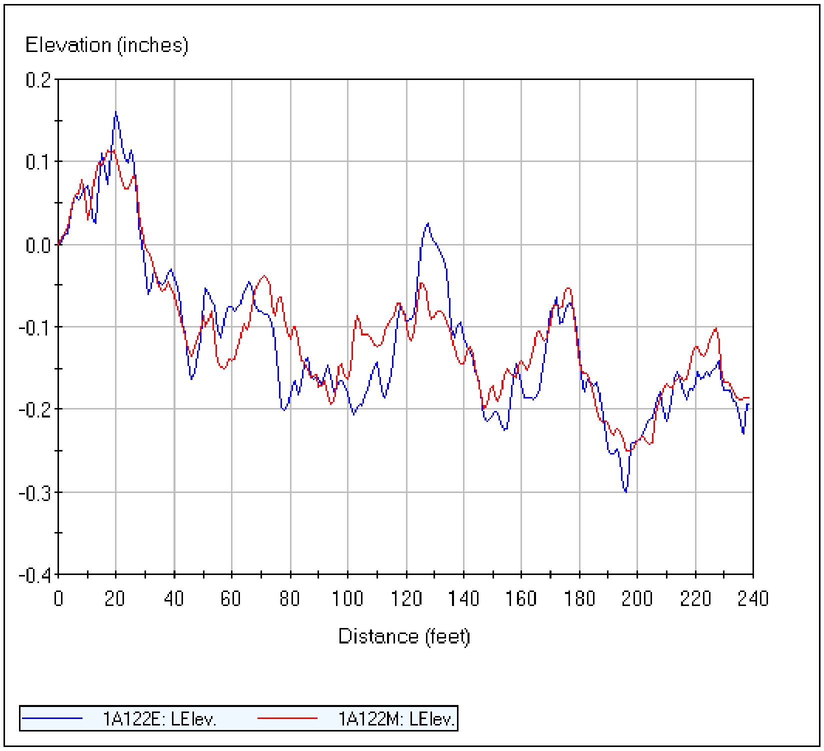


Figure B.29. Level A profile – Oct. 21, 2004 10:30

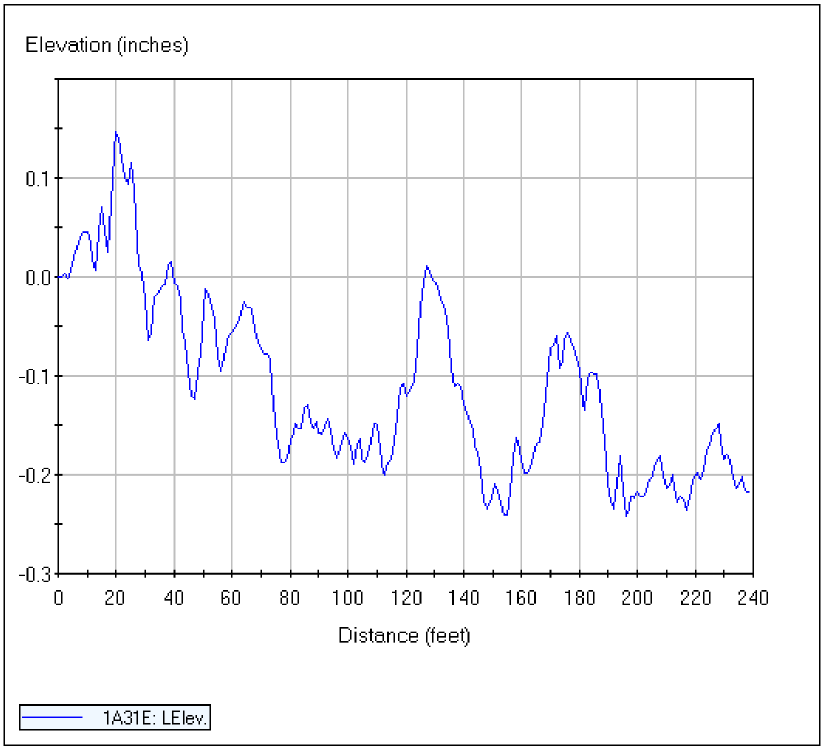


Figure B.30. Level A profile – edge only – Oct. 22, 2004 06:00

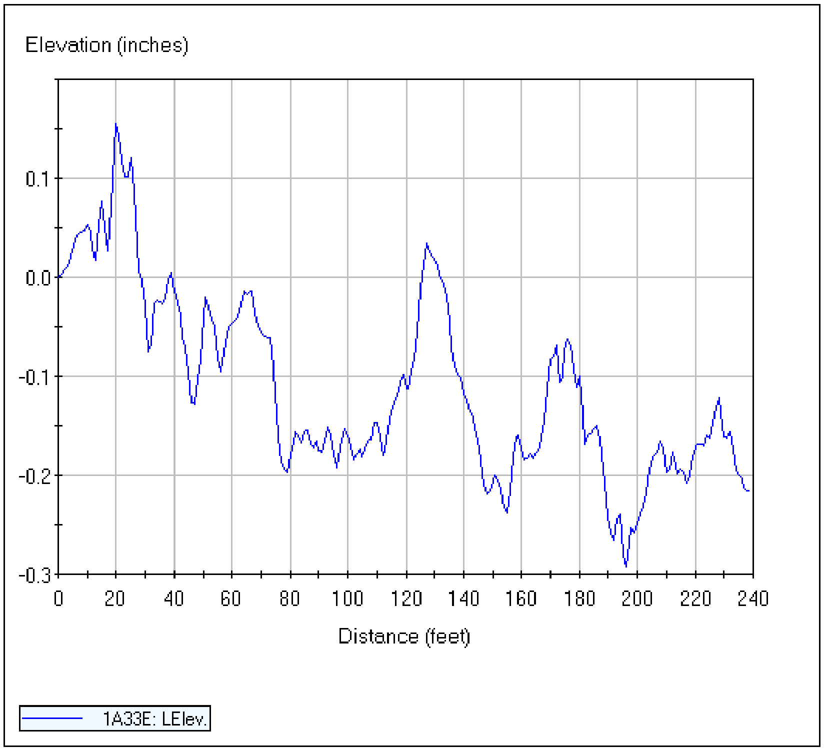


Figure B.31. Level A profile – edge Only – Oct. 22, 2004 13:00

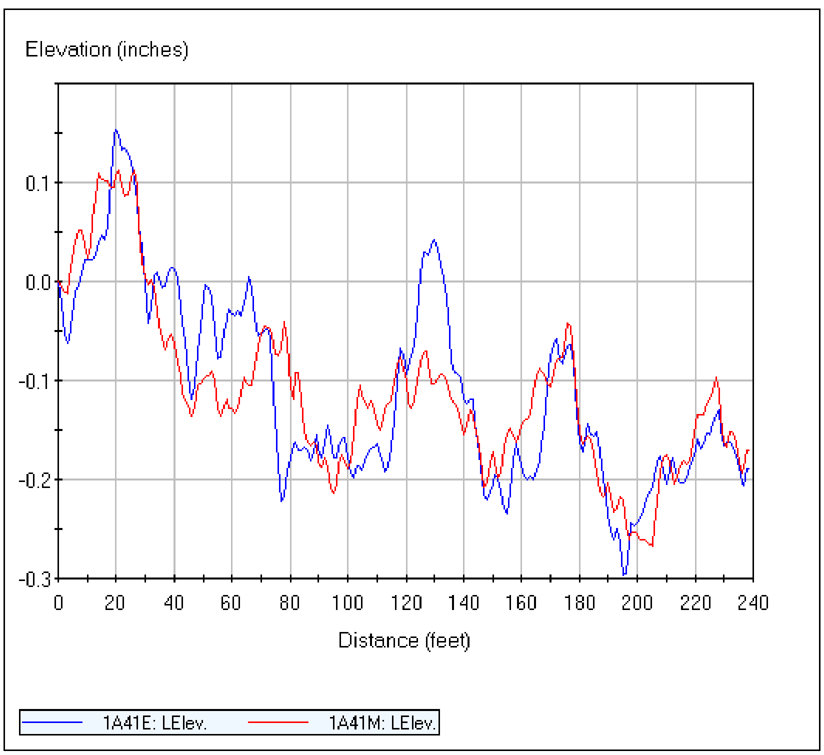


Figure B.32. Level A profile – Oct. 23, 2004 07:30

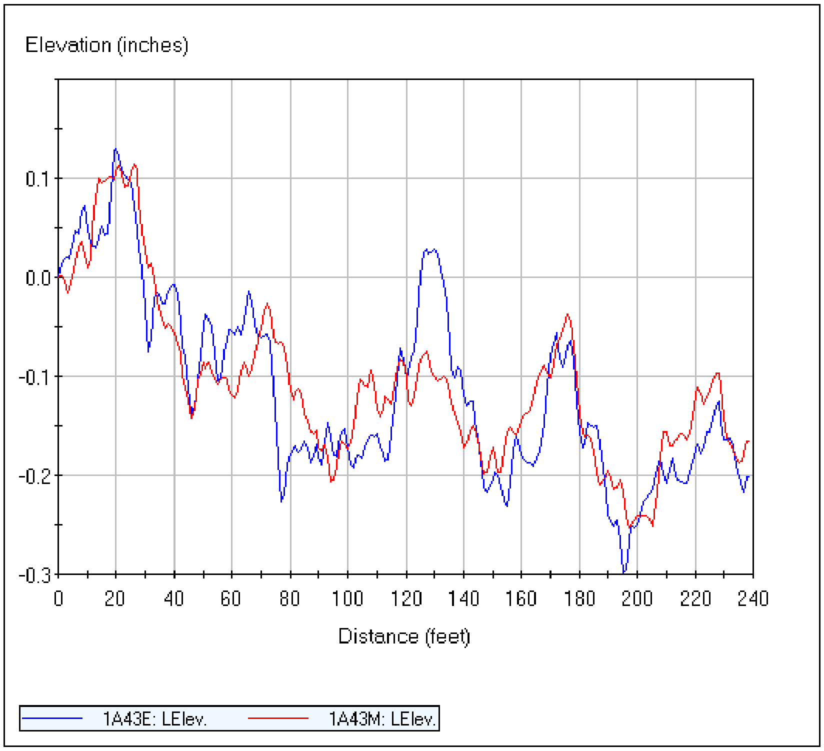


Figure B.33. Level A profile – Oct. 23, 2004 13:00

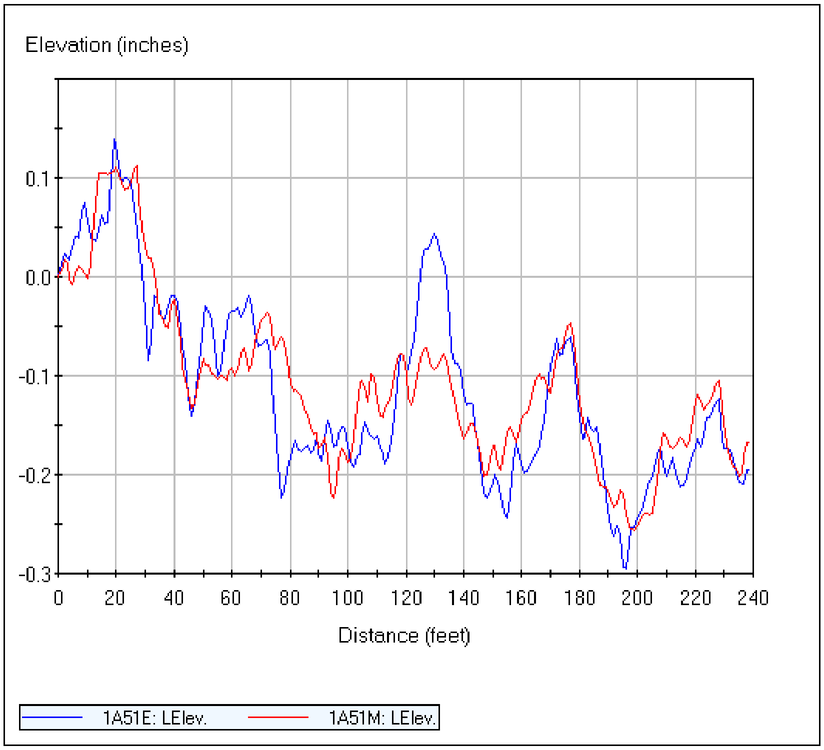


Figure B.34. Level A profile – Oct. 24, 2004 09:00

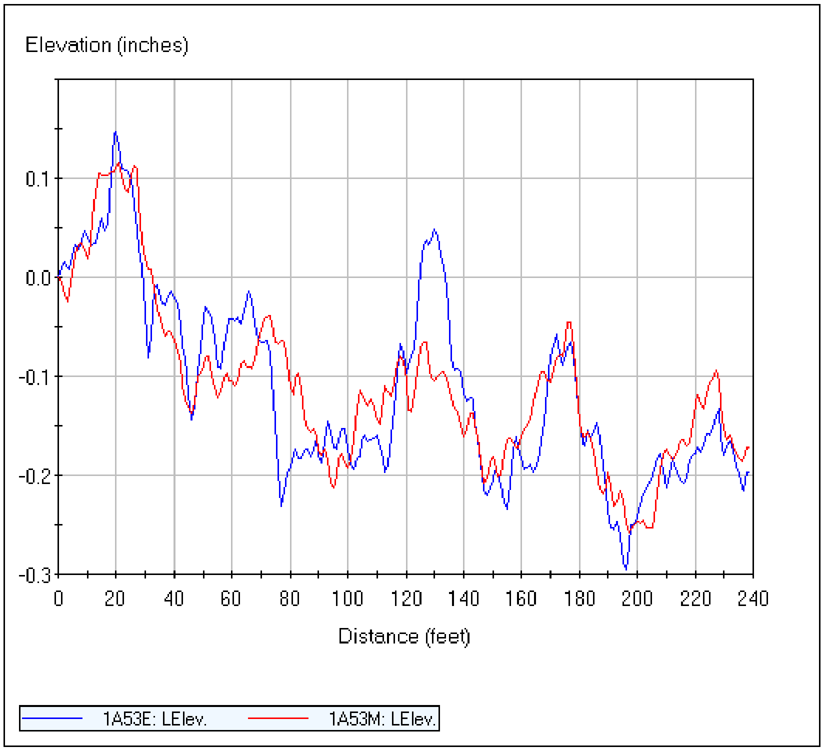


Figure B.35. Level A profile – Oct. 23, 2004 14:00

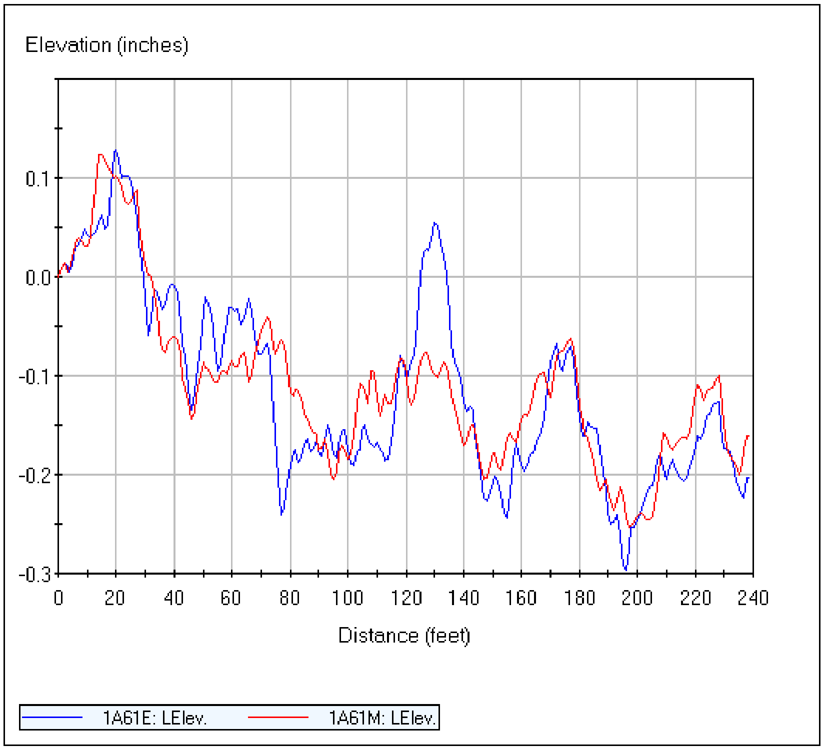


Figure B.36. Level A profile – Oct. 25, 2004 06:30

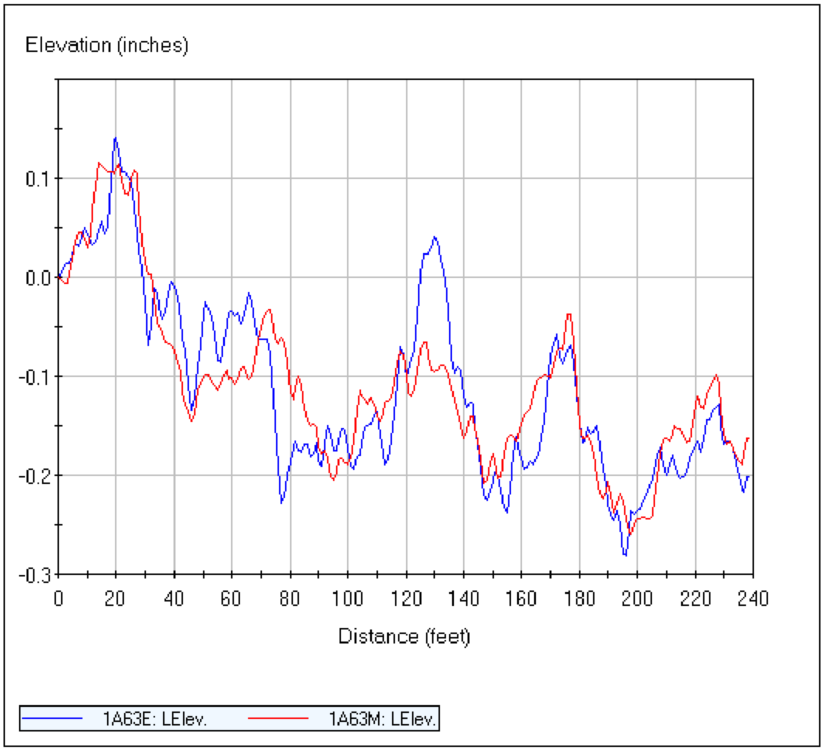


Figure B.37. Level A Profile – Oct. 25, 2004 13:10

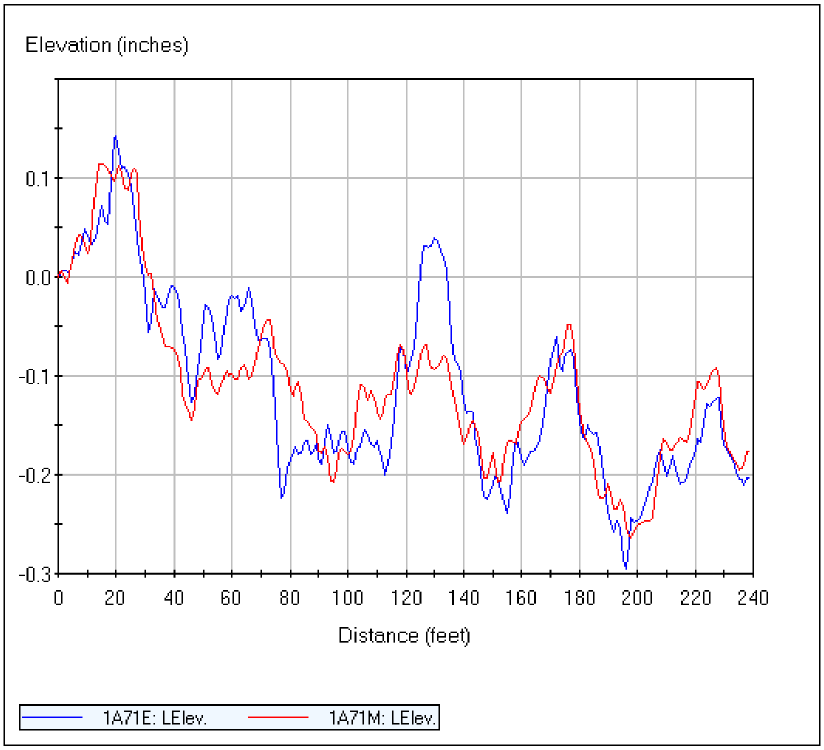


Figure B.38. Level A profile – Oct. 26, 2004 08:30

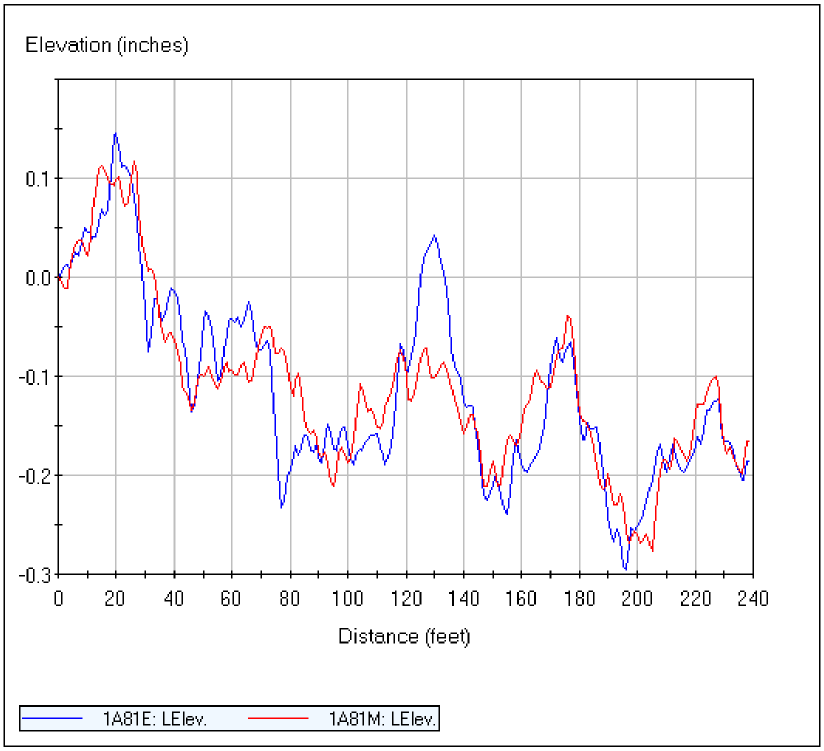


Figure B.39. Level A profile – Oct. 27, 2004 06:45

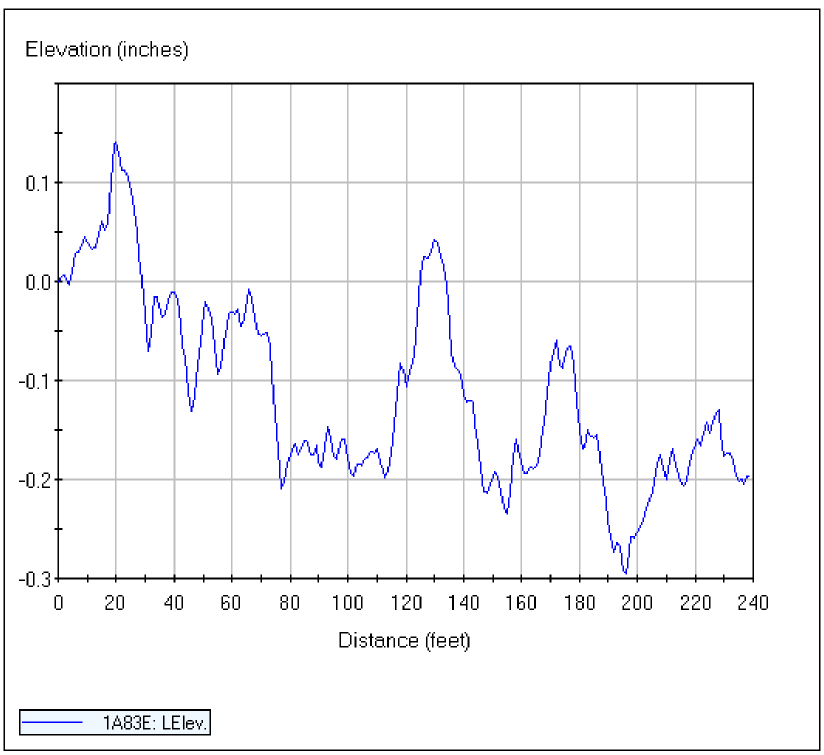


Figure B.40. Level A profile – edge only – Oct. 27, 2004 13:00

Table B.3. Level B profile summary (1.5 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
1B143	10/23/2004 14:00	76.25	17.9	15.0	62.2	134.2	3.56
1B153	10/24/2004 15:00	101.25	15.8	17.8	71.1	115.6	3.73
1B163	10/25/2004 14:10	124.42	14.9	17.0	64.2	121.6	3.68
1B173	10/26/2004 14:00	148.25	12.1	9.6	64.2	128.6	3.61
1B183	10/27/2004 14:00	172.25	11.8	11.4	68.3	138.2	3.53

Table B.4. Level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
1B243	10/23/2004 14:00	76.25	17.9	15.0	94.2	151.1	3.41
1B253	10/24/2004 15:00	101.25	15.8	17.8	96.9	166.4	3.28
1B263	10/25/2004 14:10	124.42	14.9	17.0	88.2	143	3.48
1B273	10/26/2004 14:00	148.25	12.1	9.6	83.8	142.8	3.49
1B283	10/27/2004 14:00	172.25	11.8	11.4	84.1	136.3	3.54

Table B.5. Level B profile summary (3 ft. from longitudinal joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
1B343A	10/23/2004 14:00	76.25	17.9	15.0	109.5	157.3	3.36
1B353A	10/24/2004 15:00	101.25	15.8	17.8	121	177.3	3.2
1B363A	10/25/2004 14:10	124.42	14.9	17.0	117.3	180.3	3.17
1B373A	10/26/2004 14:00	148.25	12.1	9.6	122.1	167.7	3.27
1B383A	10/27/2004 14:00	172.25	11.8	11.4	120.8	170.8	3.25

Table B.6. Level B profile summary (1 ft. from longitudinal joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
1B343B	10/23/2004 14:00	76.25	17.9	15.0	87.8	113.5	3.75
1B353B	10/24/2004 15:00	101.25	15.8	17.8	89.2	127.9	3.62
1B363B	10/25/2004 14:10	124.42	14.9	17.0	89.8	123	3.66
1B373B	10/26/2004 14:00	148.25	12.1	9.6	96.7	135.3	3.55
1B383B	10/27/2004 14:00	172.25	11.8	11.4	91.3	125.4	3.64

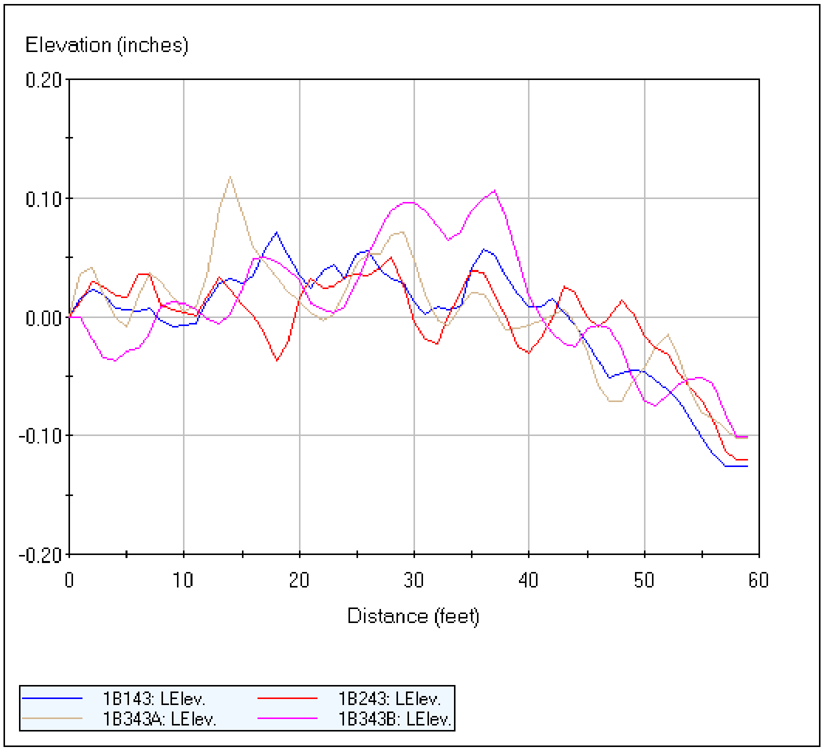


Figure B.41. Level B profile – Oct. 23, 2004 14:00

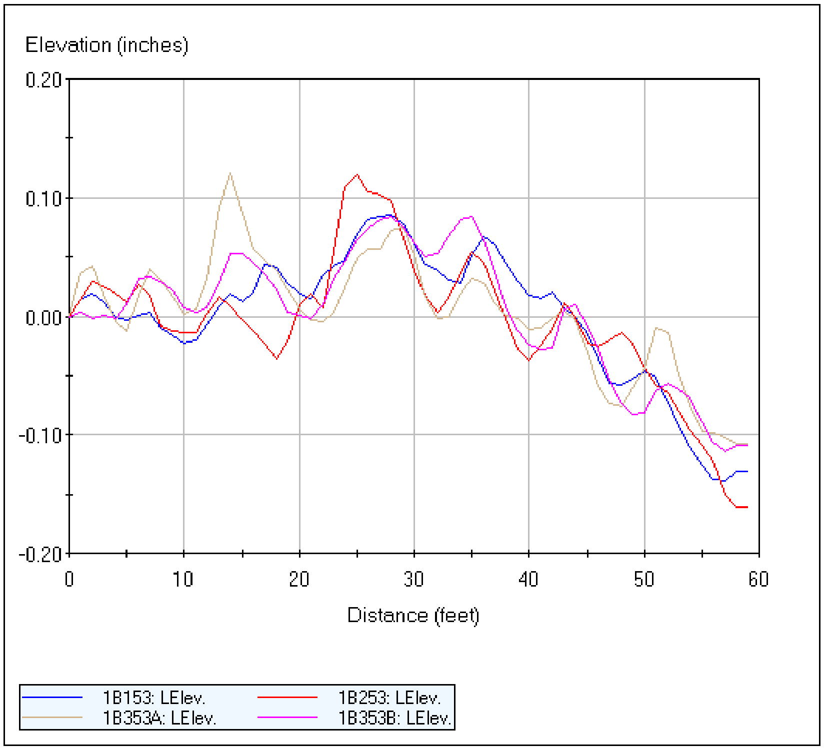


Figure B.42. Level B profile – Oct. 24, 2004 15:00

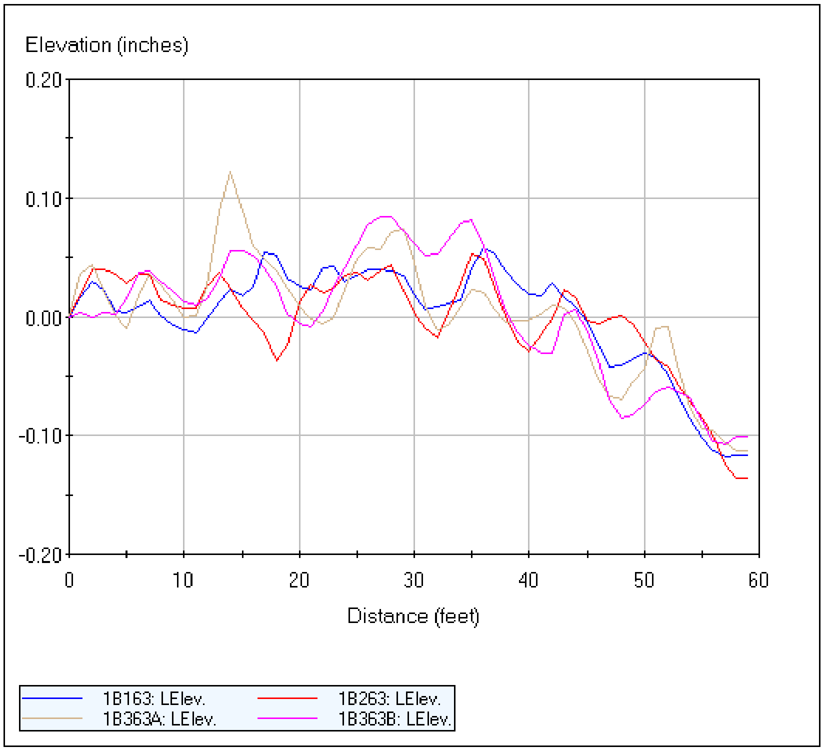


Figure B.43. Level B profile – Oct. 25, 2004 14:10

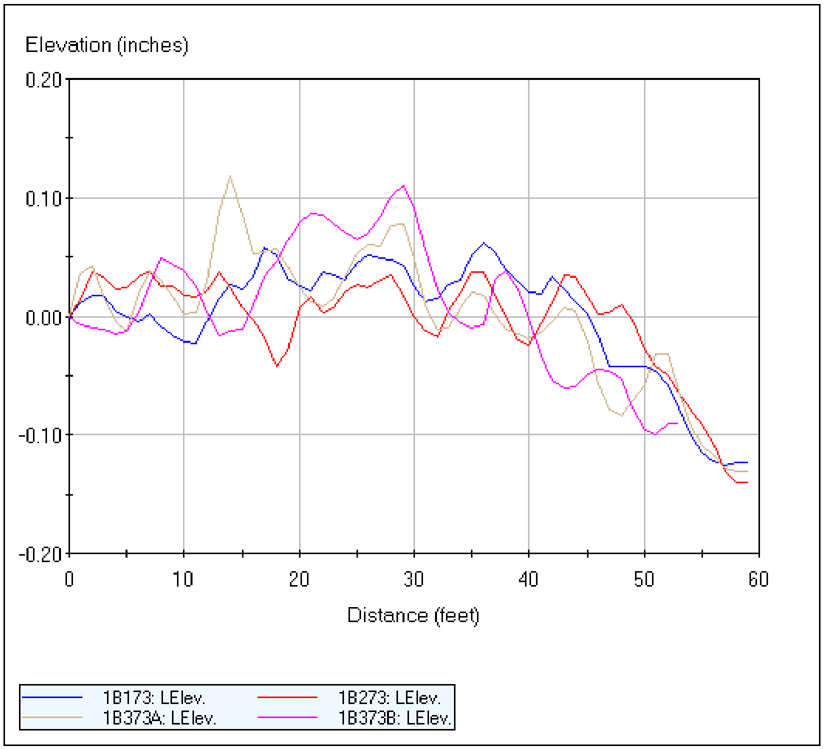


Figure B.44. Level B profile – Oct. 26, 2004 14:00

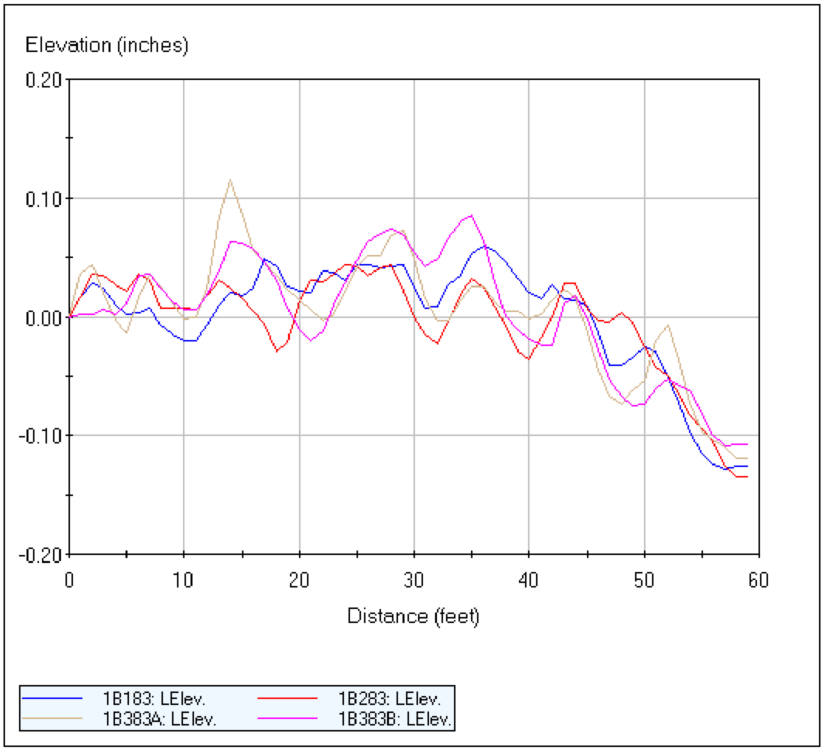


Figure B.45. Level B profile – Oct. 27, 2004 14:00

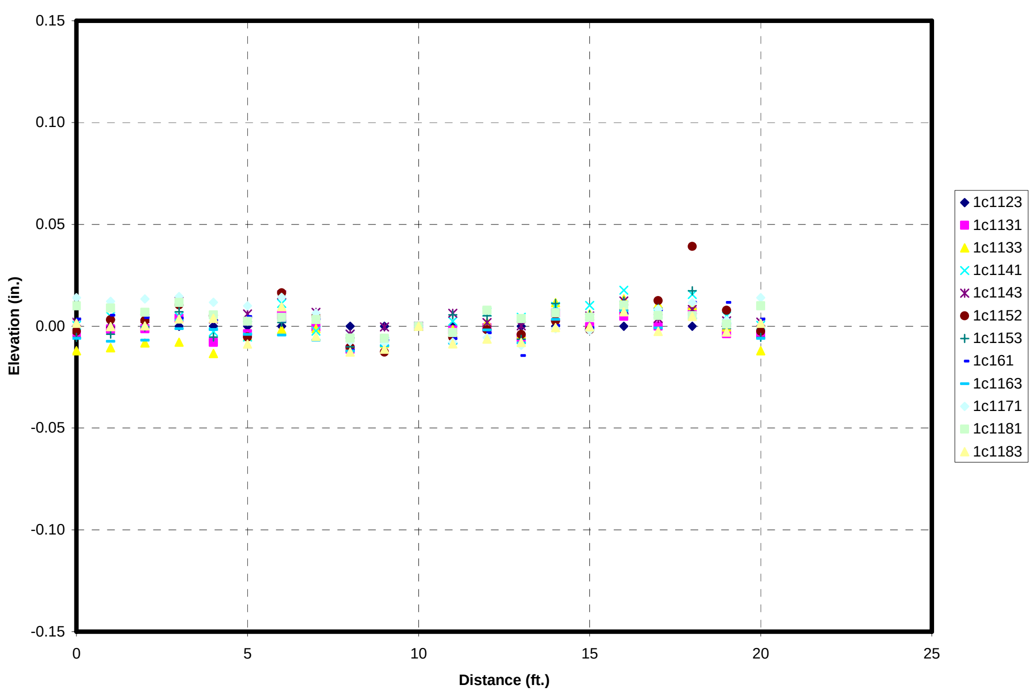


Figure B.46. Level C profiles path 1 – slab 8

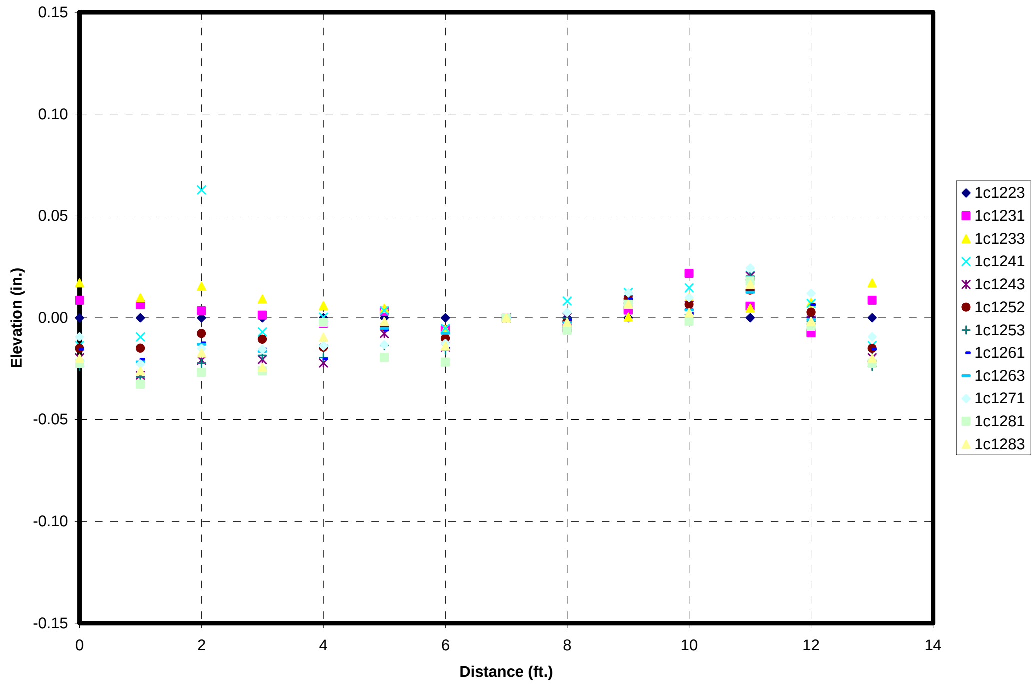


Figure B.47. Level C profiles path 2 – slab 8

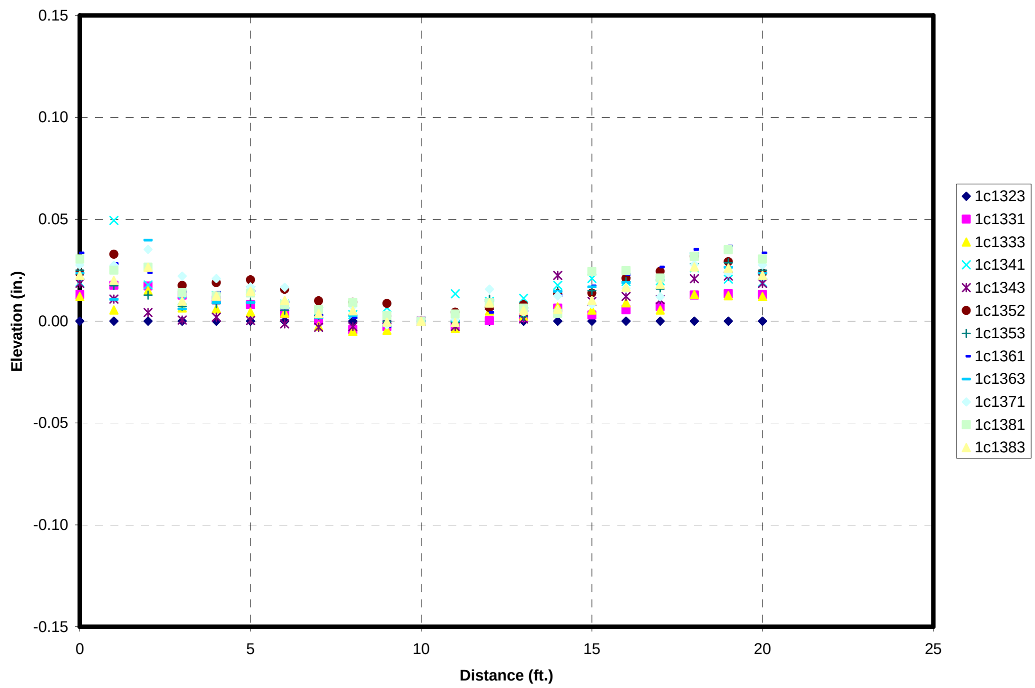


Figure B.48. Level C profiles path 3 – Slab 8

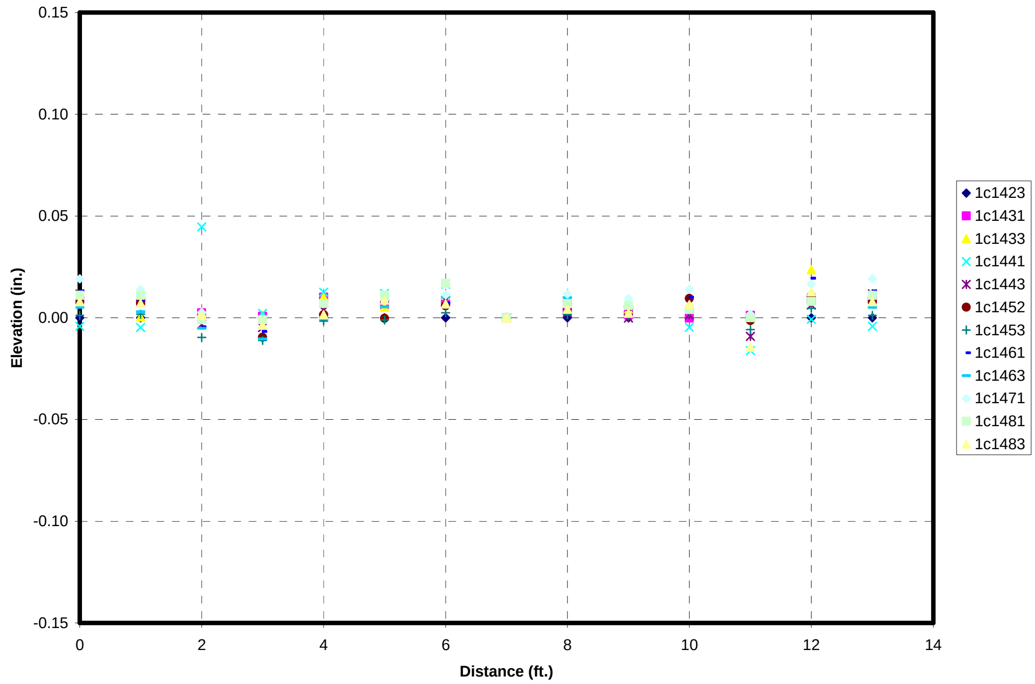


Figure B.49. Level C profiles path 4 – slab 8

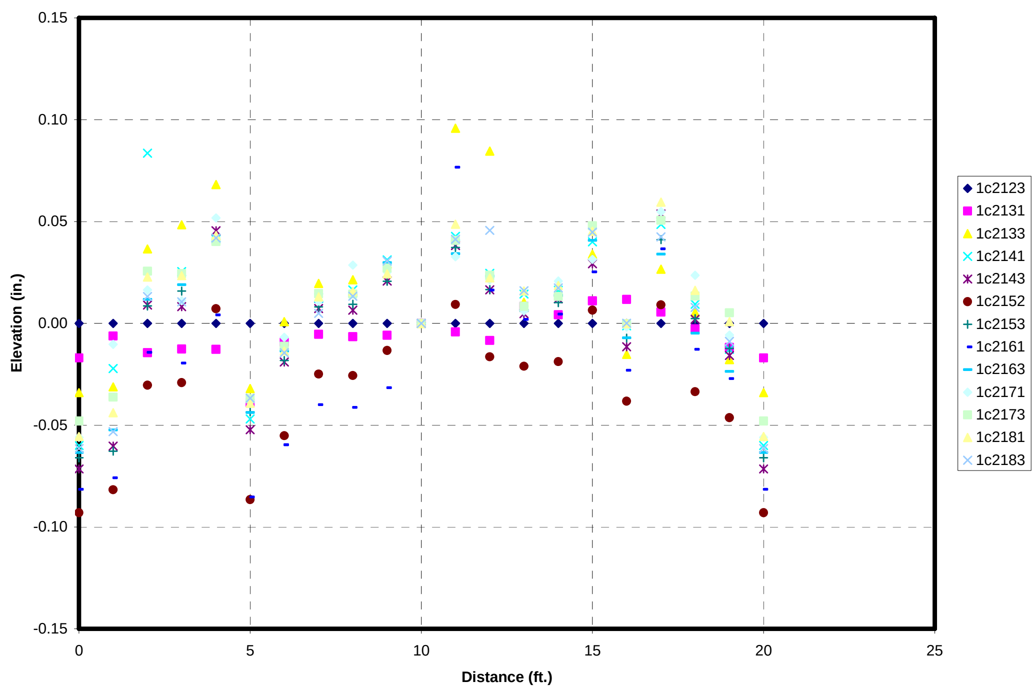


Figure B.50. Level C profiles path 1 – slab 9

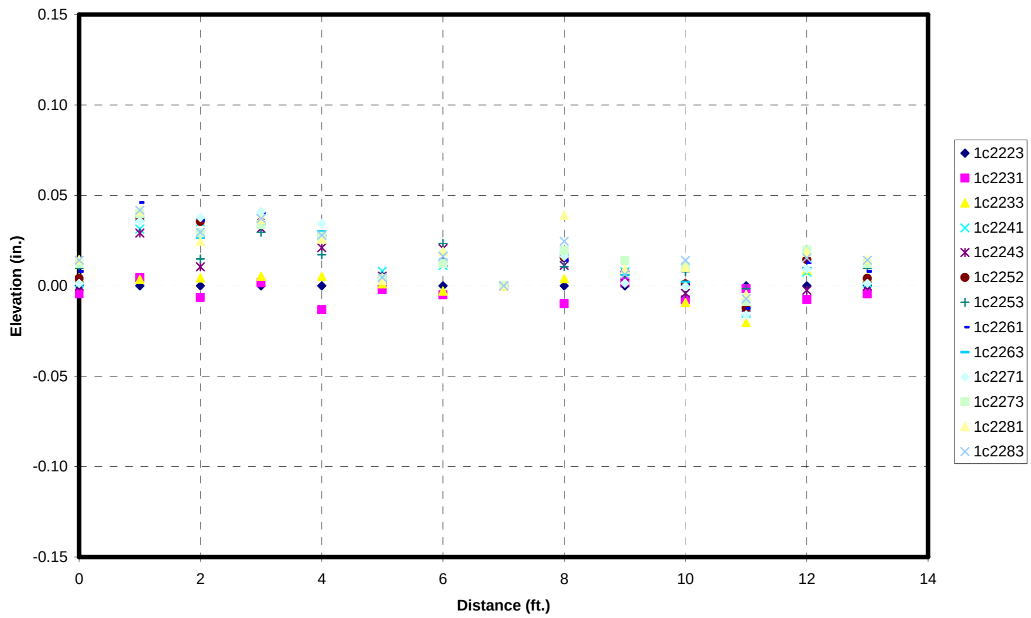


Figure B.51. Level C profiles path 2 – slab 9

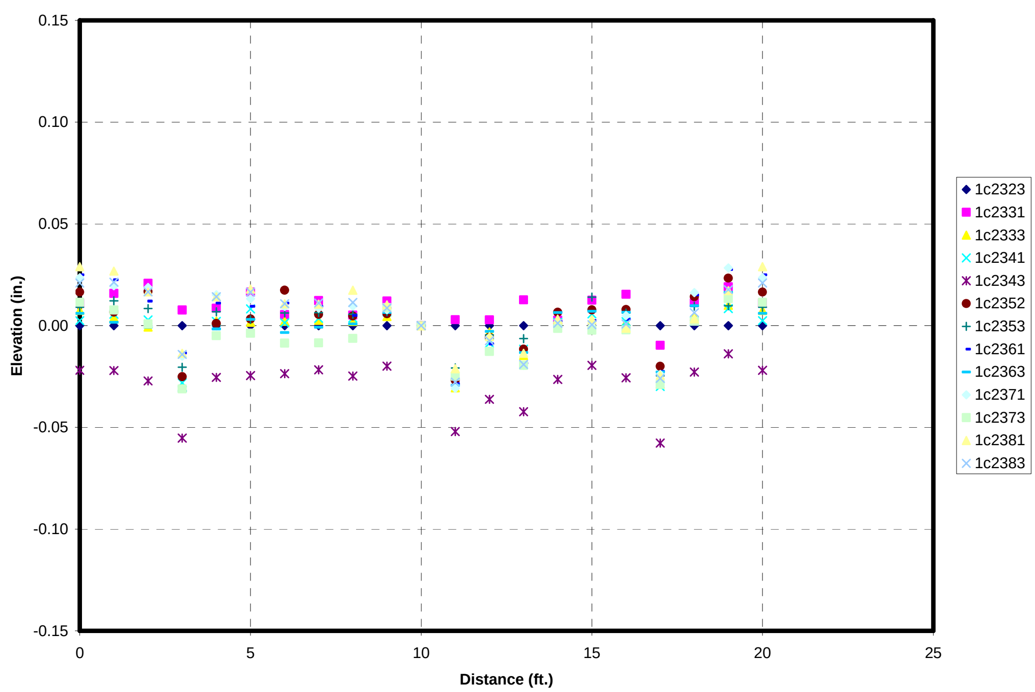


Figure B.52. Level C profiles path 3 – slab 9

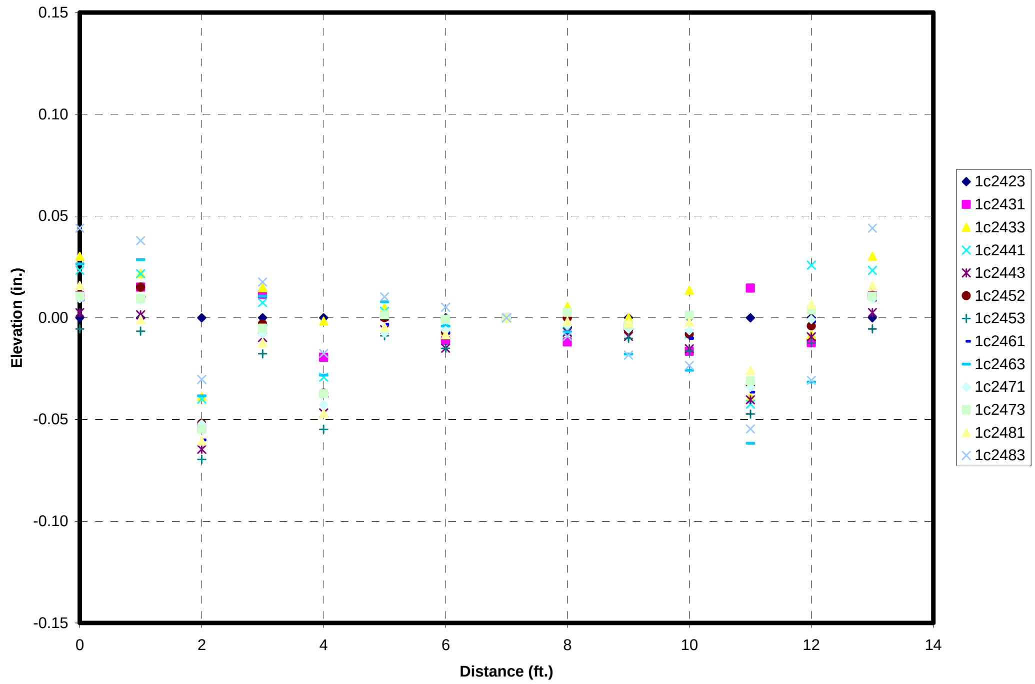


Figure B.53. Level C profiles path 4 – slab 9

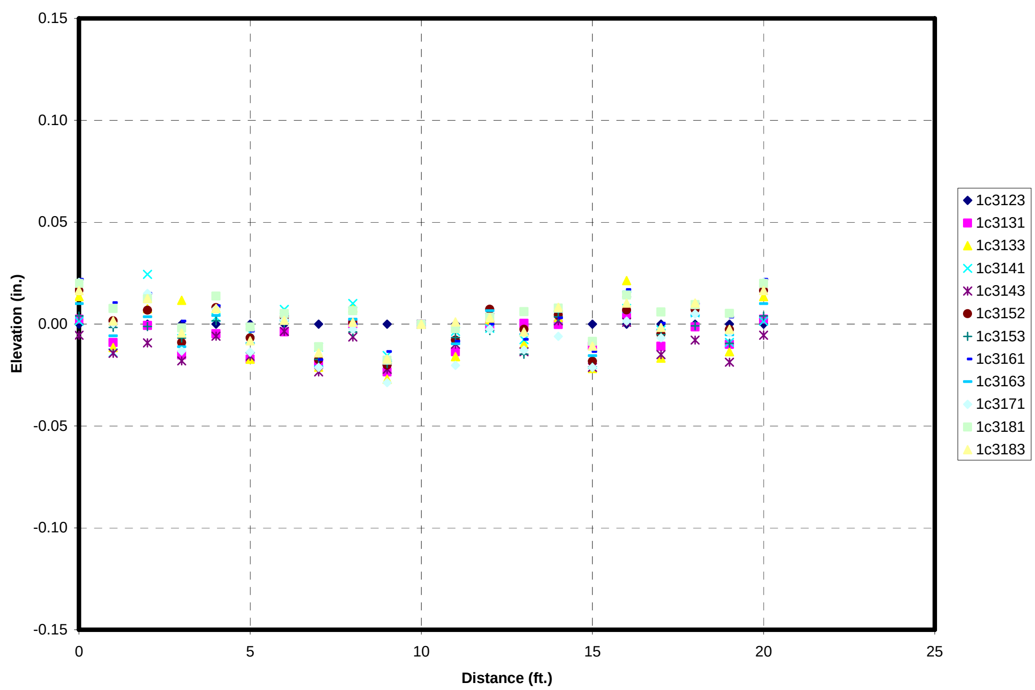


Figure B.54. Level C profiles path 1 – slab 10

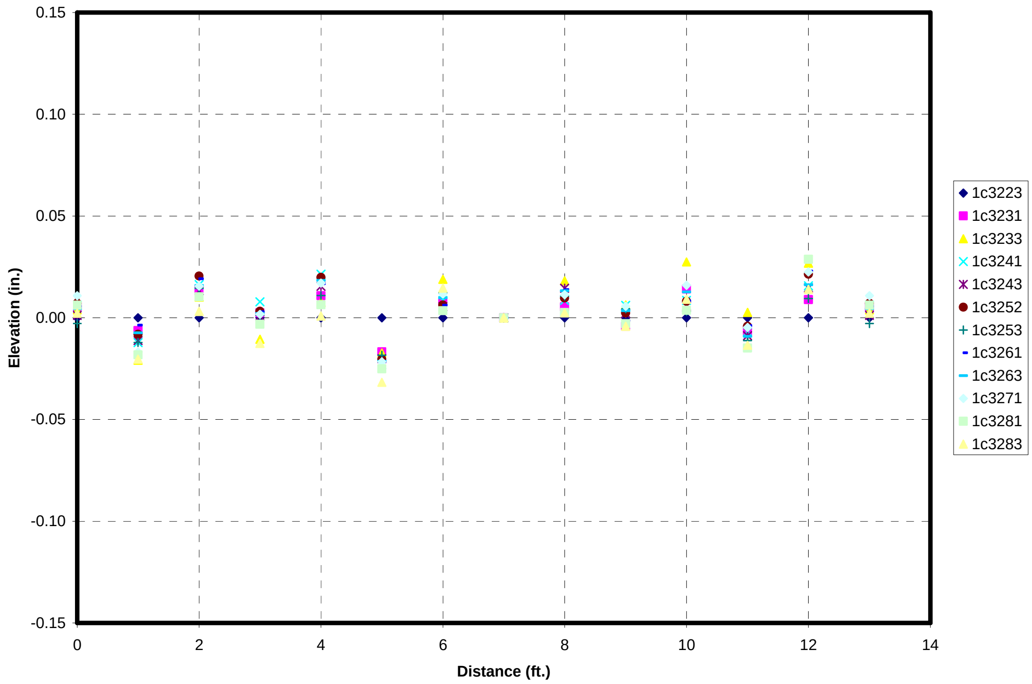


Figure B.55. Level C profiles path 2 – slab 10

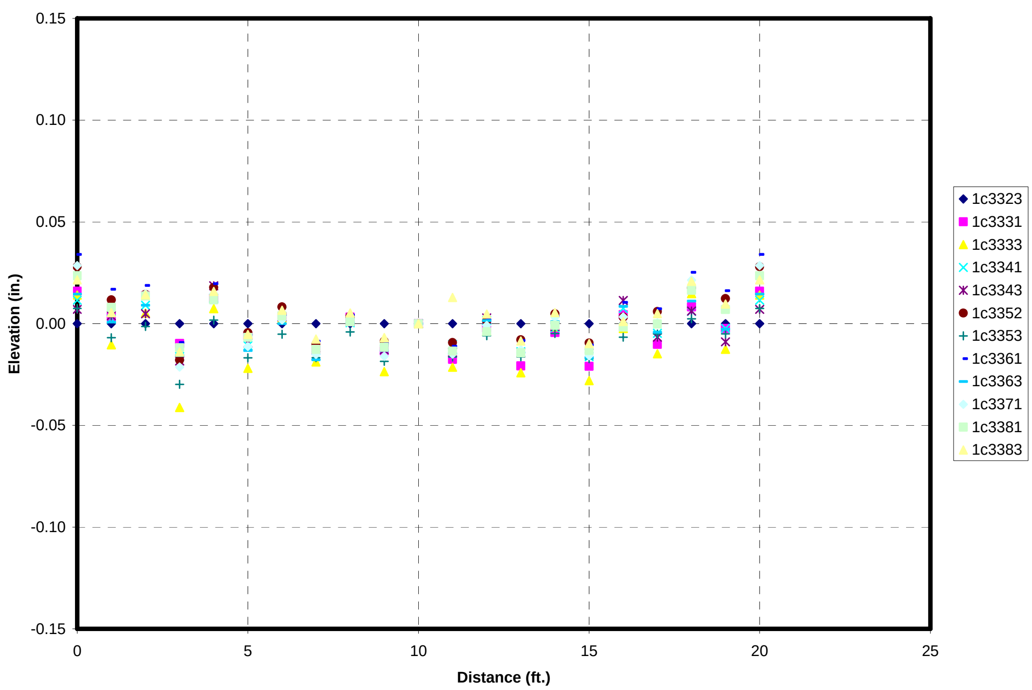


Figure B.56. Level C profiles path 3 – slab 10

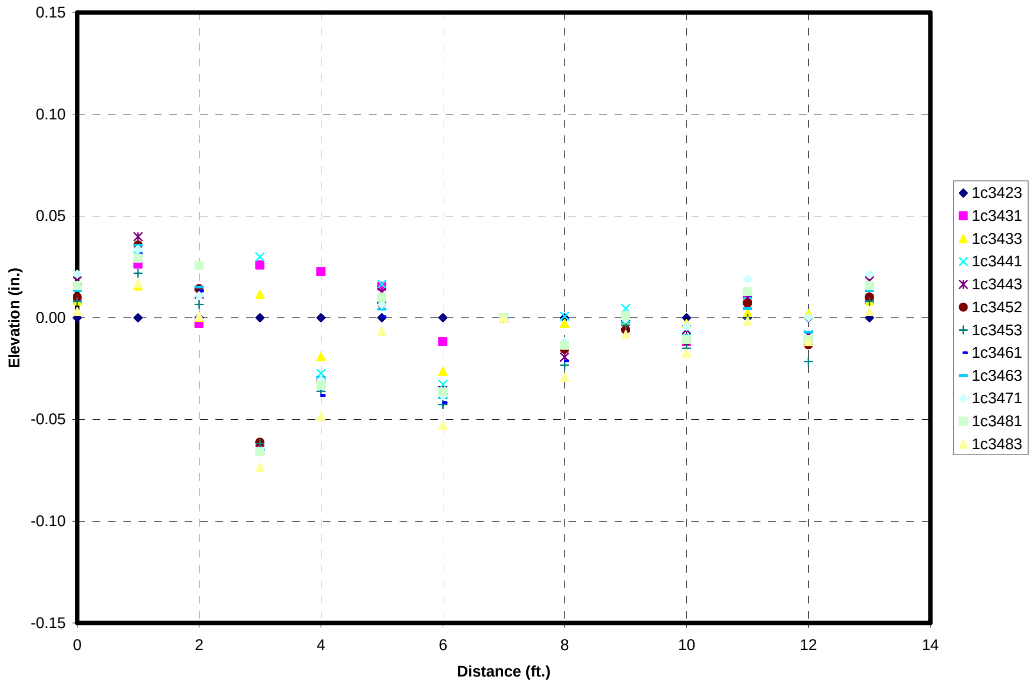


Figure B.57. Level C profiles path 4 – slab 10

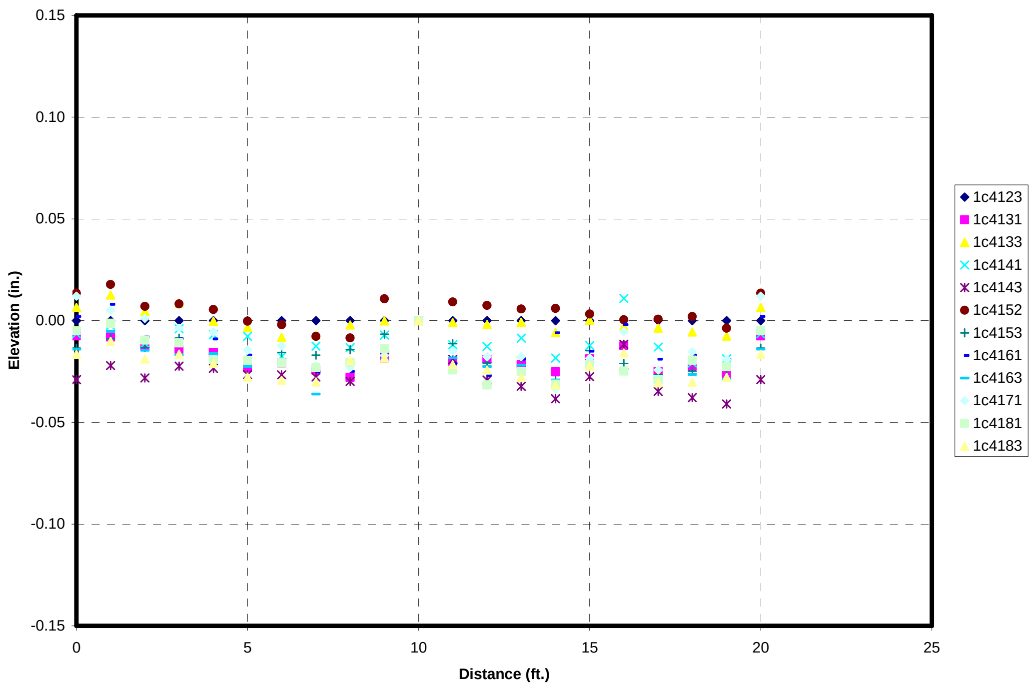


Figure B.58. Level C profiles path 1 – slab 11

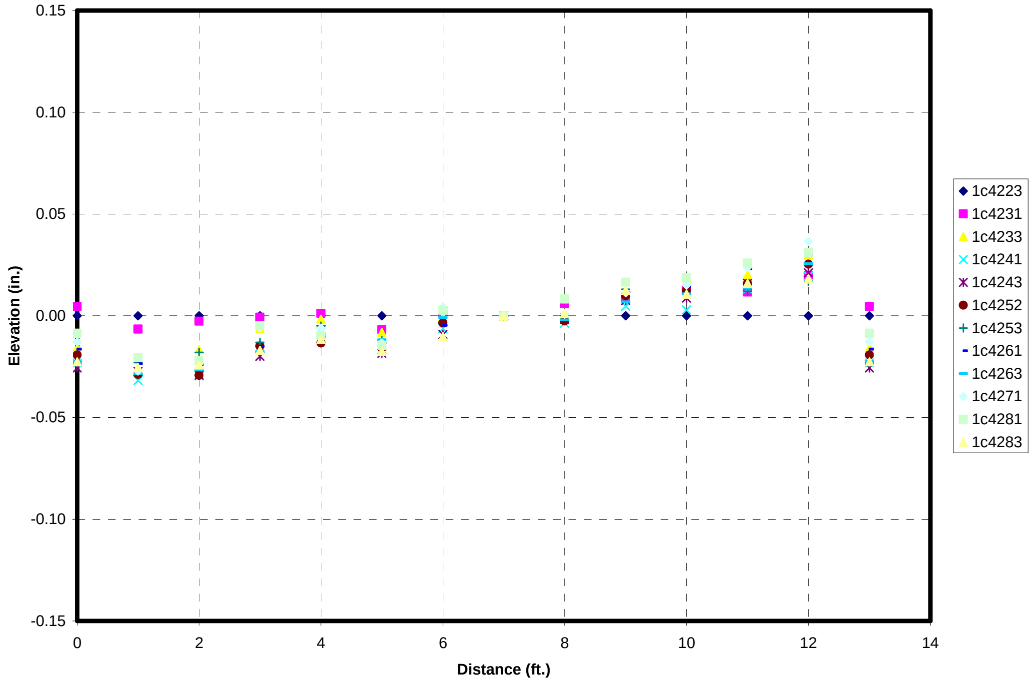


Figure B.59. Level C profiles path 2 – slab 11

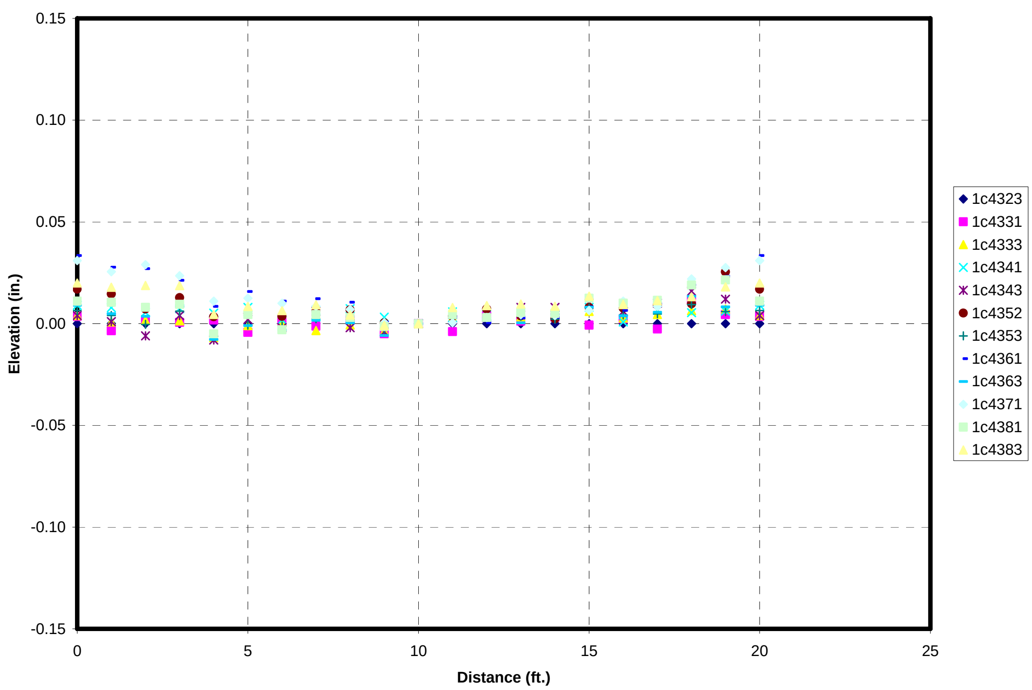


Figure B.60. Level C profiles path 3 – slab 11

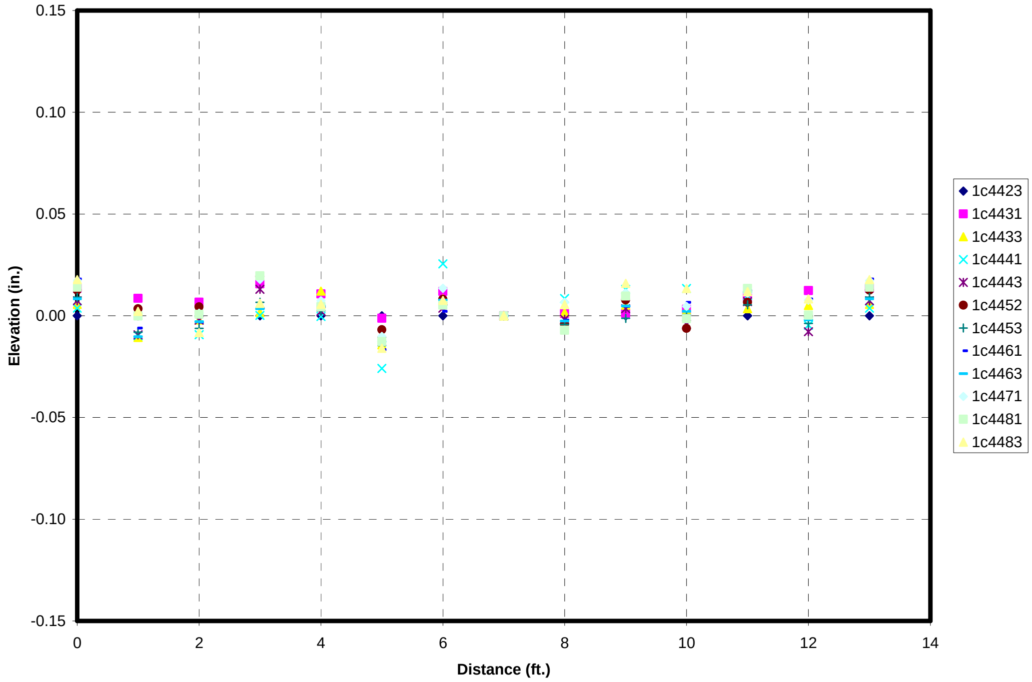


Figure B.61. Level C profiles path 4 – slab 11

APPENDIX C: PLATTEVILLE SITE AFTERNOON PAVING TEST SECTION

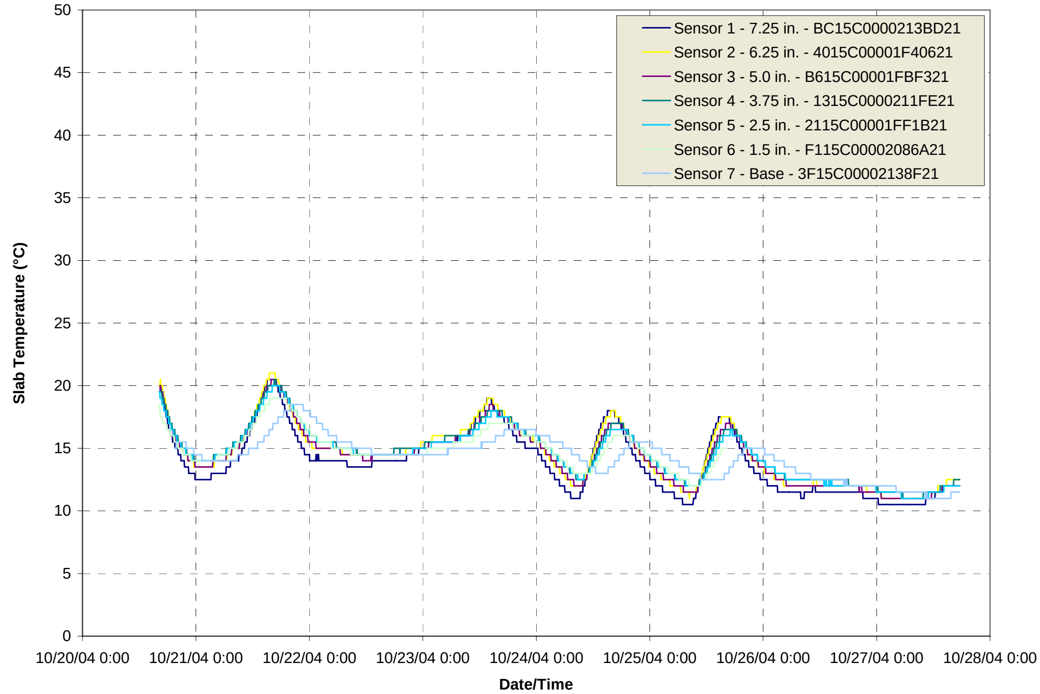


Figure C.1. Slab temperature data

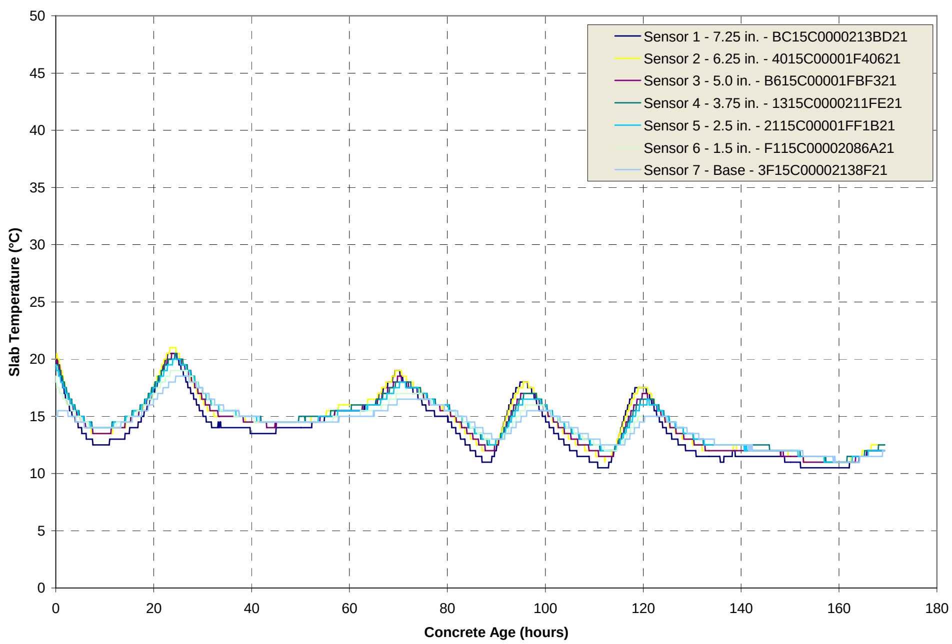


Figure C.2. Slab temperature data

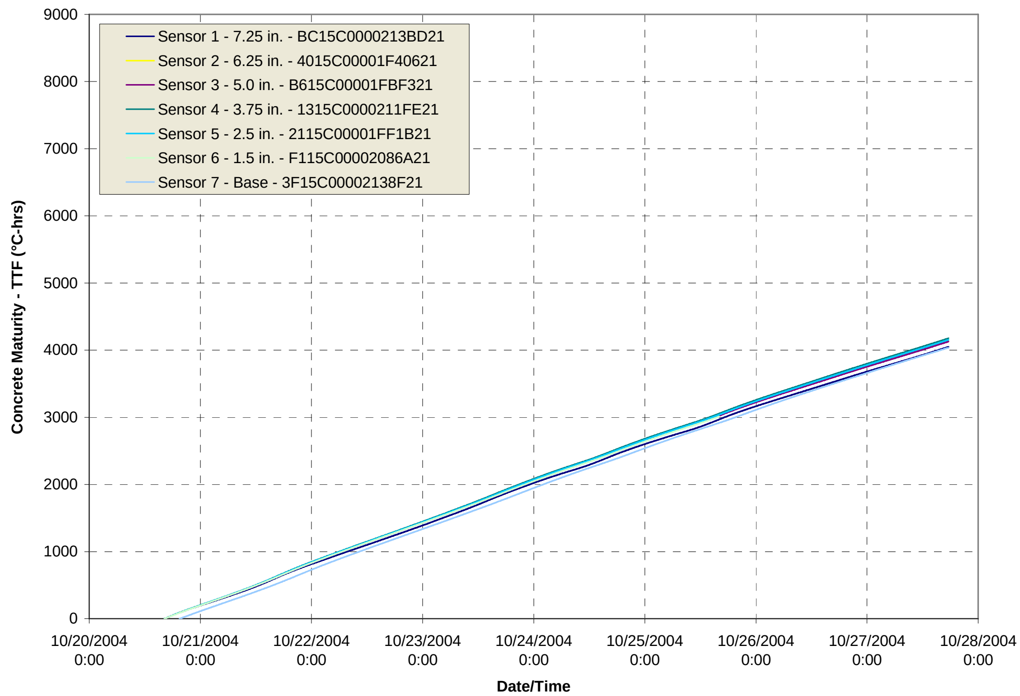


Figure C.3. Slab maturity data

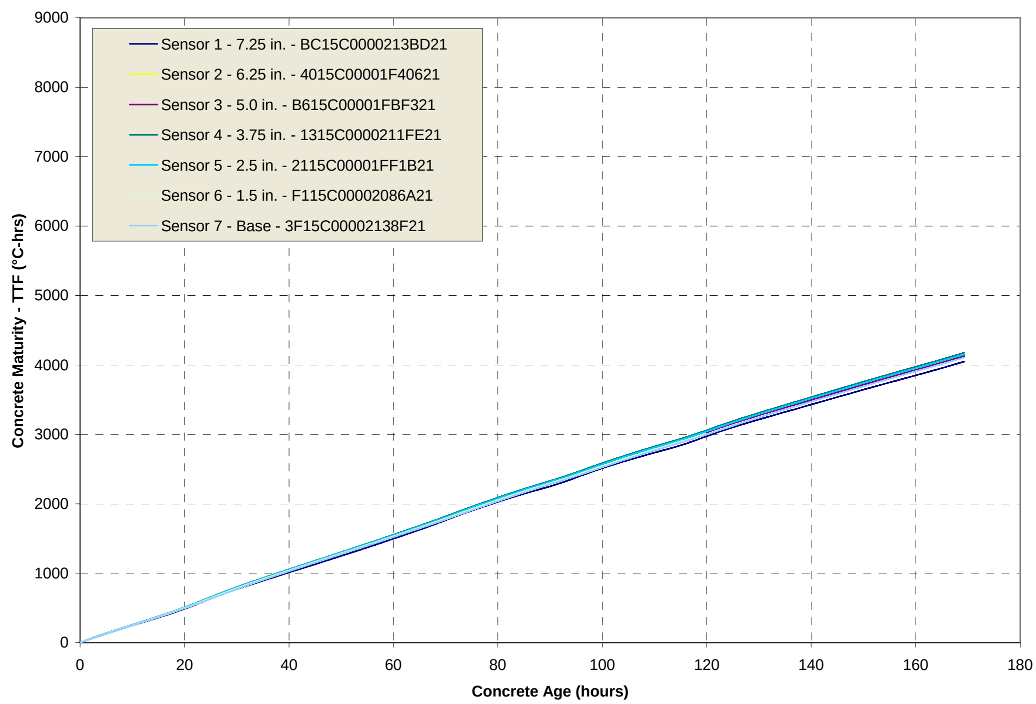


Figure C.4. Slab maturity data

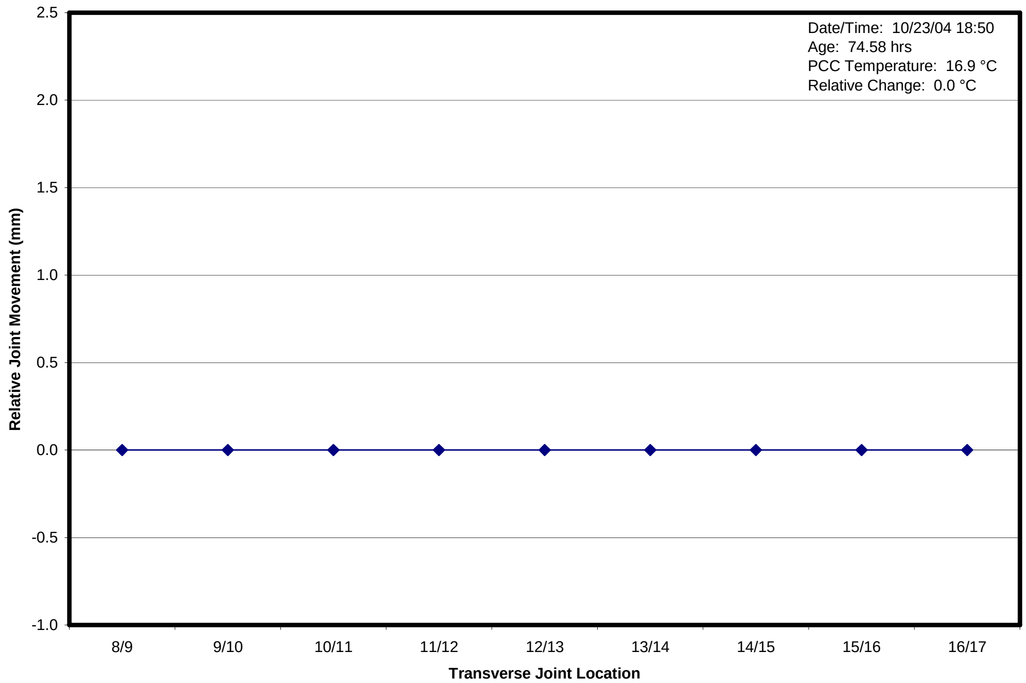


Figure C.5. Transverse joint relative opening

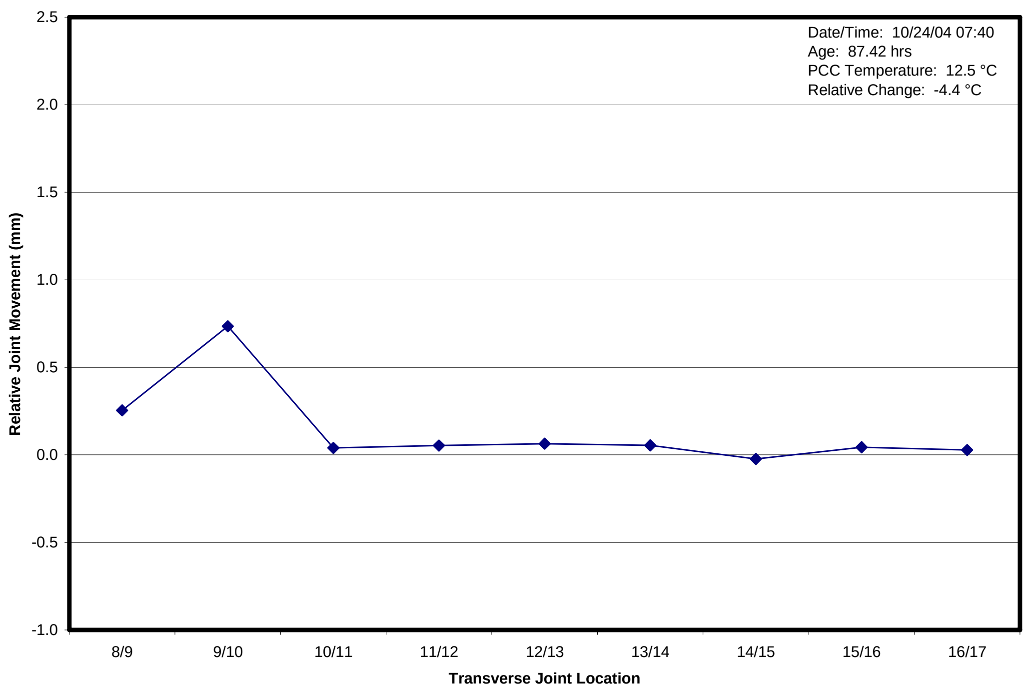


Figure C.6. Transverse joint relative opening

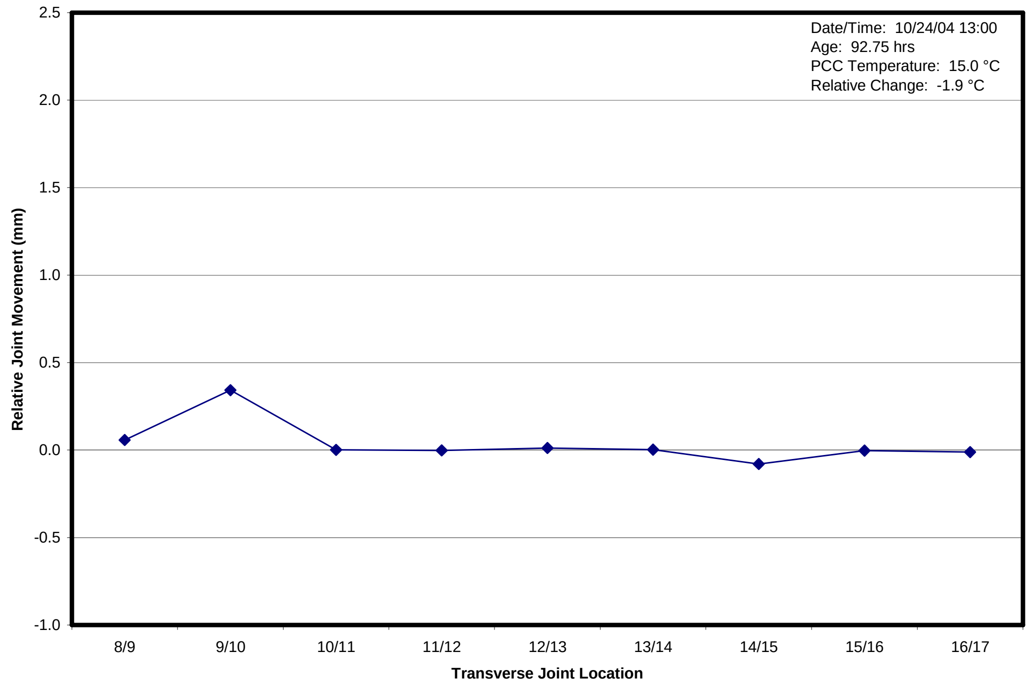


Figure C.7. Transverse joint relative opening

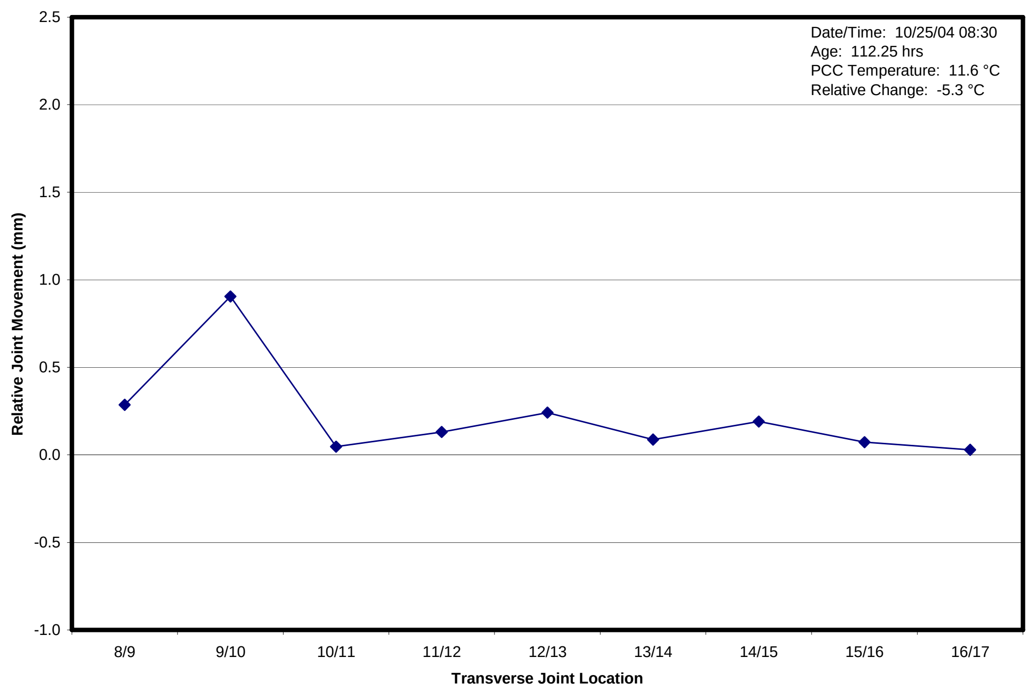


Figure C.8. Transverse joint relative opening

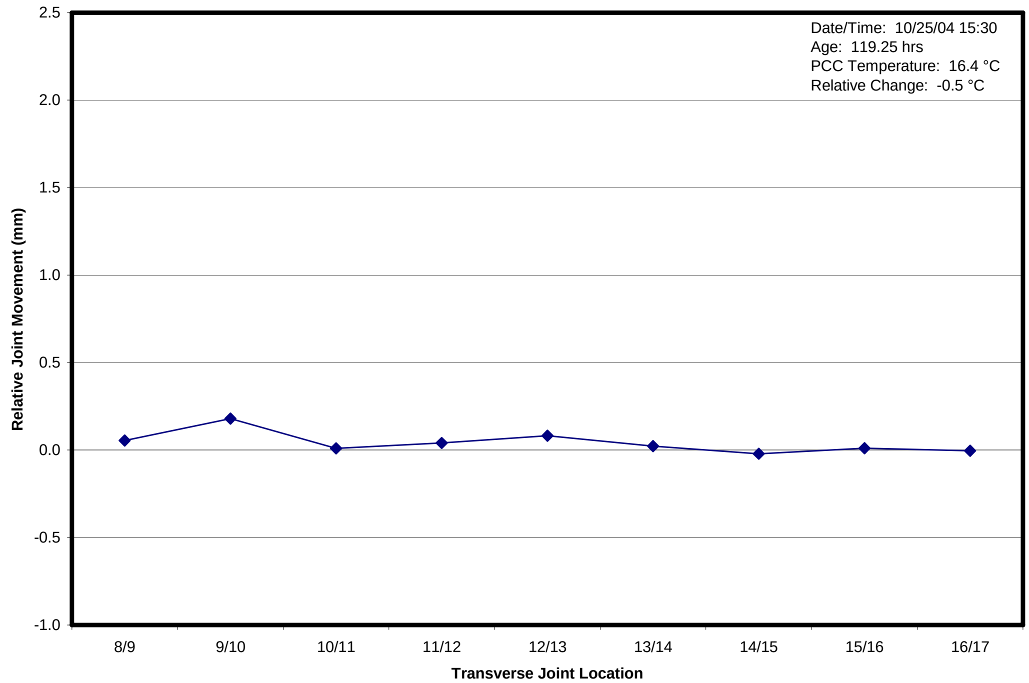


Figure C.9. Transverse joint relative opening

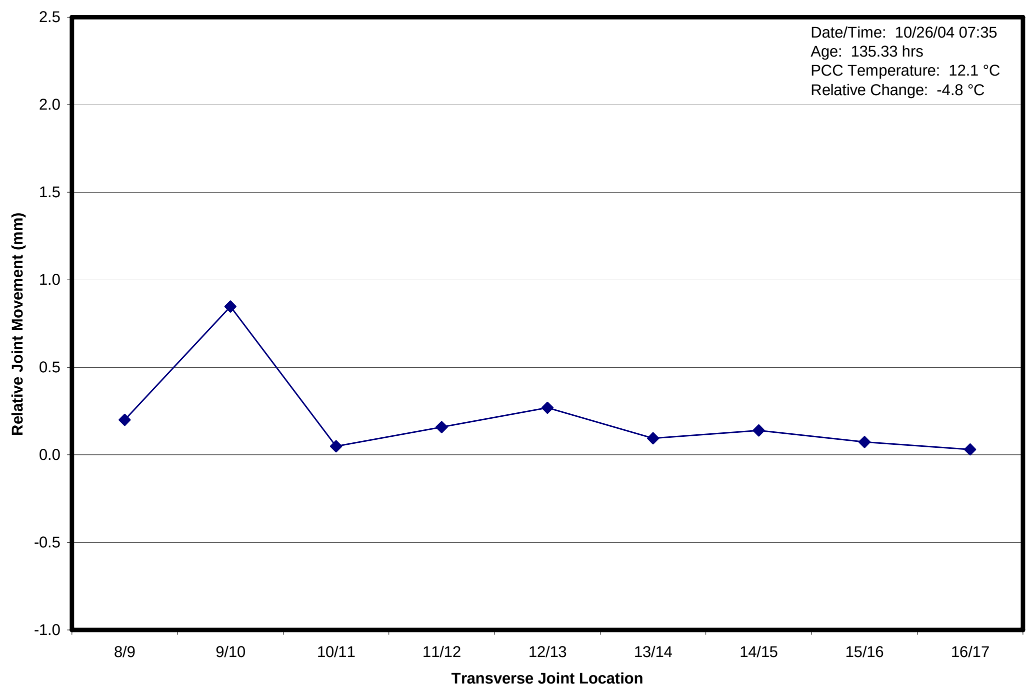


Figure C.10. Transverse joint relative opening

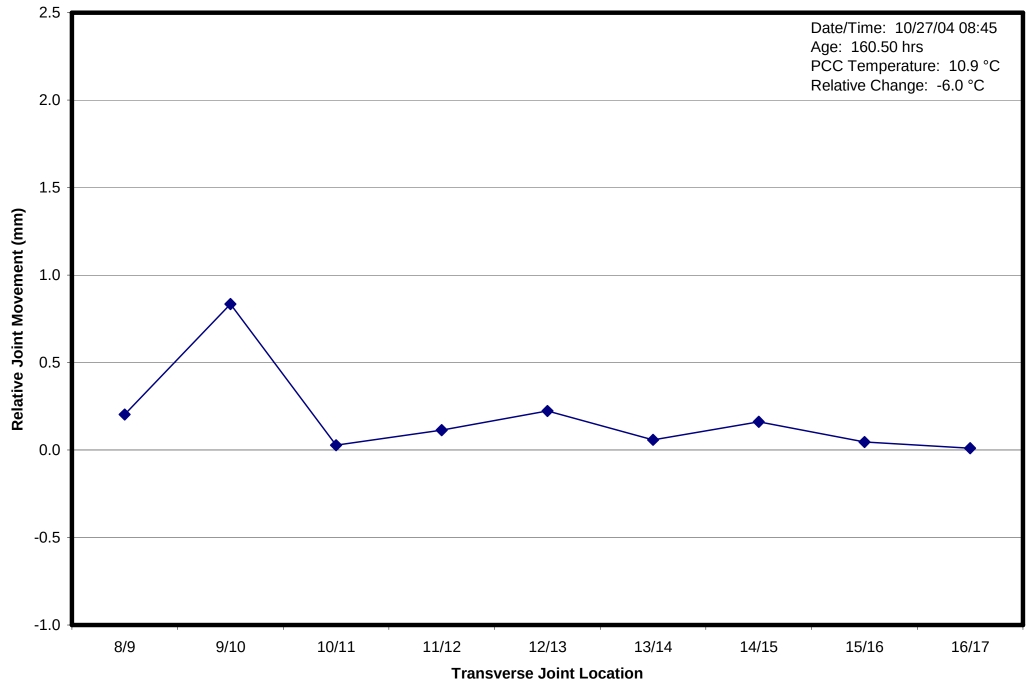


Figure C.11. Transverse joint relative opening

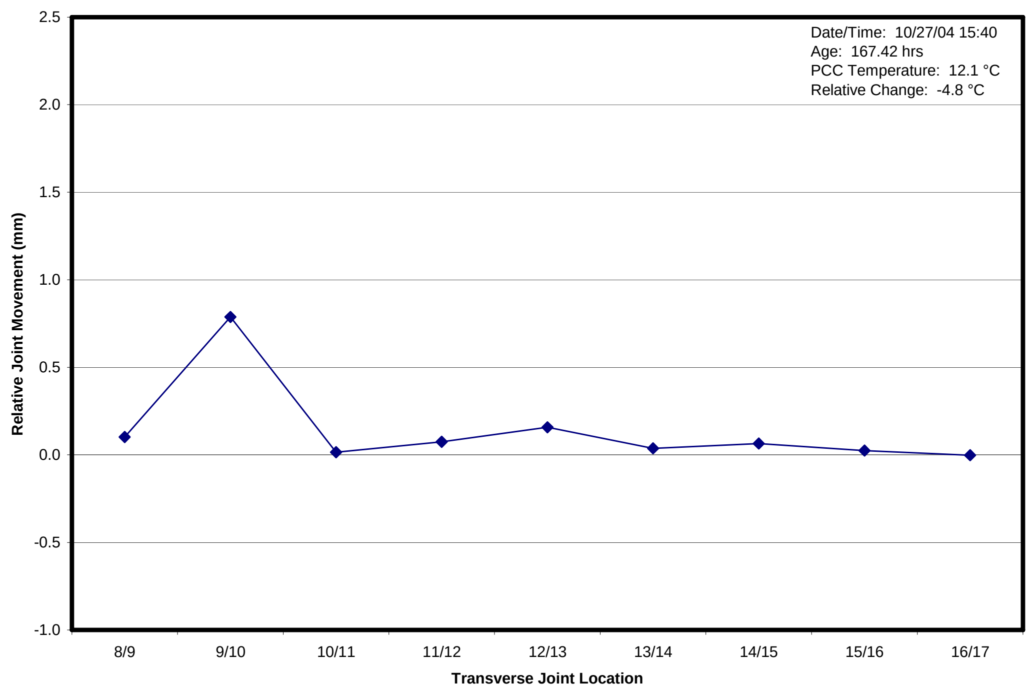


Figure C.12. Transverse joint relative opening

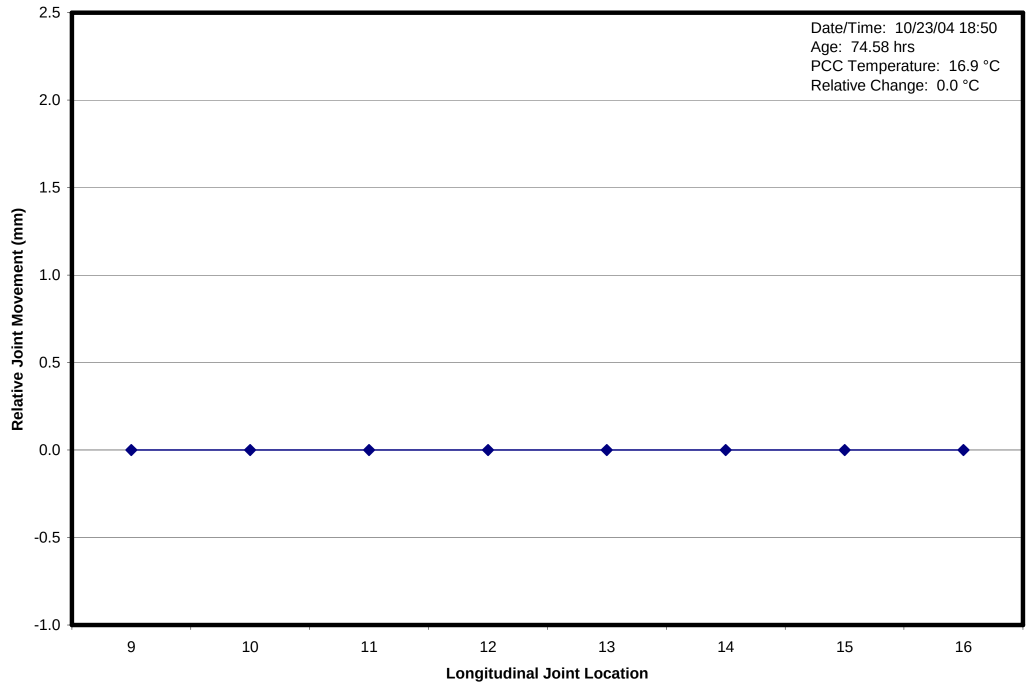


Figure C.13. Longitudinal joint relative opening

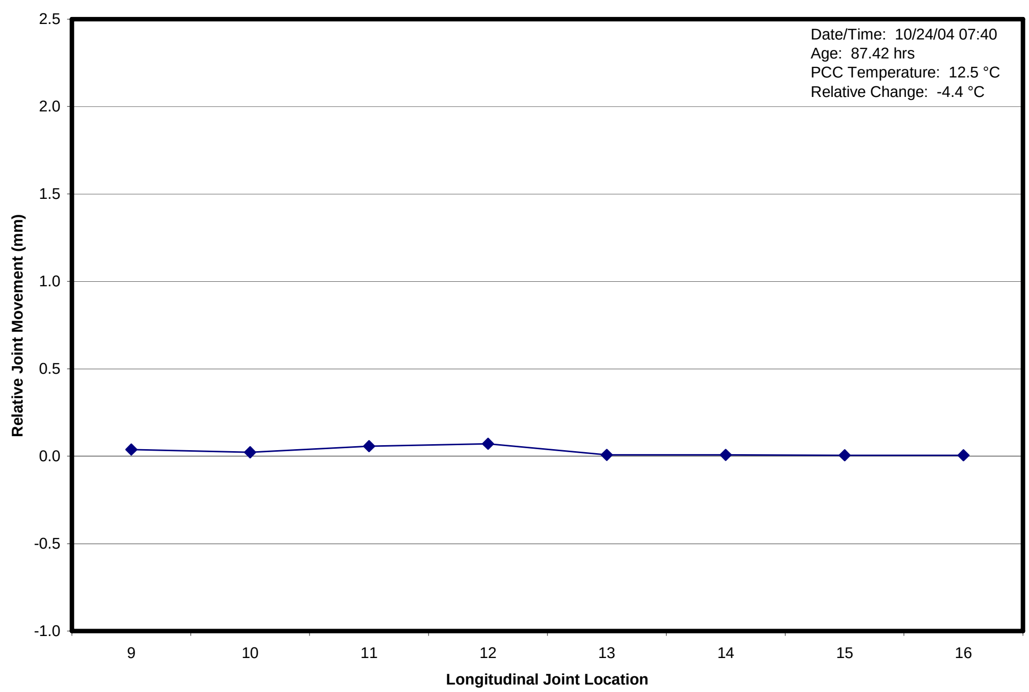


Figure C.14. Longitudinal joint relative opening

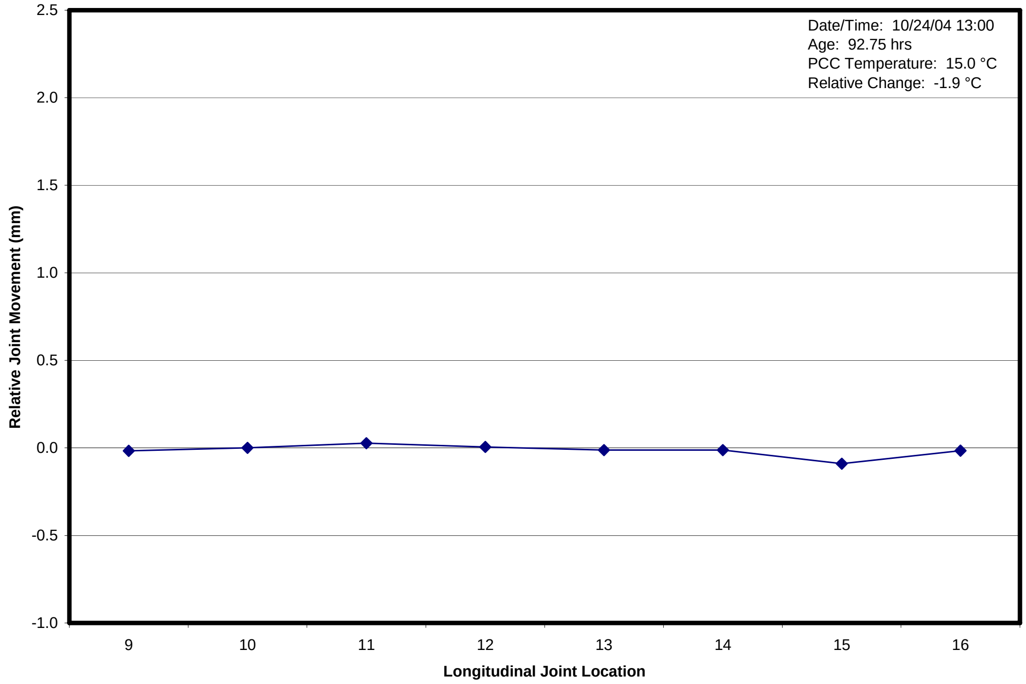


Figure C.15. Longitudinal joint relative opening

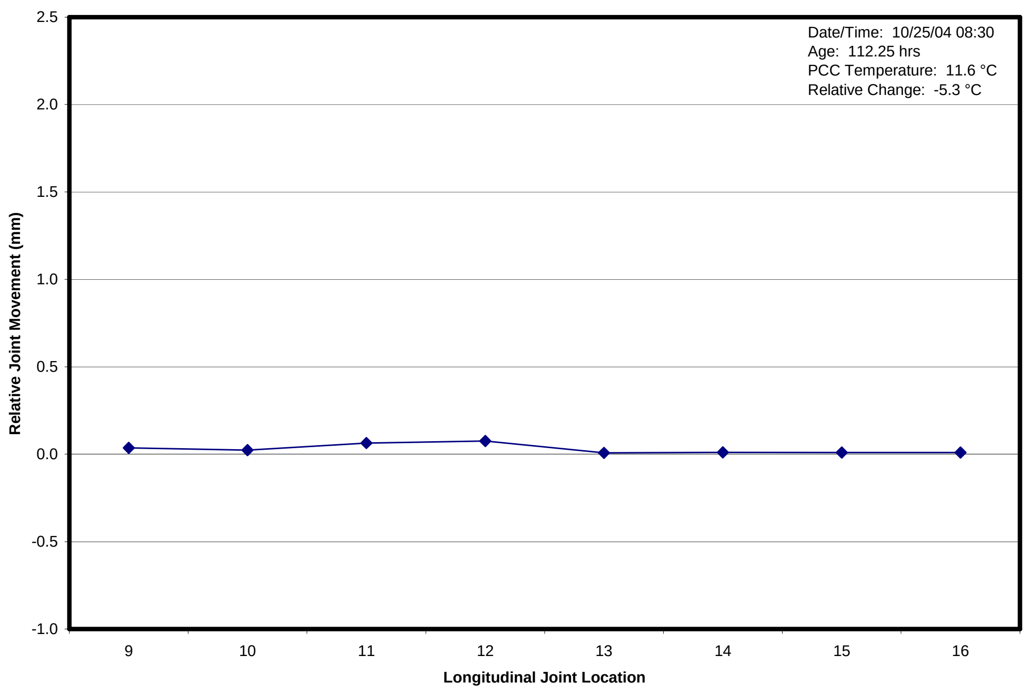


Figure C.16. Longitudinal joint relative opening

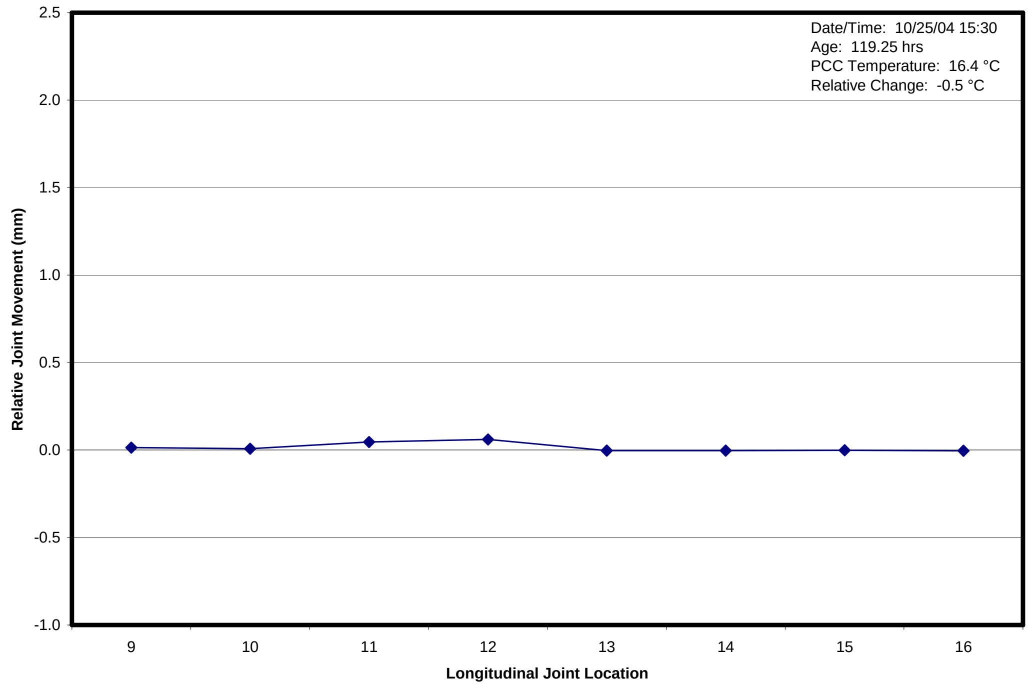


Figure C.17. Longitudinal joint relative opening

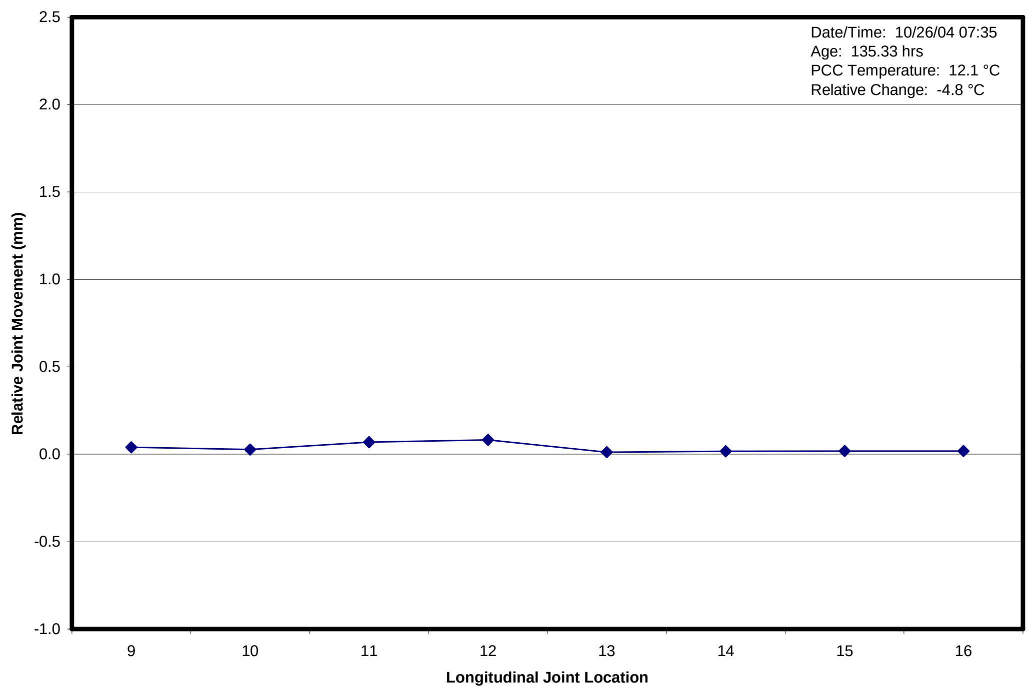


Figure C.18. Longitudinal joint relative opening

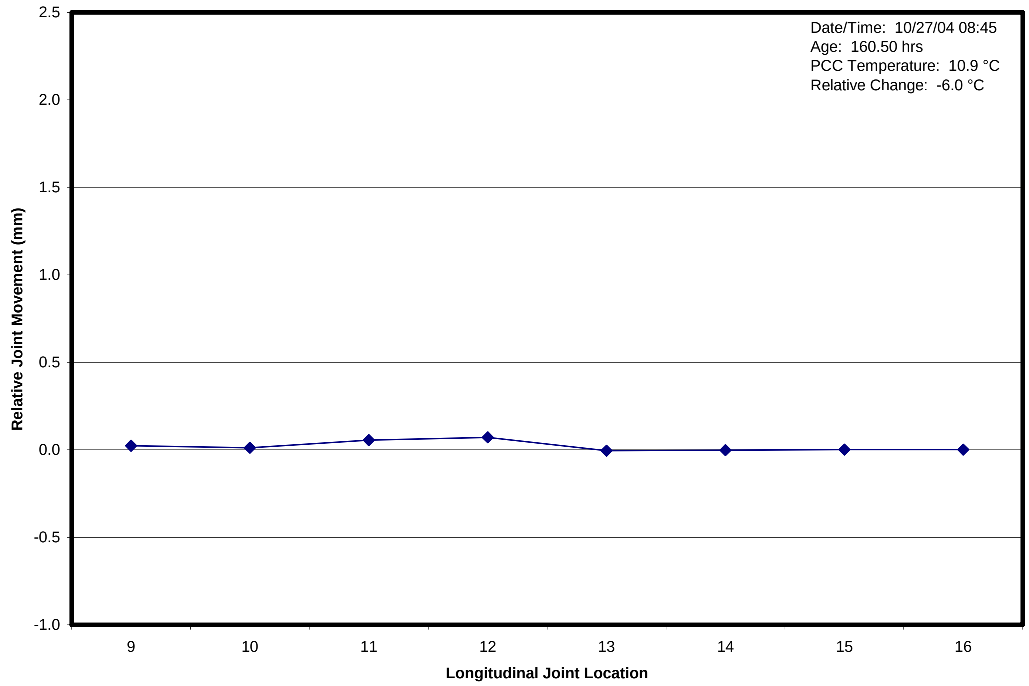


Figure C.19. Longitudinal joint relative opening

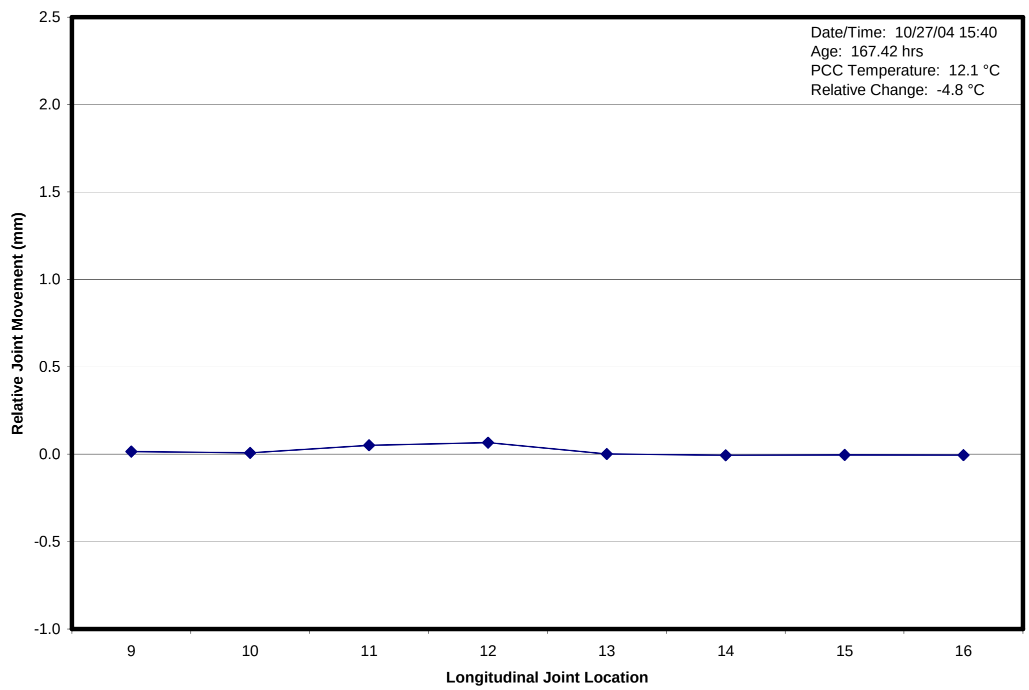


Figure C.20. Longitudinal joint relative opening

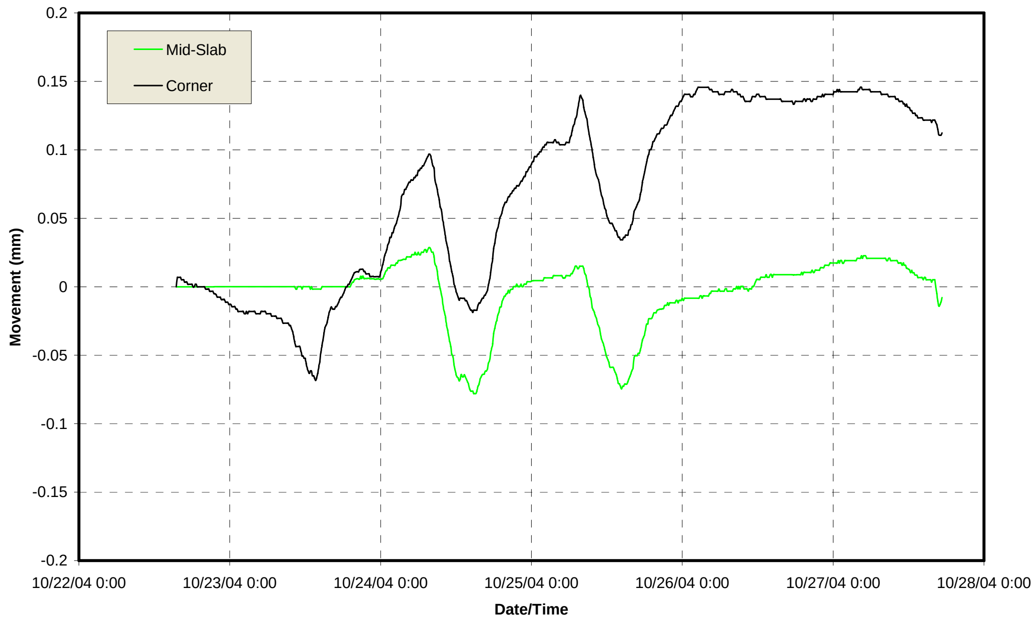


Figure C.21. LVDT Record

Table C.1. Level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
2A23E	10/21/2004 16:00	23.75	20.1	15.3	99.2	211.9	2.93
2A31E	10/22/2004 8:30	40.25	14.6	10.1	101.4	190.3	3.09
2A42E	10/23/2004 9:45	65.50	16.2	18.7	99.8	164.9	3.3
2A43E	10/23/2004 15:15	71.00	17.9	13.7	89.5	165.2	3.29
2A51E	10/24/2004 7:30	87.25	12.5	10.3	92.5	158.8	3.35
2A53E	10/24/2004 12:00	91.75	14.0	14.2	90.4	156.2	3.37
2A61E	10/25/2004 8:20	112.08	11.6	8.4	85.1	149.1	3.43
2A63E	10/25/2004 15:15	119.00	16.3	17.2	88.2	144.9	3.47
2A71E	10/26/2004 6:30	134.25	12.1	9.6	88.1	162.8	3.31
2A81E	10/27/2004 8:30	160.25	10.9	9.6	88.5	145.8	3.46
2A83E	10/27/2004 15:00	166.75	12.1	11.8	91.3	148.3	3.44

Table C.2. Level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
2A31M	10/22/2004 8:30	40.25	14.6	10.1	73.4	122.1	3.67
2A42M	10/23/2004 9:45	65.50	16.2	18.7	84.1	269.4	2.53
2A43M	10/23/2004 15:15	71.00	17.9	13.7	71.9	112.6	3.76
2A51M	10/24/2004 7:30	87.25	12.5	4.8	67.4	114.8	3.74
2A53M	10/24/2004 12:00	91.75	14.0	14.2	71.7	121.4	3.68
2A61M	10/25/2004 8:20	112.08	11.6	8.4	69.9	117.6	3.72
2A63M	10/25/2004 15:15	119.00	16.3	17.2	74.7	119.7	3.7
2A71M	10/26/2004 6:30	134.25	12.1	9.6	68.9	124.9	3.65
2A81M	10/27/2004 8:30	160.25	10.9	9.6	68.1	122.9	3.67
2A83M	10/27/2004 15:00	166.75	12.1	11.8	72.6	118.6	3.71

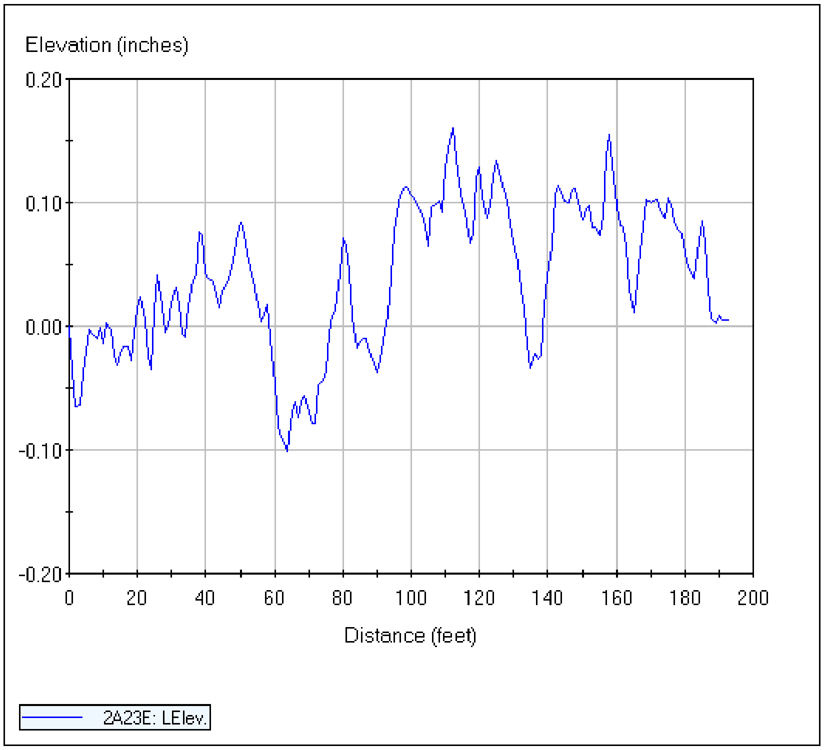


Figure C.22. Level A profile – edge only – Oct. 21, 2004 16:00

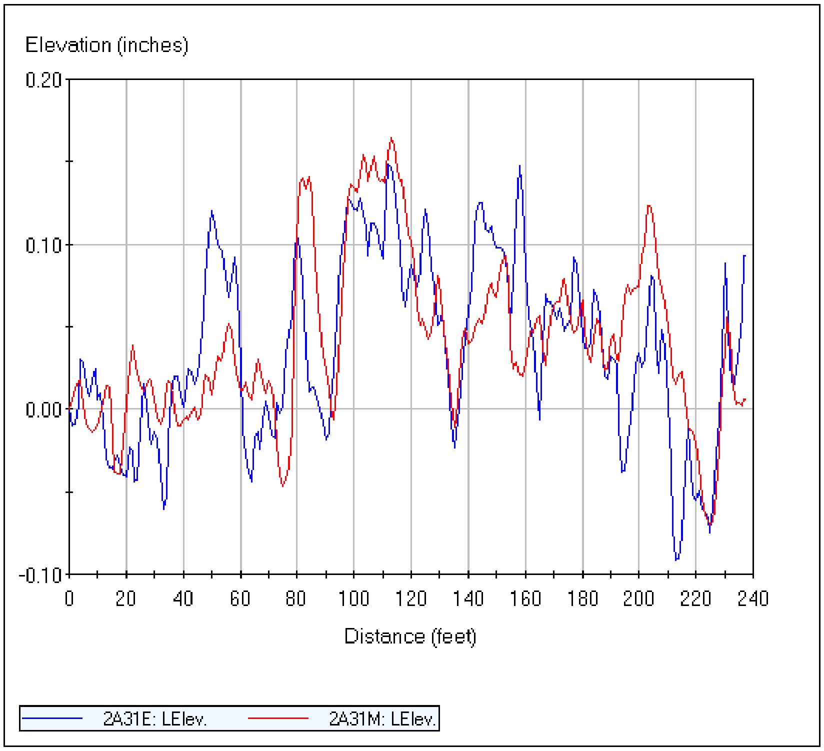


Figure C.23. Level A profile – Oct. 22, 2004 08:30

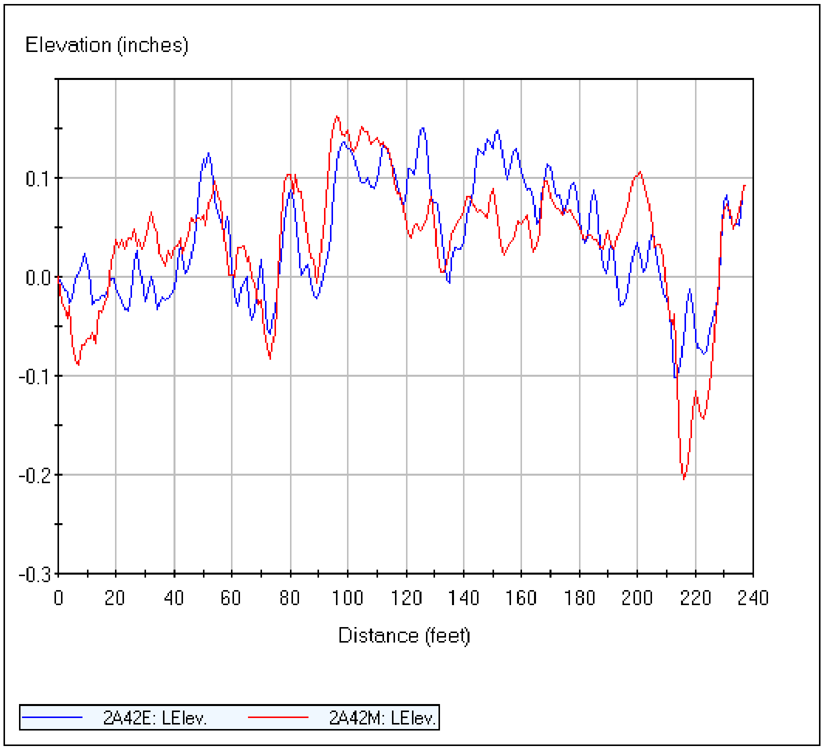


Figure C.24. Level A profile – Oct. 23, 2004 09:45

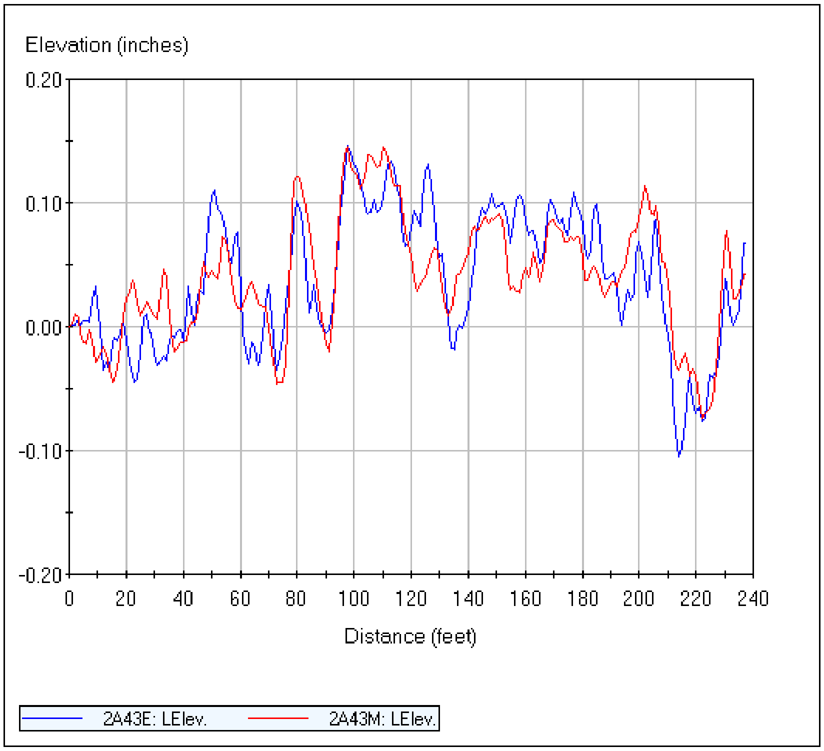


Figure C.25. Level A profile – Oct. 23, 2004 15:15

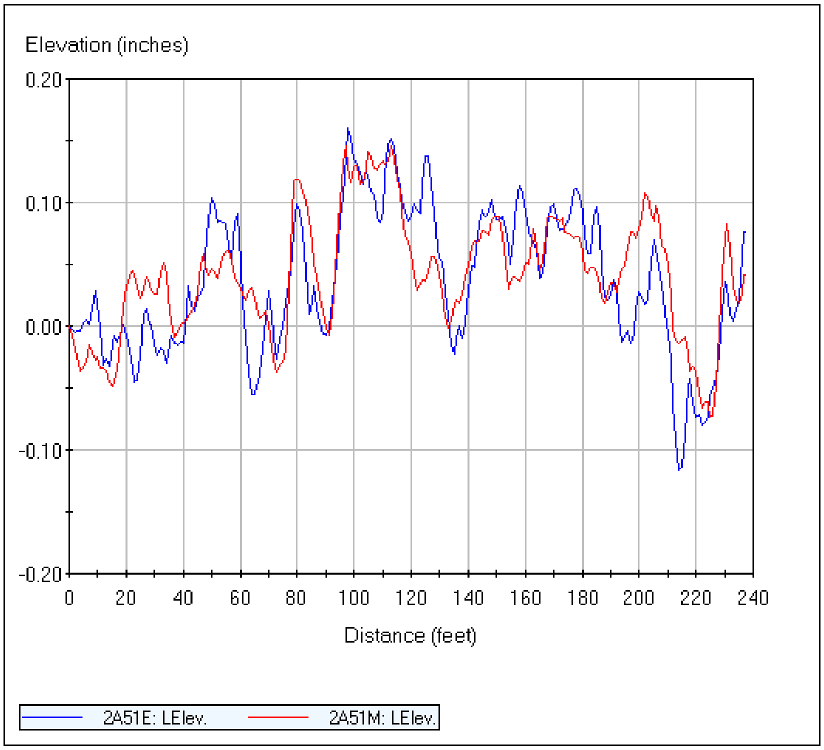


Figure C.26. Level A profile – Oct. 24, 2004 07:30

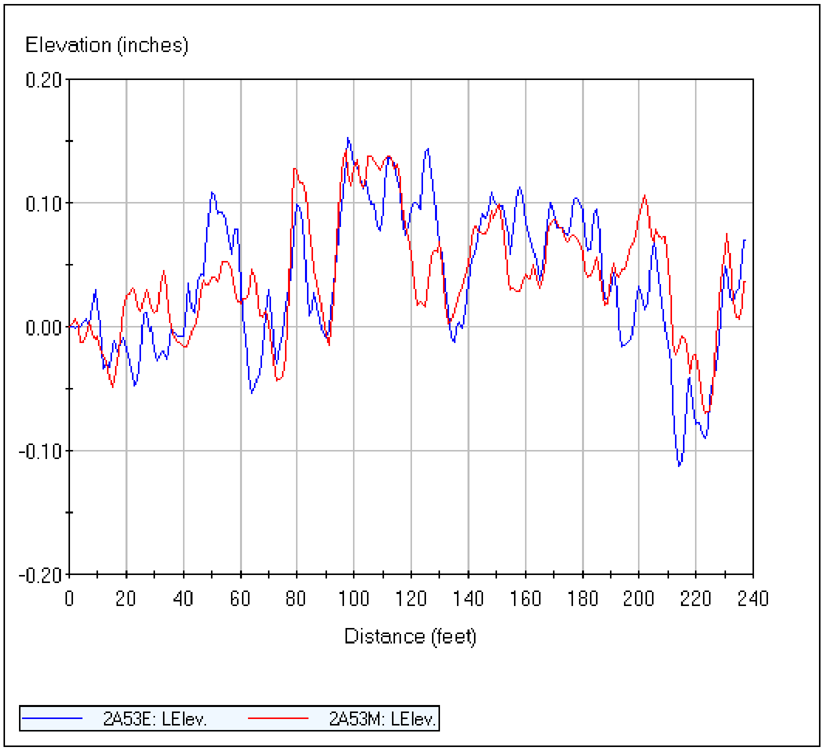


Figure C.27. Level A profile – Oct. 24, 2004 12:00

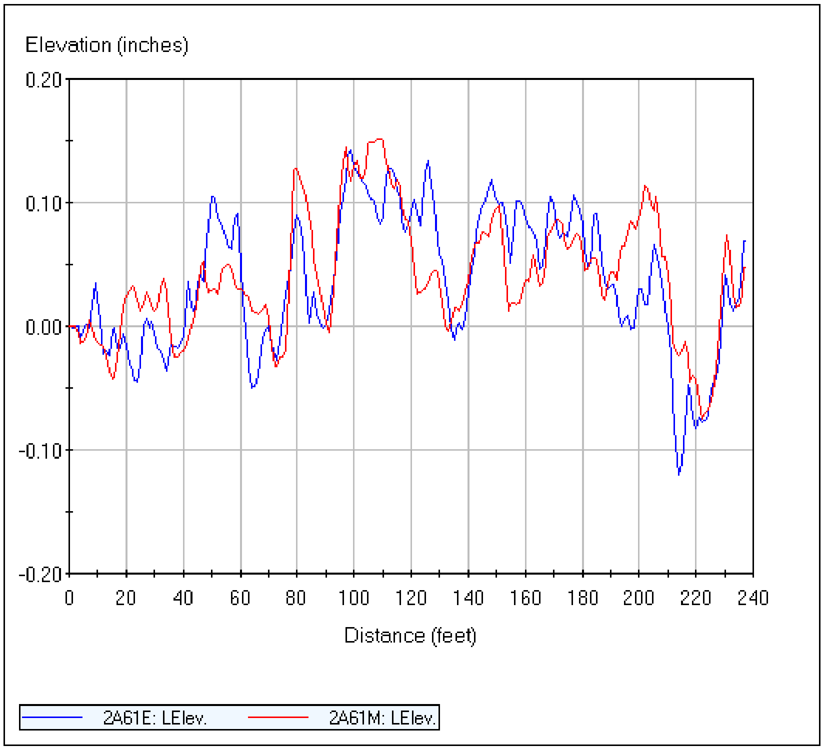


Figure C.28. Level A profile – Oct. 25, 2004 08:20

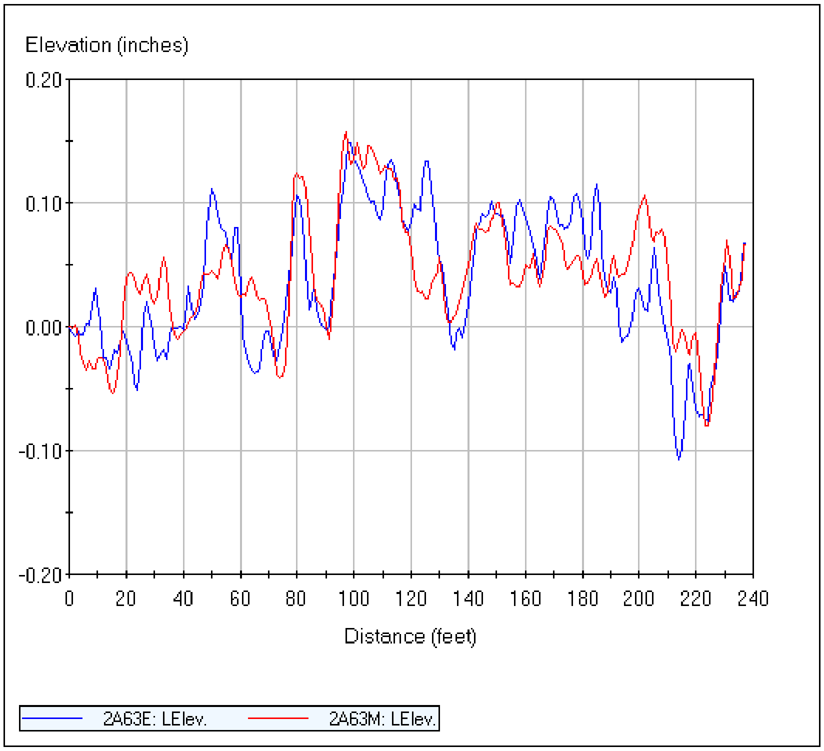


Figure C.29. Level A profile – Oct. 25, 2004 15:15

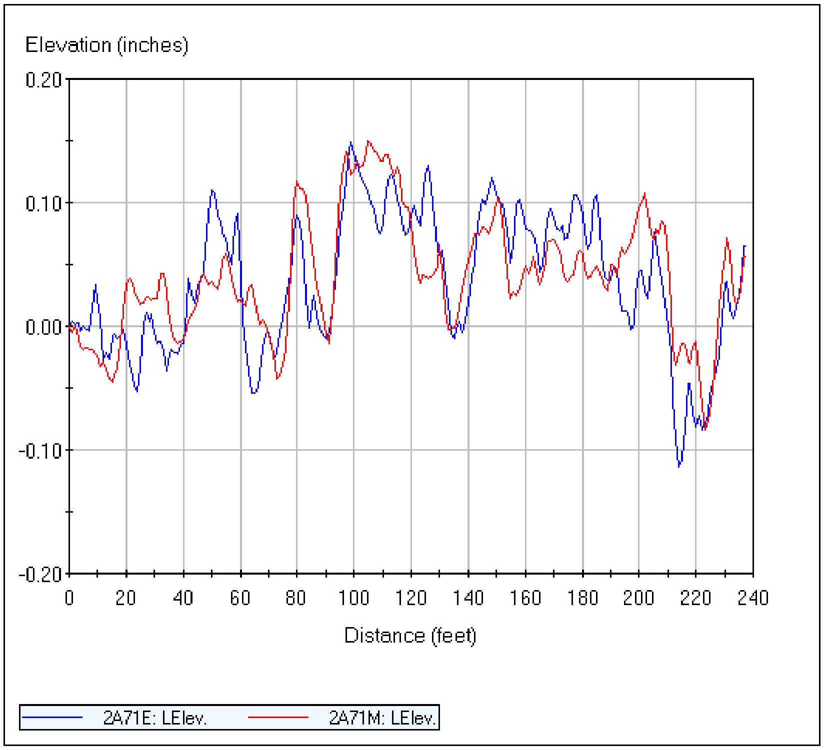


Figure C.30. Level A profile – Oct. 26, 2004 06:30

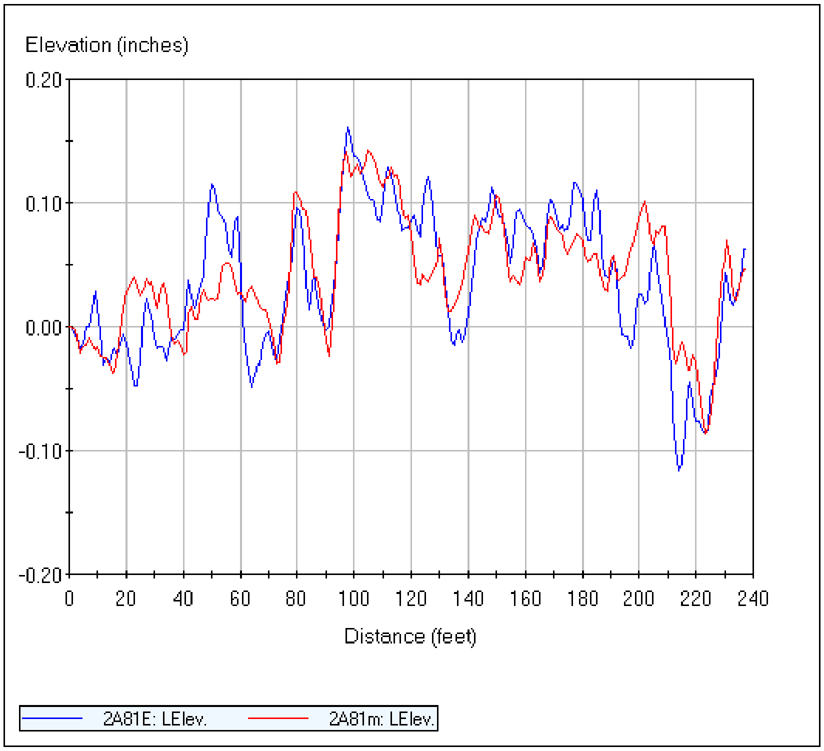


Figure C.31. Level A profile – Oct. 27, 2004 08:30

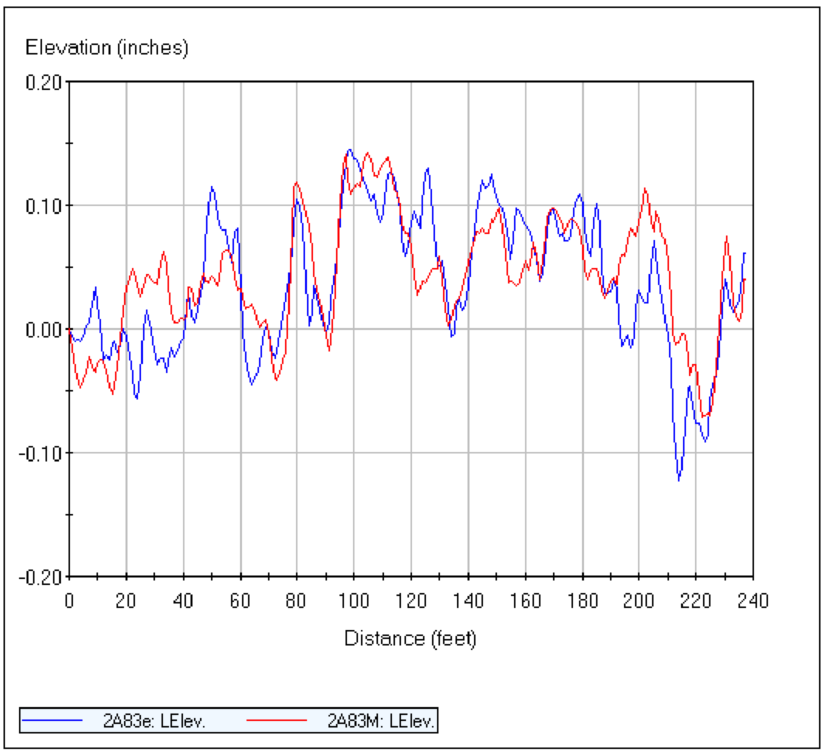


Figure C.32. Level A Profile – Oct. 27, 2004 15:00

Table C.3. Level B profile summary (1.5 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
2B143A	10/23/2004 16:15	72.00	17.7	13.3	61.2	159.8	3.34
2B153A	10/24/2004 13:00	92.75	15.0	16.1	60.3	135.1	3.55
2B163A	10/25/2004 16:15	120.00	16.9	16.9	60.1	121.9	3.68
2B183A	10/27/2004 16:00	167.75	12.1	11.8	55.6	127.3	3.63

Table C.4. Level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
2B143B	10/23/2004 16:15	72.00	17.7	13.3	60.4	145.5	3.46
2B153B	10/24/2004 13:00	92.75	15.0	16.1	72.9	137.4	3.53
2B163B	10/25/2004 16:15	120.00	16.9	16.9	58.4	116.9	3.72
2B183B	10/27/2004 16:00	167.75	12.1	11.8	59.2	106.2	3.82

Table C.5. Level B profile summary (3 ft. from longitudinal joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
2B243A	10/23/2004 16:15	72.00	17.7	13.3	47.7	118.1	3.71
2B253A	10/24/2004 13:00	92.75	15.0	16.1	48.8	105	3.84
2B263A	10/25/2004 16:15	120.00	16.9	16.9	47.4	109.5	3.79
2B283A	10/27/2004 16:00	167.75	12.1	11.8	44.2	107.2	3.81

Table C.6. Level B profile summary (1 ft. from longitudinal joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
2B243B	10/23/2004 16:15	72.00	17.7	13.3	70	148.7	3.43
2B253B	10/24/2004 13:00	92.75	15.0	16.1	67.4	138.1	3.53
2B263B	10/25/2004 16:15	120.00	16.9	16.9	56.8	109.3	3.79
2B283B	10/27/2004 16:00	167.75	12.1	11.8	54.7	84.8	4.04

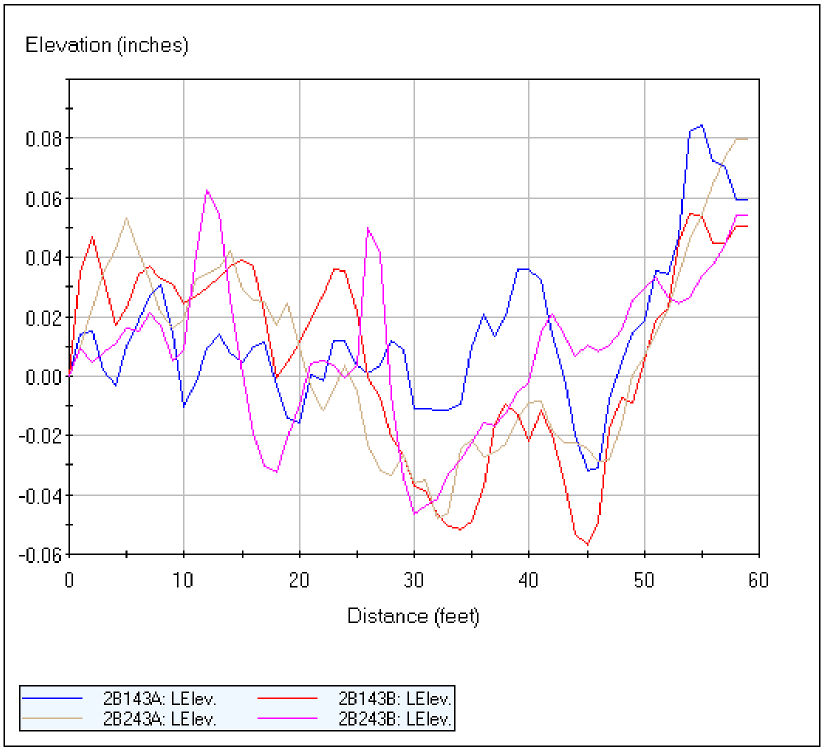


Figure C.33. Level B profile – Oct. 23, 2004 16:15

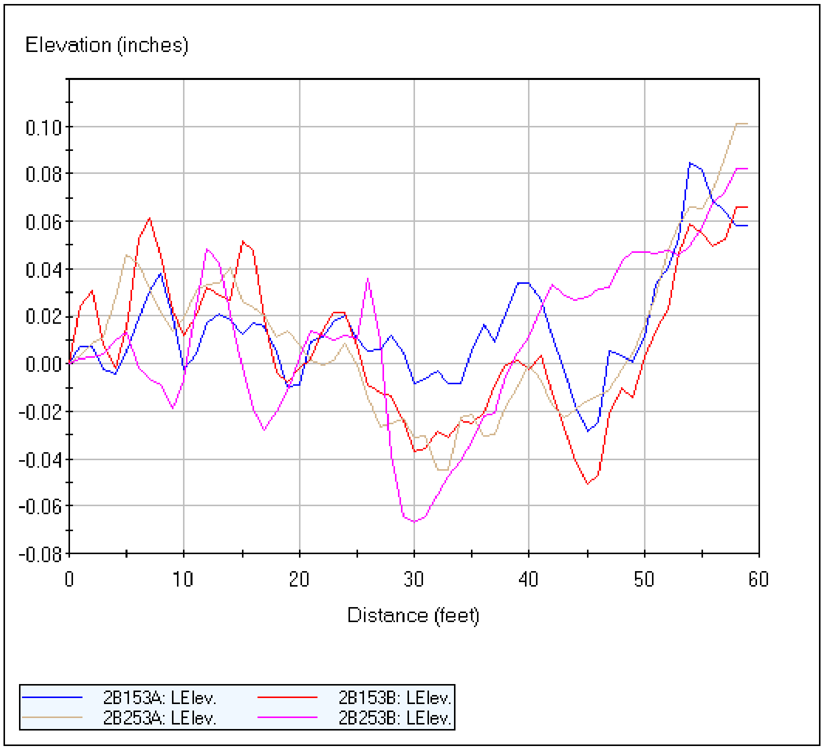


Figure C.34. Level B profile – Oct. 24, 2004 13:00

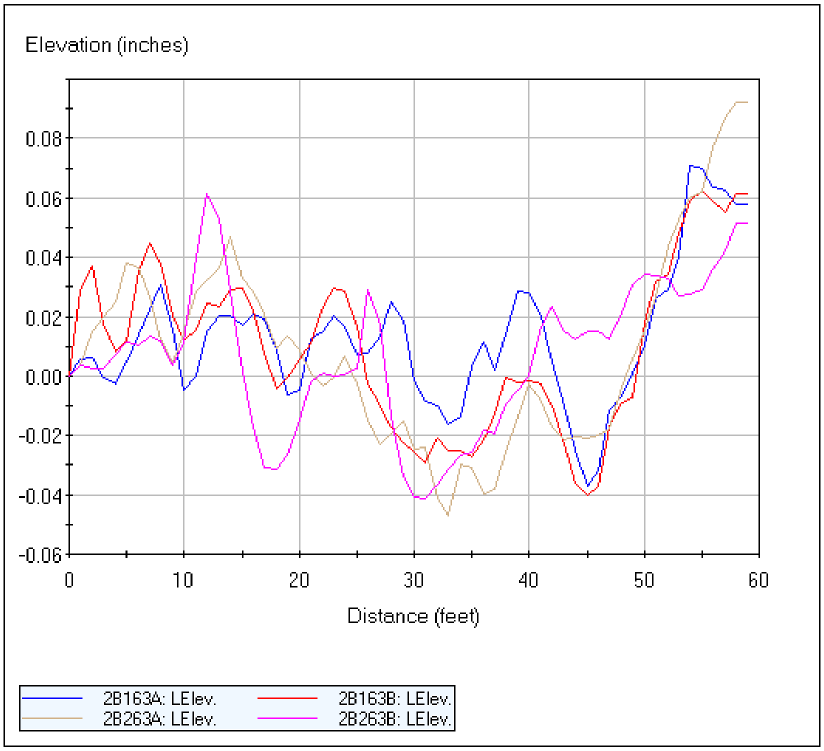


Figure C.35. Level B profile – Oct. 25, 2004 16:15

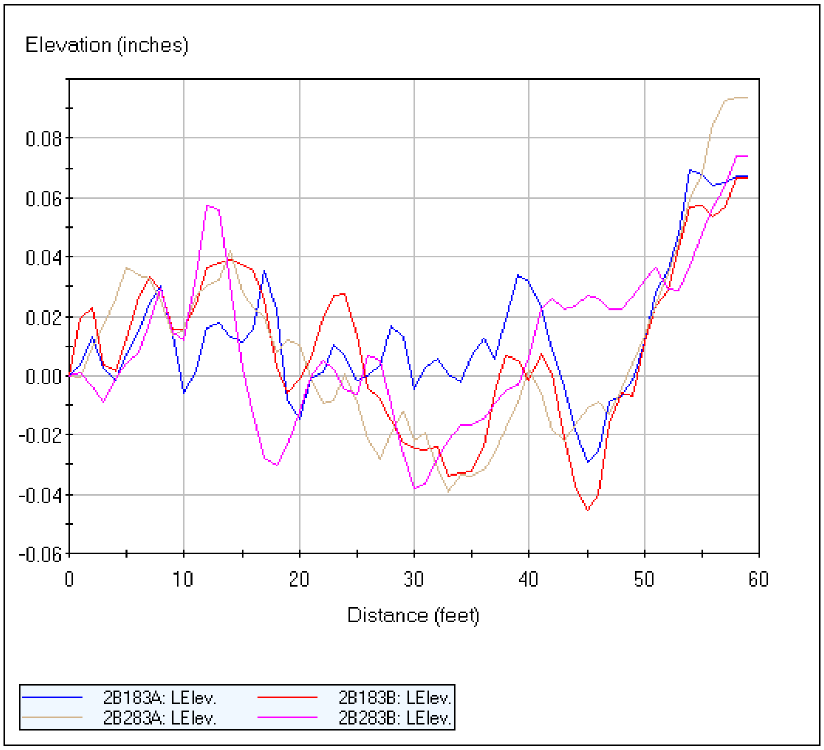


Figure C.36. Level B profile – Oct. 27, 2004 16:00

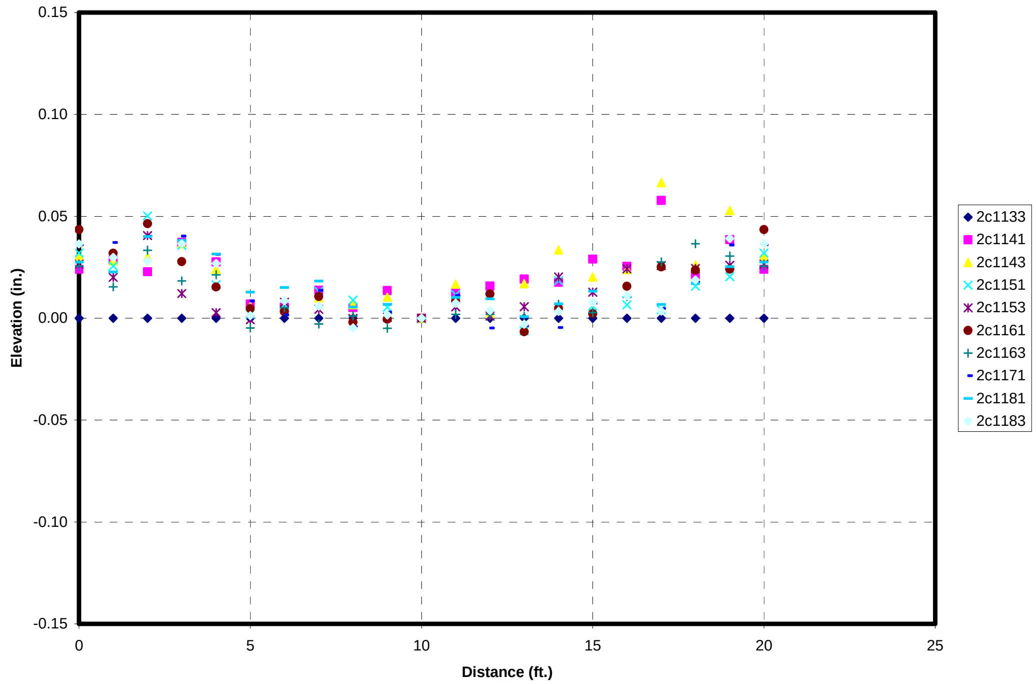


Figure C.37. Level C profiles path 1 – slab 11

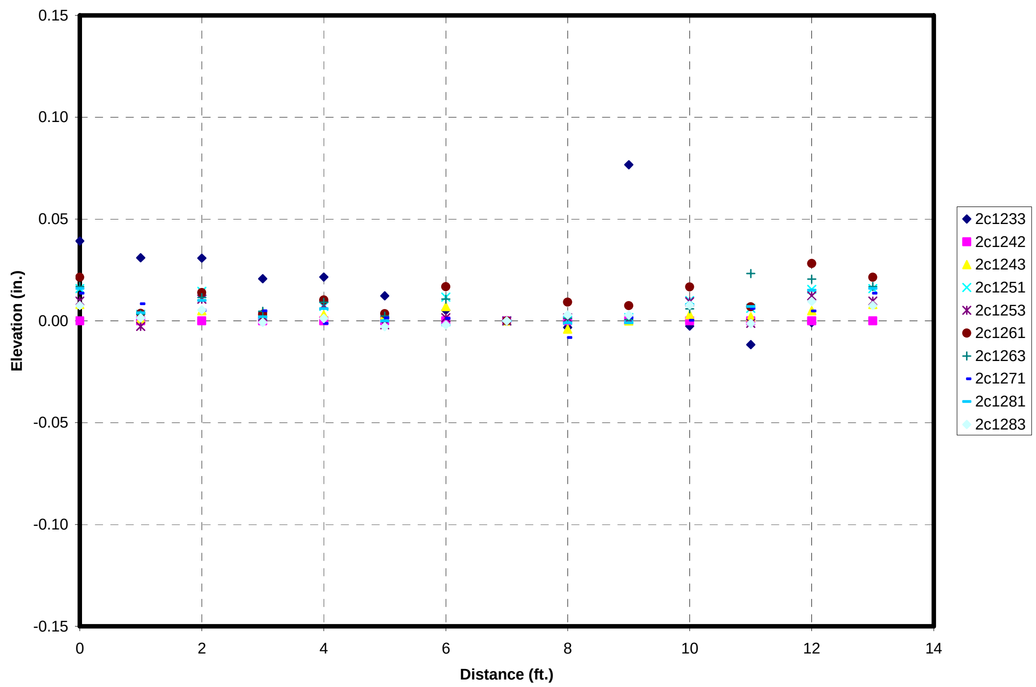


Figure C.38. Level C profiles path 2 – slab 11

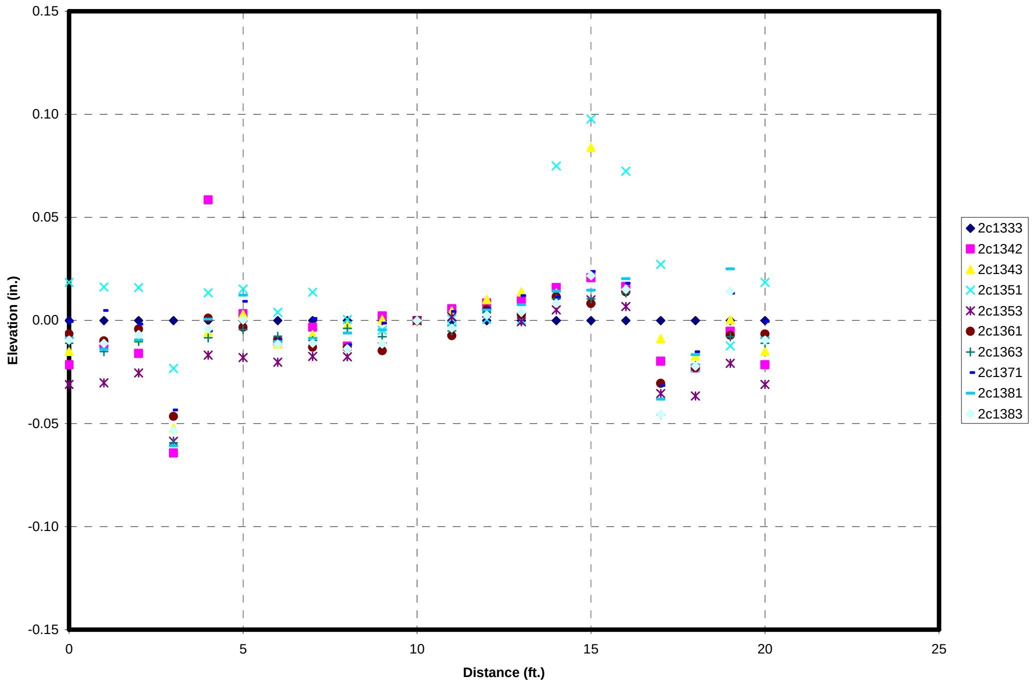


Figure C.39. Level C profiles path 3 – slab 11

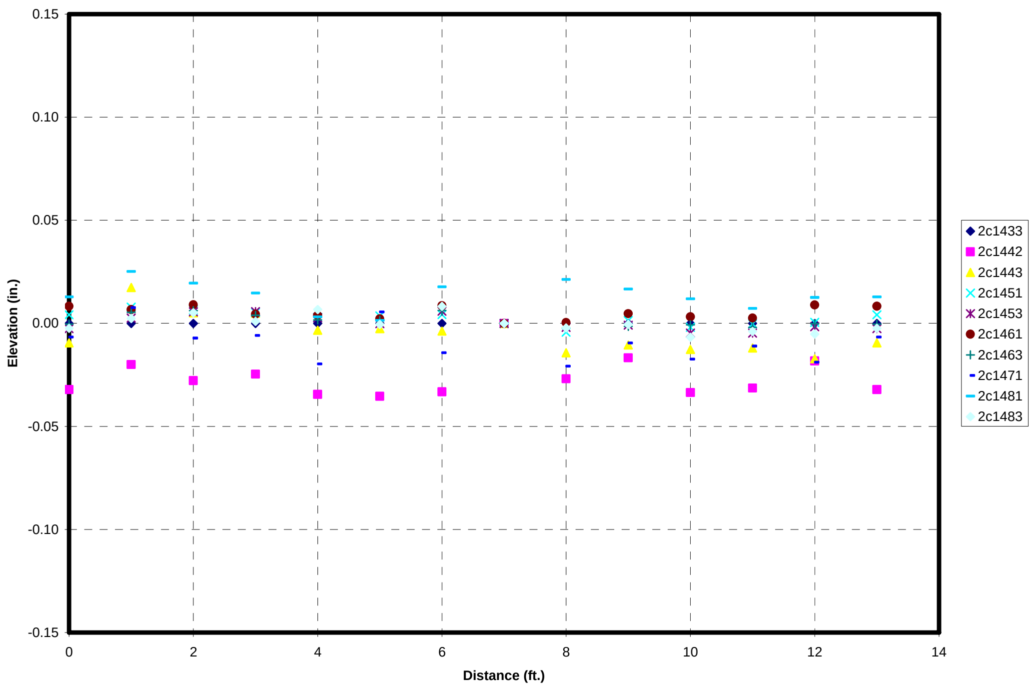


Figure C.40. Level C profiles path 4 – slab 11

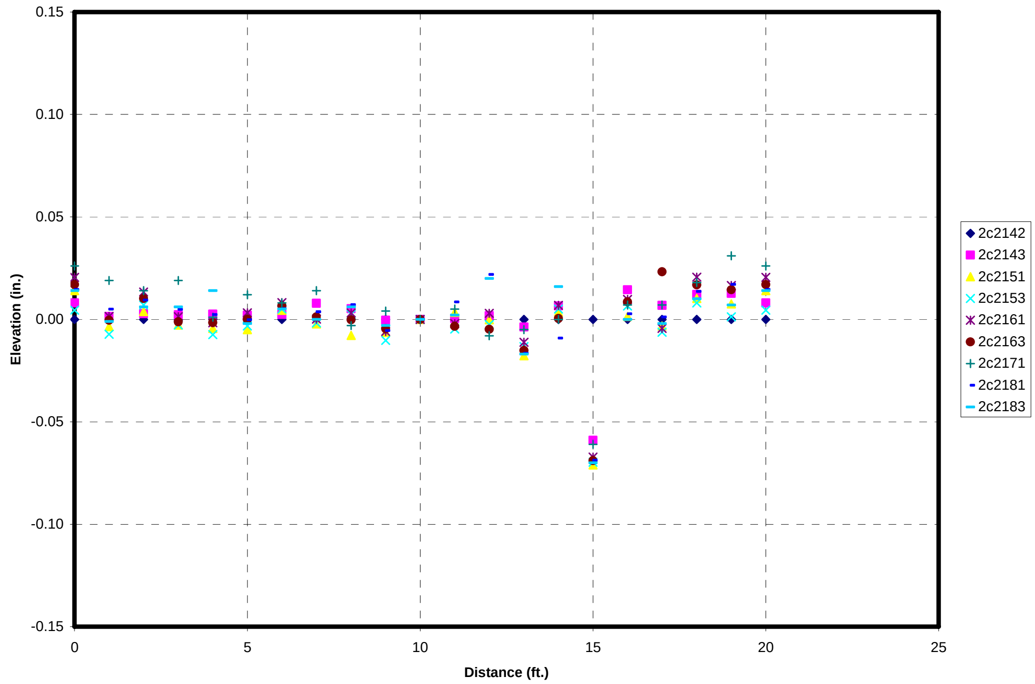


Figure C.41. Level C profiles path 1 – slab 12

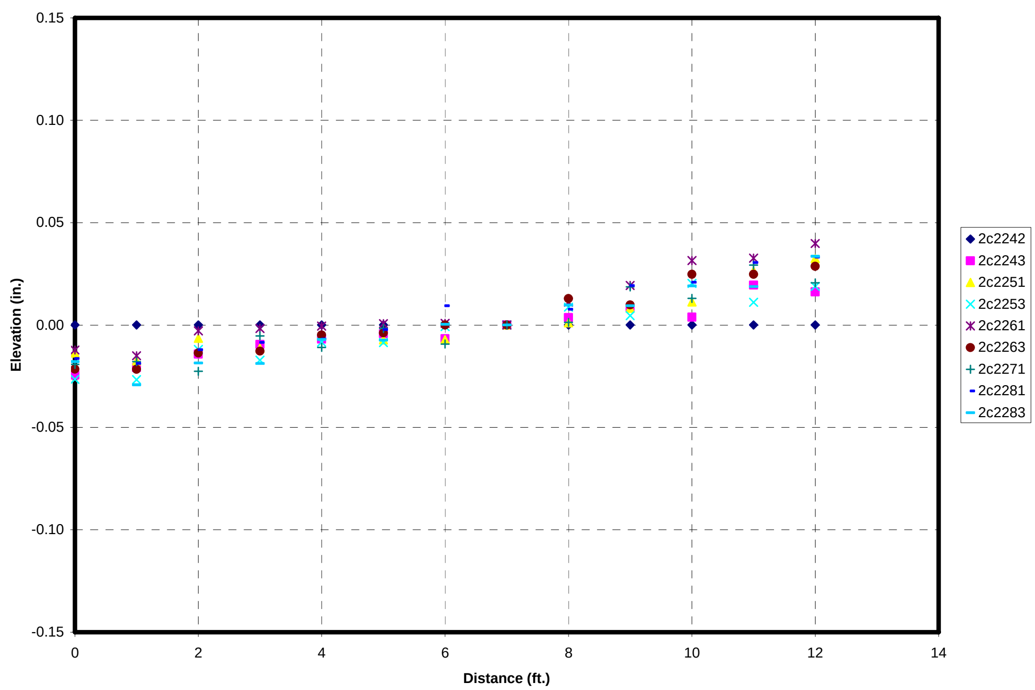


Figure C.42. Level C profiles path 2 – slab 12

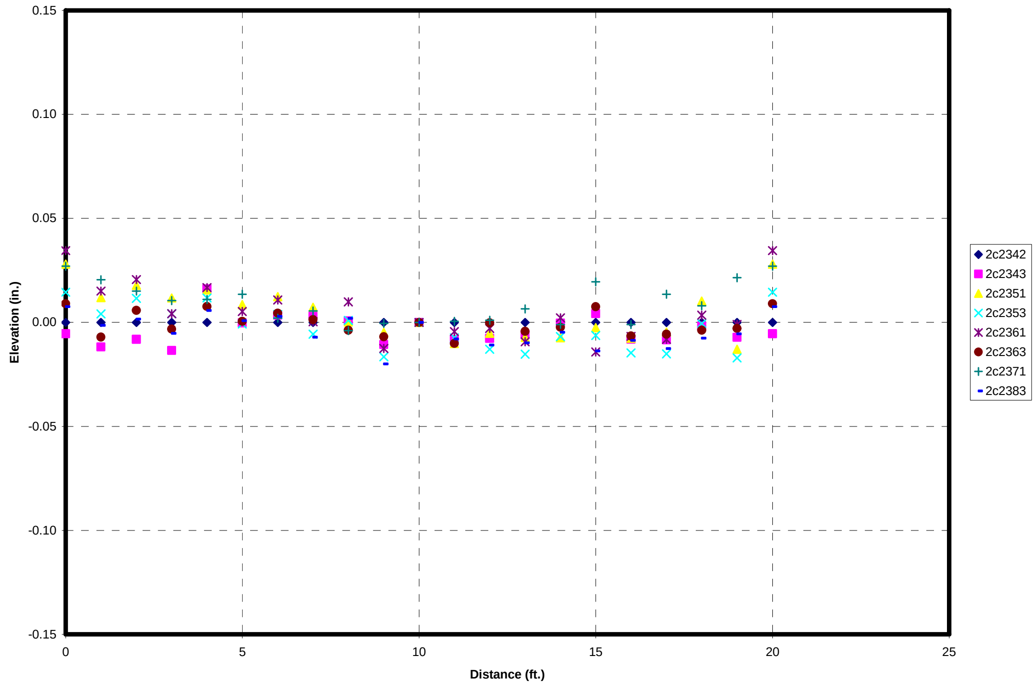


Figure C.43. Level C profiles path 3 – slab 12

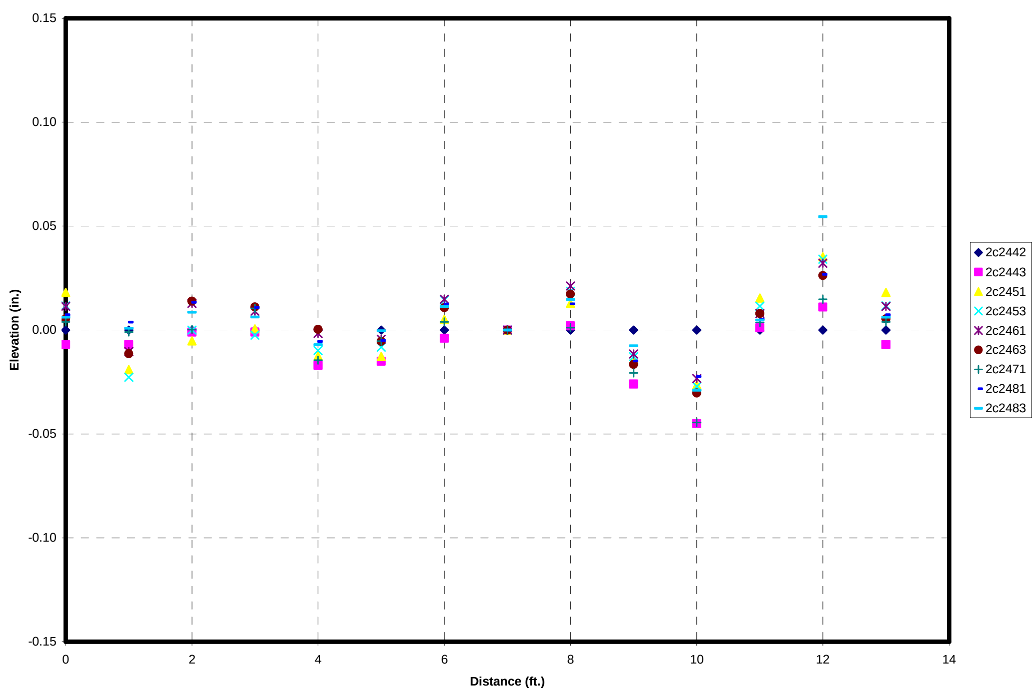


Figure C.44. Level C profiles path 4 – slab 12

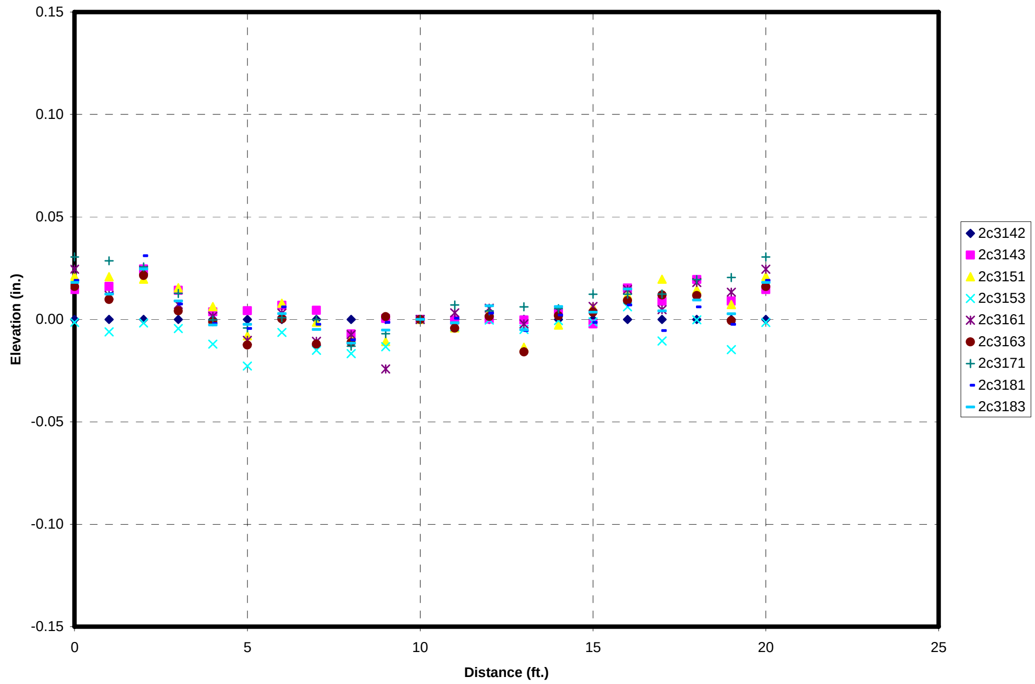


Figure C.45. Level C profiles path 1 – slab 13

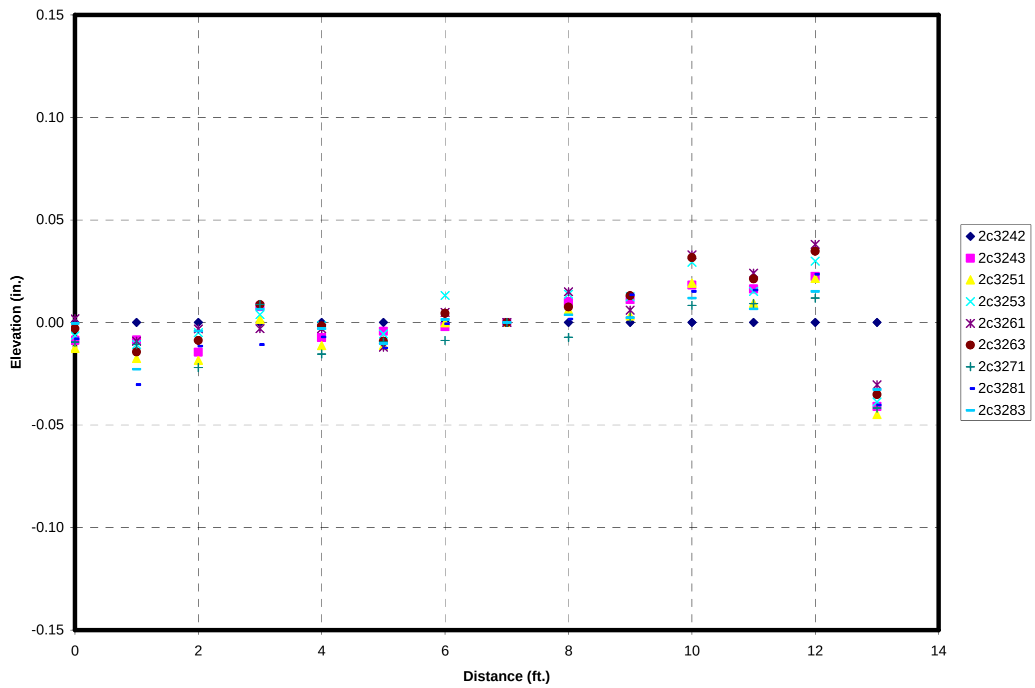


Figure C.46. Level C profiles path 2 – slab 13

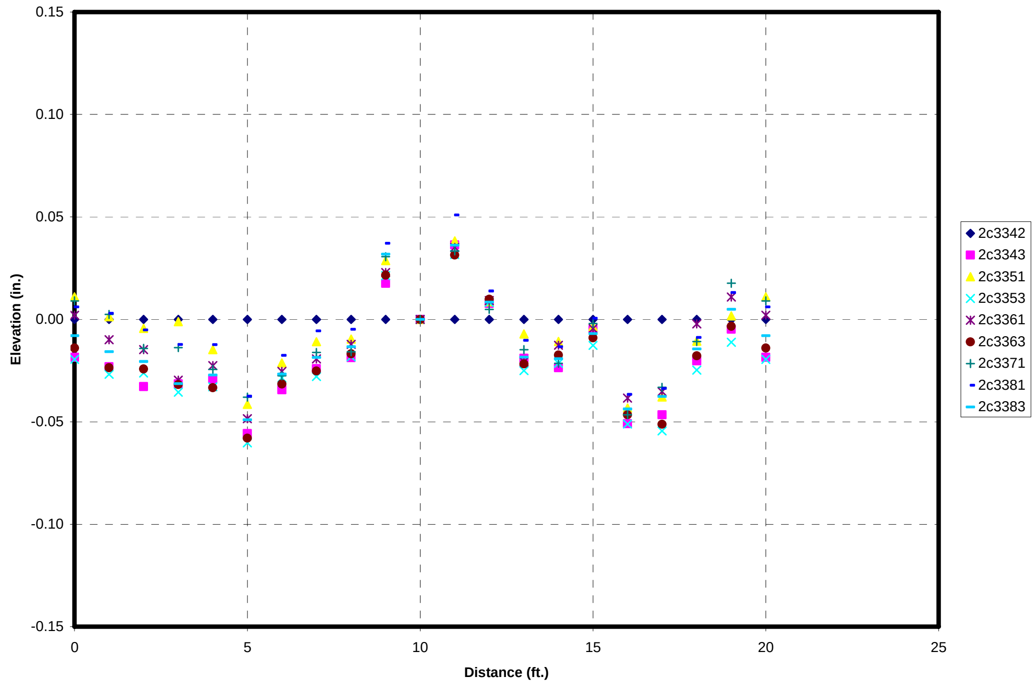


Figure C.47. Level C profiles path 3 – slab 13

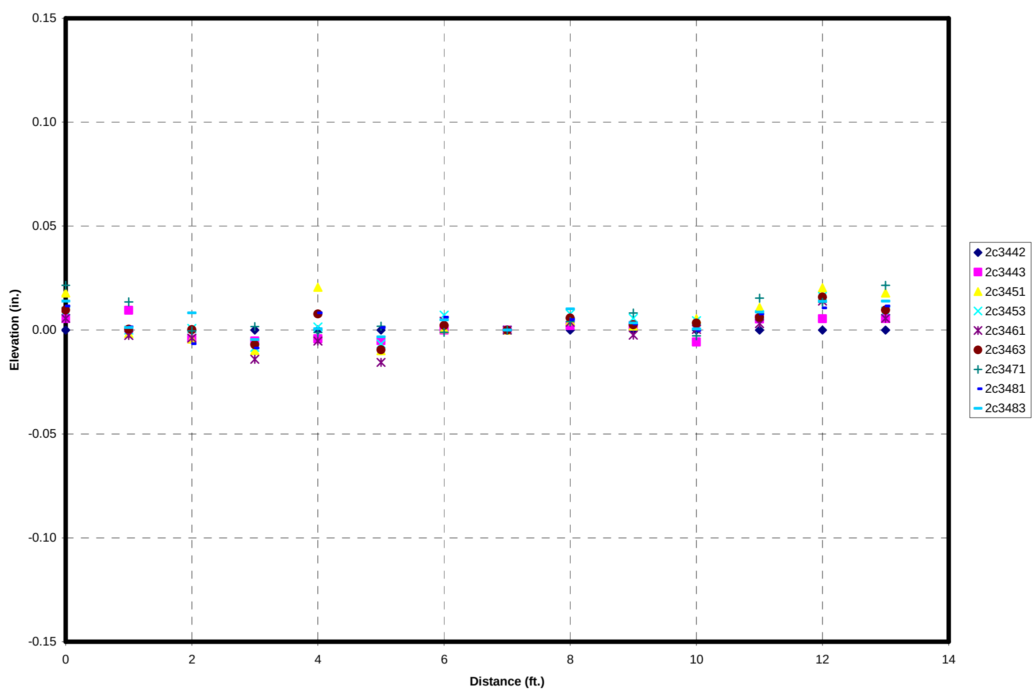


Figure C.48. Level C profiles path 4 – slab 13

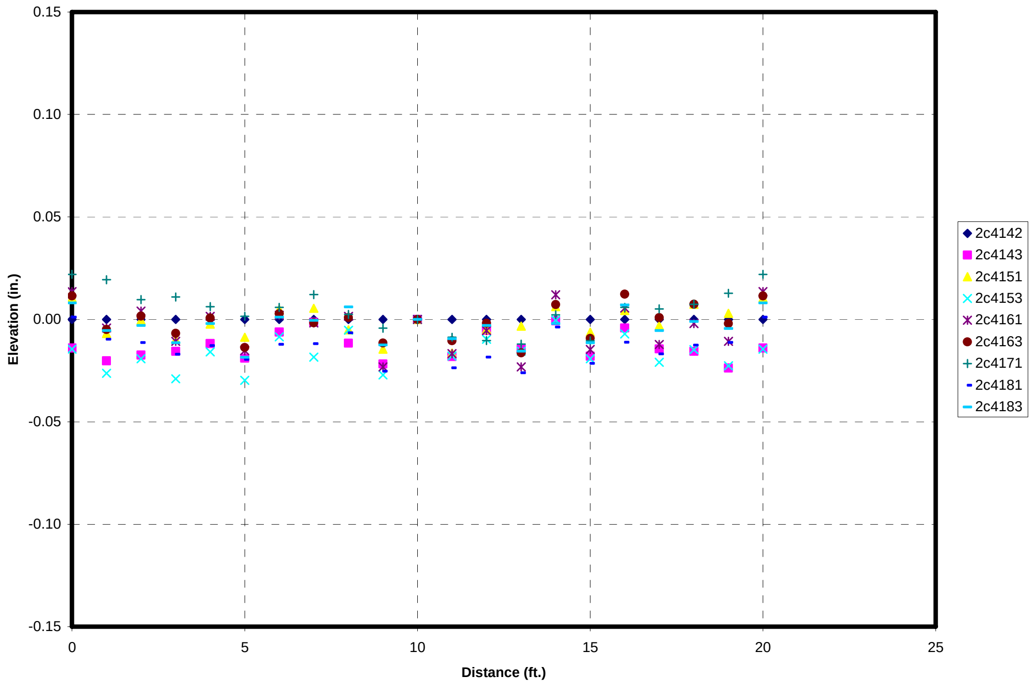


Figure C.49. Level C profiles path 1 – slab 14

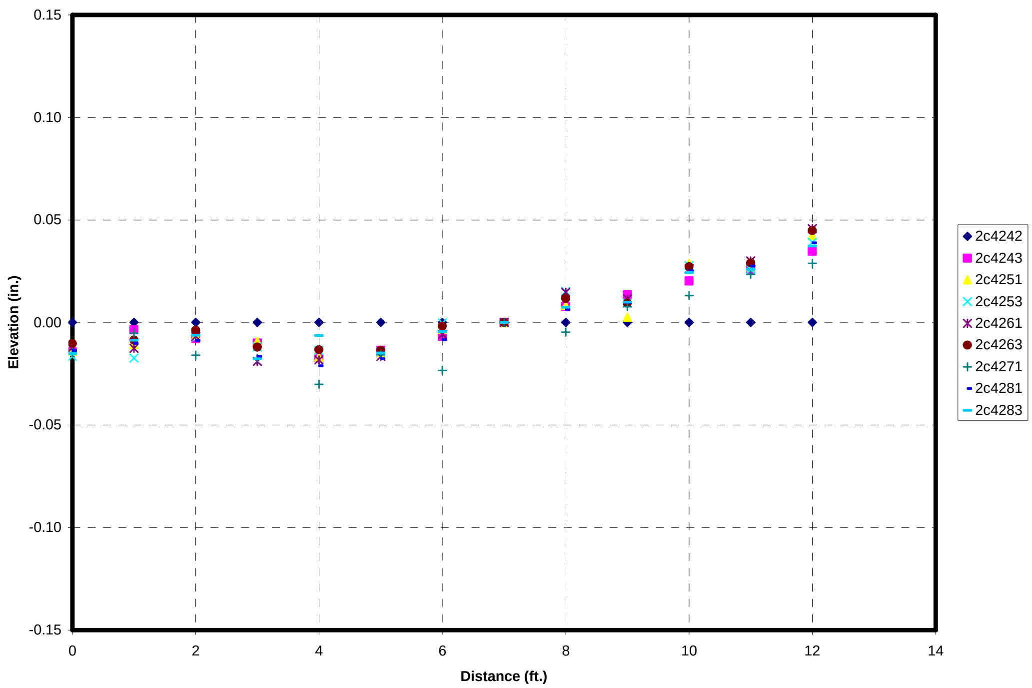


Figure C.50. Level C profiles path 2 – slab 14

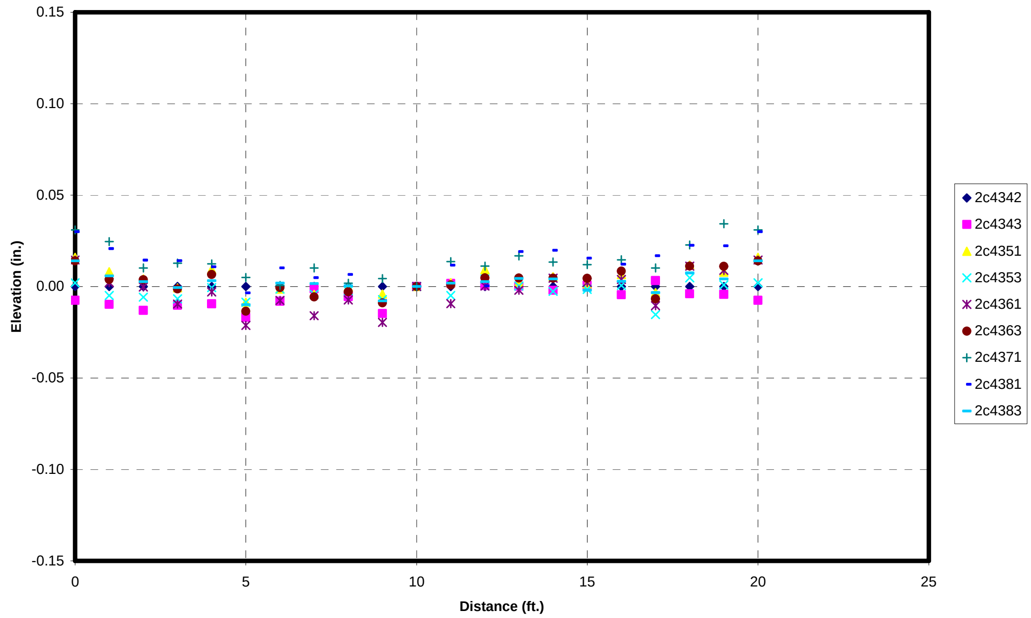


Figure C.51. Level C profiles path 3 – slab 14

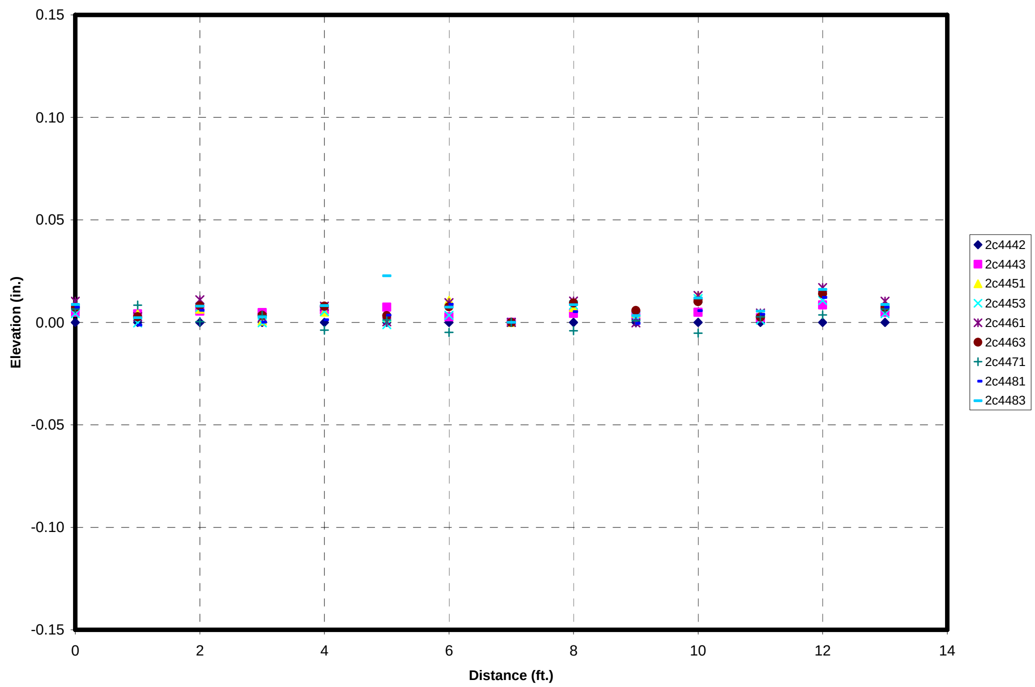


Figure C.52. Level C profiles path 4 – slab 14

APPENDIX D: BURLINGTON SITE PHOTO LOG

Figure D.1. Concrete delivery and paving operation

Figure D.2. Concrete delivery and placement operations

Figure. D.3. Finishing operations

Figure. D.4. Longitudinal sawcut operations

Figure D.5. Motor grader operations prior to acceptance profile measurements

Figure D.6. Temperature instrumentation installation

Figure D.7. Temperature instrumentation installation

Figure D.8. Temperature instrumentation installation

Figure D.9. Air Void Analyzer (AVA) sampling

Figure D.10. Relative humidity instrumentation instillation following AVA sampling

Figure D.11. Relative humidity instrumentation location

Figure D.12. LVDT installation before thunderstorm

Figure D.13. LVDT instrumentation location

Figure D.14. Corner DEMEC location with crack at transverse joint

Figure D.15. Transverse joint DEMEC location in afternoon (no visible crack)

Figure D.16. Transverse joint DEMEC location in morning (visible crack)

Figure D.17. Inclinometer profiler

Figure D.18. Longitudinal inclinometer profile collection

Figure D.19. Transverse inclinometer profile collection

APPENDIX E: BURLINGTON SITE MORNING PAVING TEST SECTION

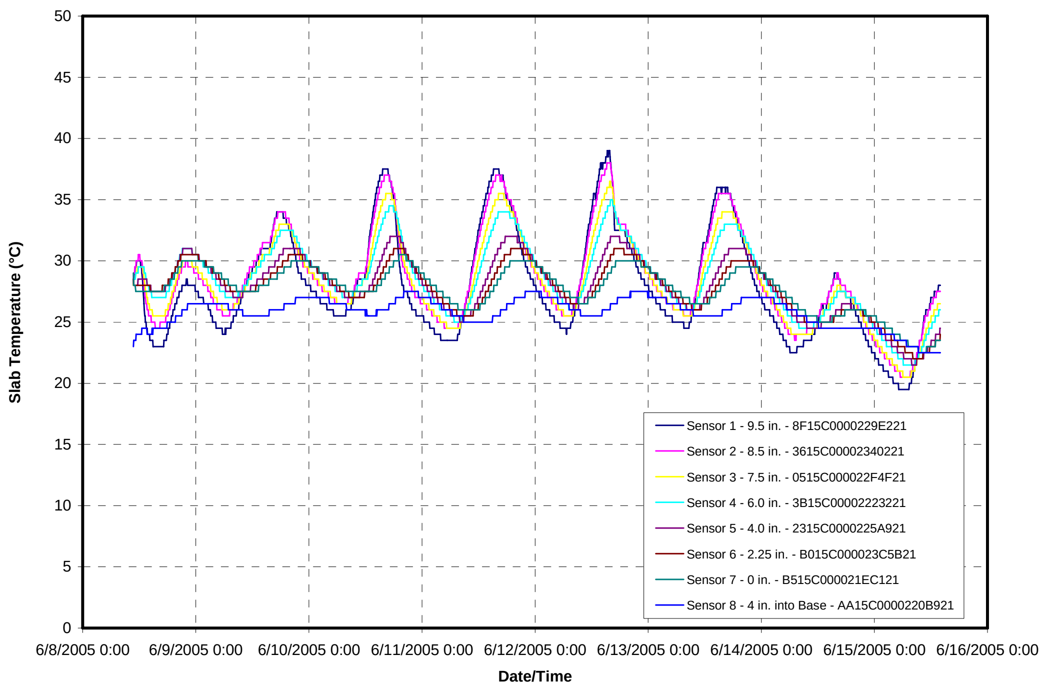


Figure E.1. Slab temperature data

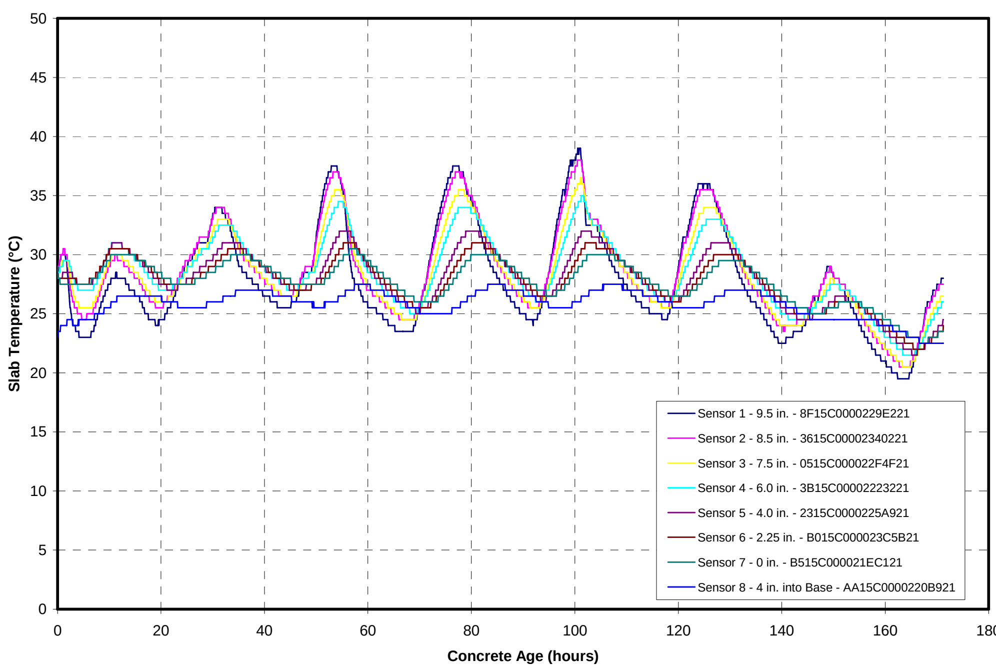


Figure E.2. Slab temperature data

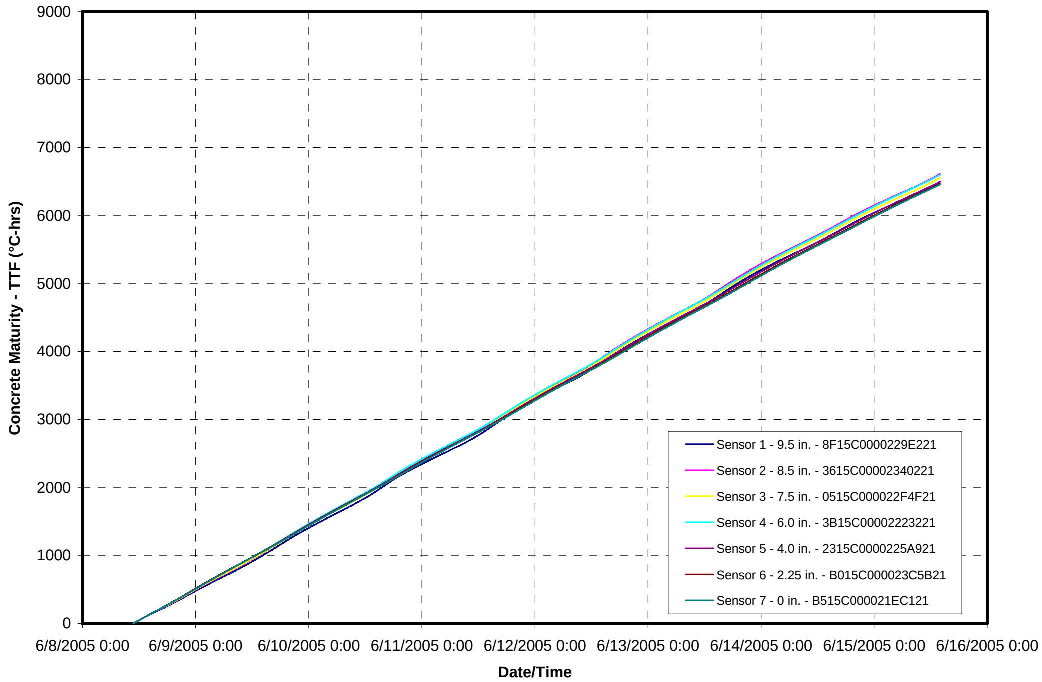


Figure E.3. Slab maturity data

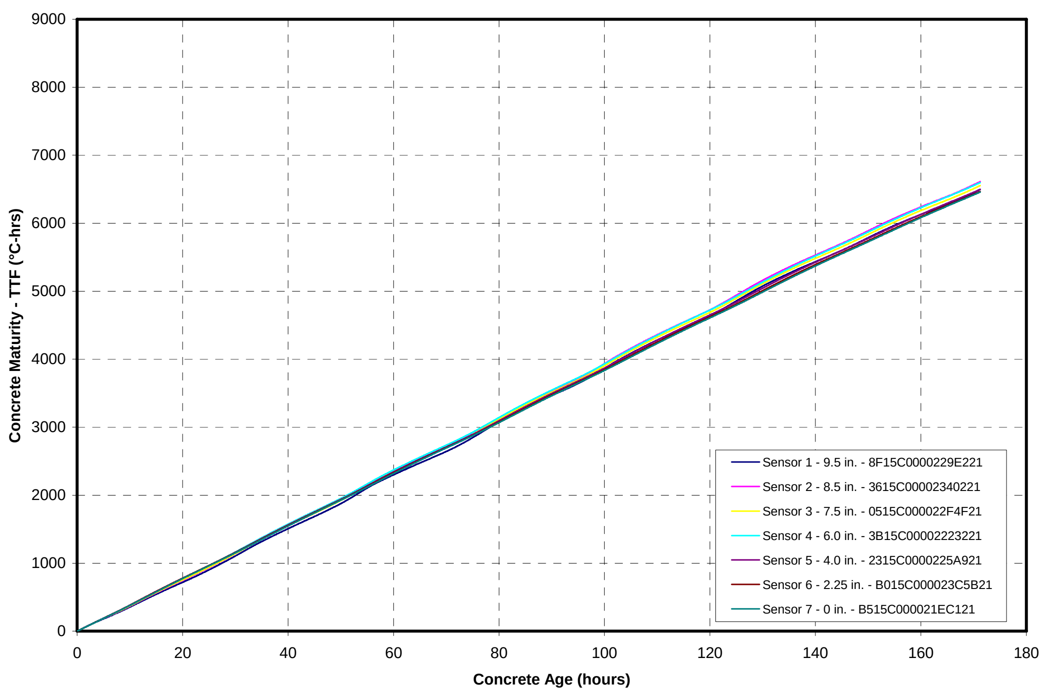


Figure E.4. Slab maturity data

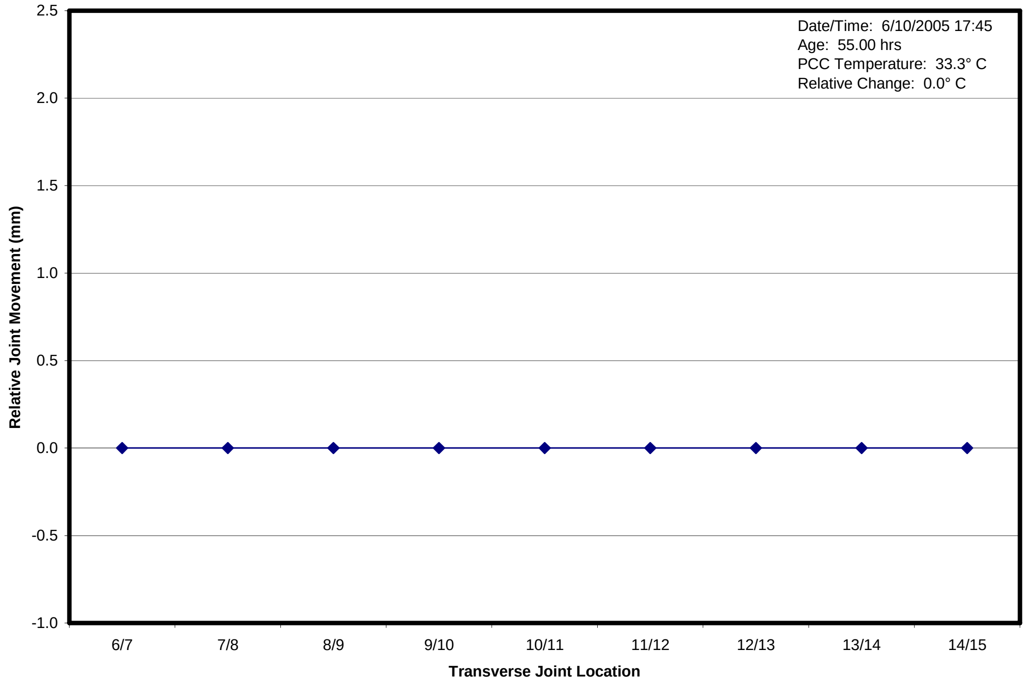


Figure E.5. Transverse joint relative opening

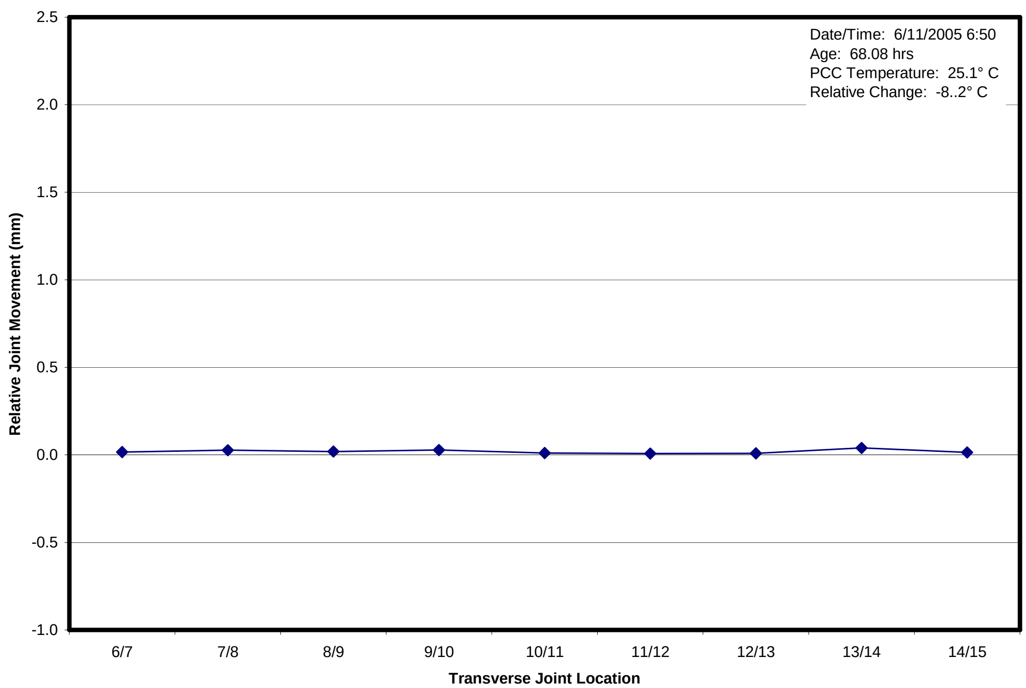


Figure E.6. Transverse joint relative opening

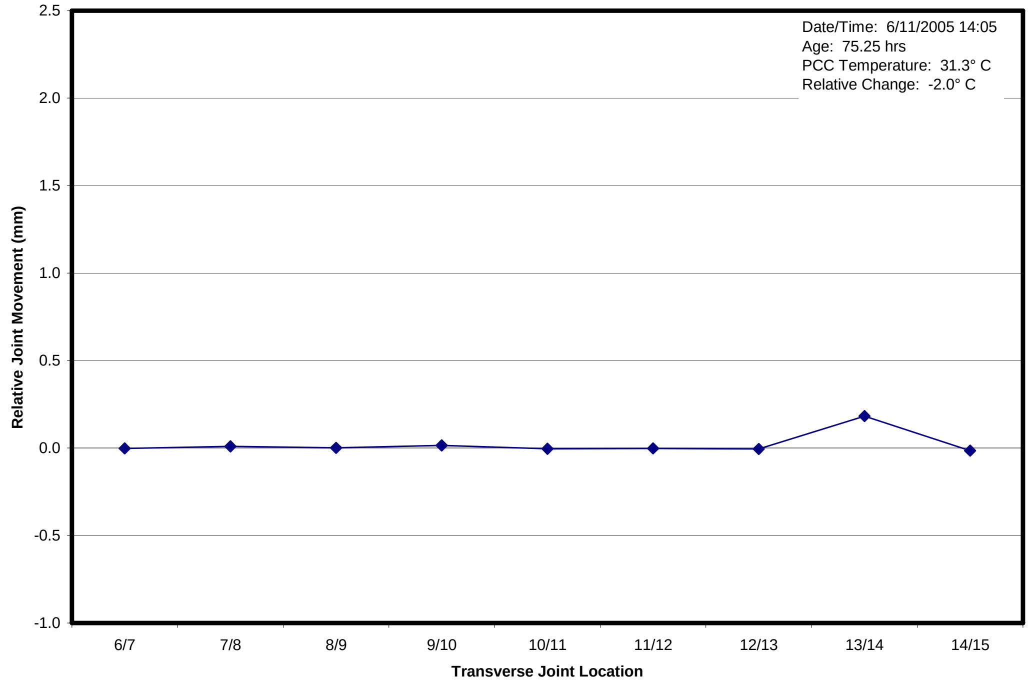


Figure E.7. Transverse joint relative opening

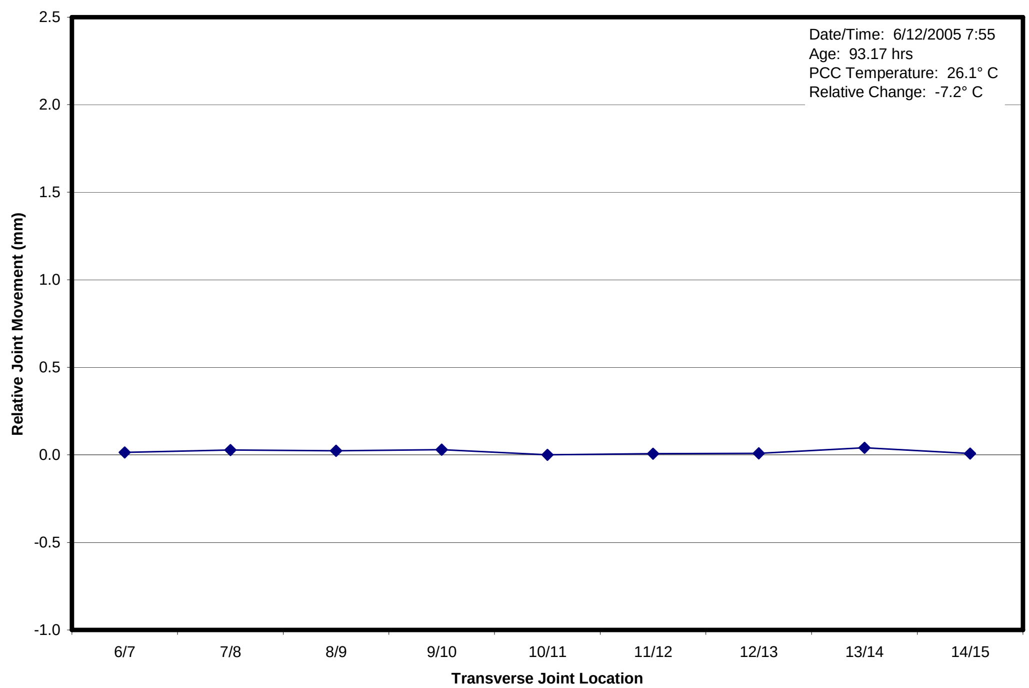


Figure E.8. Transverse joint relative opening

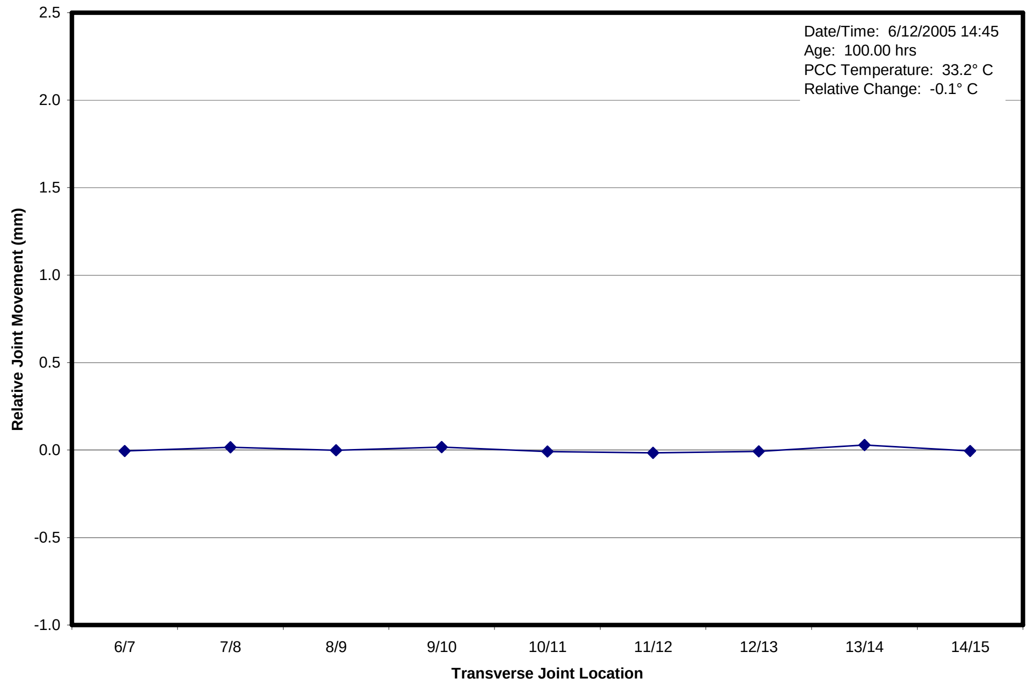


Figure E.9. Transverse joint relative opening

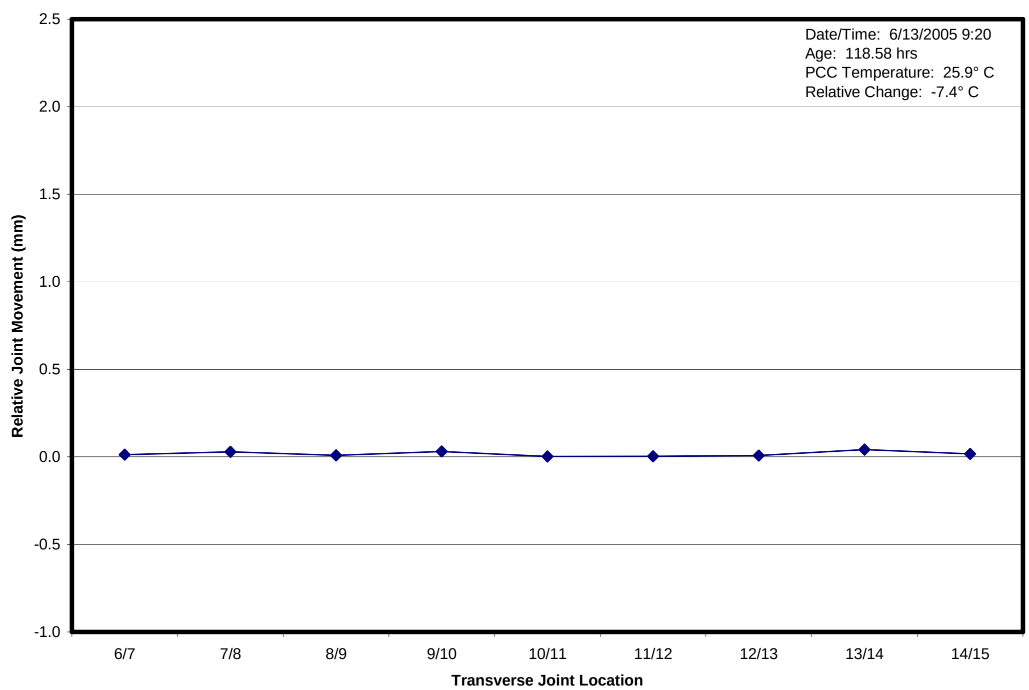


Figure E.10. Transverse joint relative opening

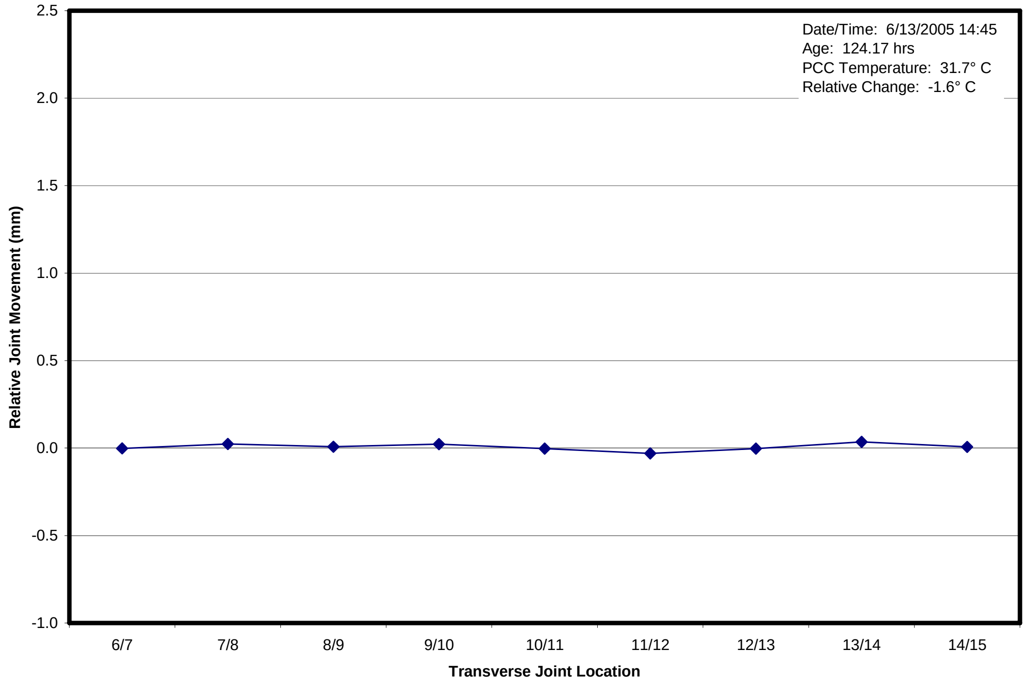


Figure E.11. Transverse joint relative opening

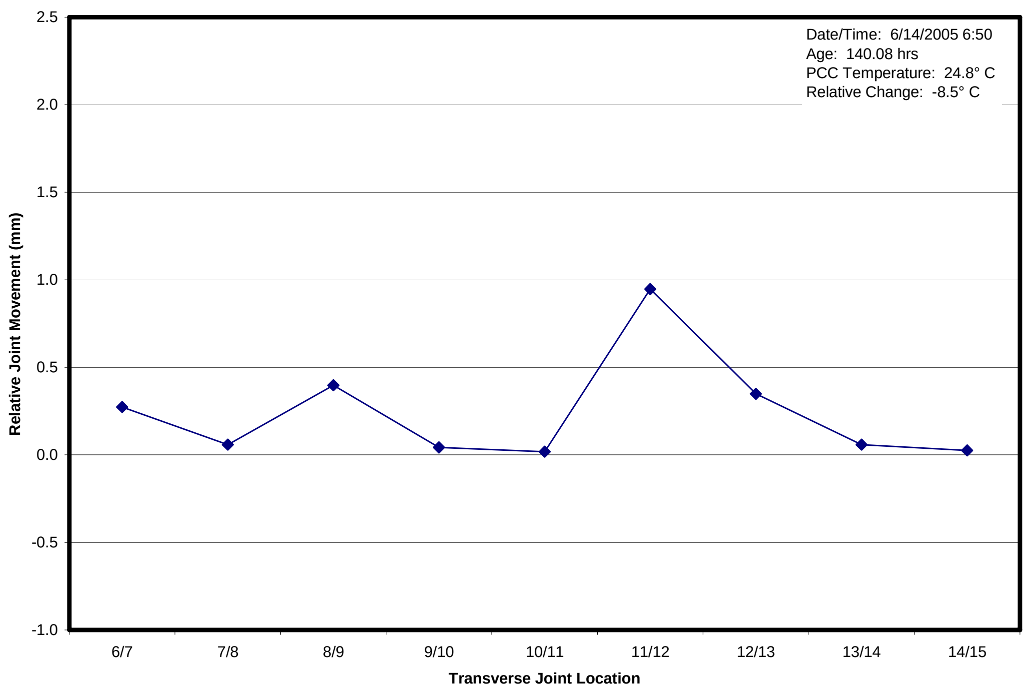


Figure E.12. Transverse joint relative opening

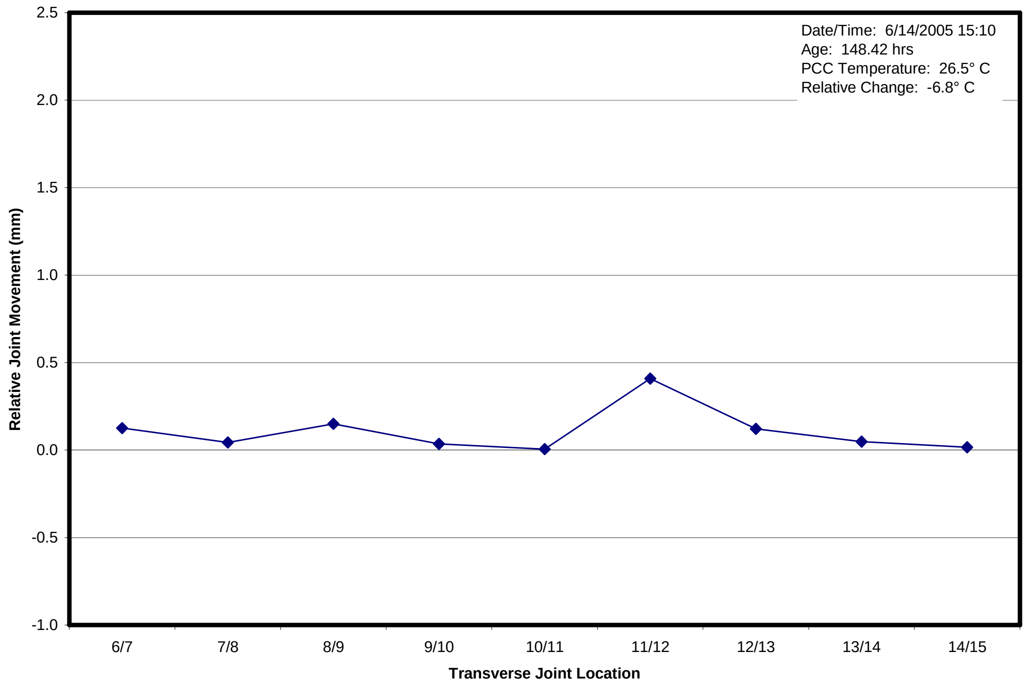


Figure E.13. Transverse joint relative opening

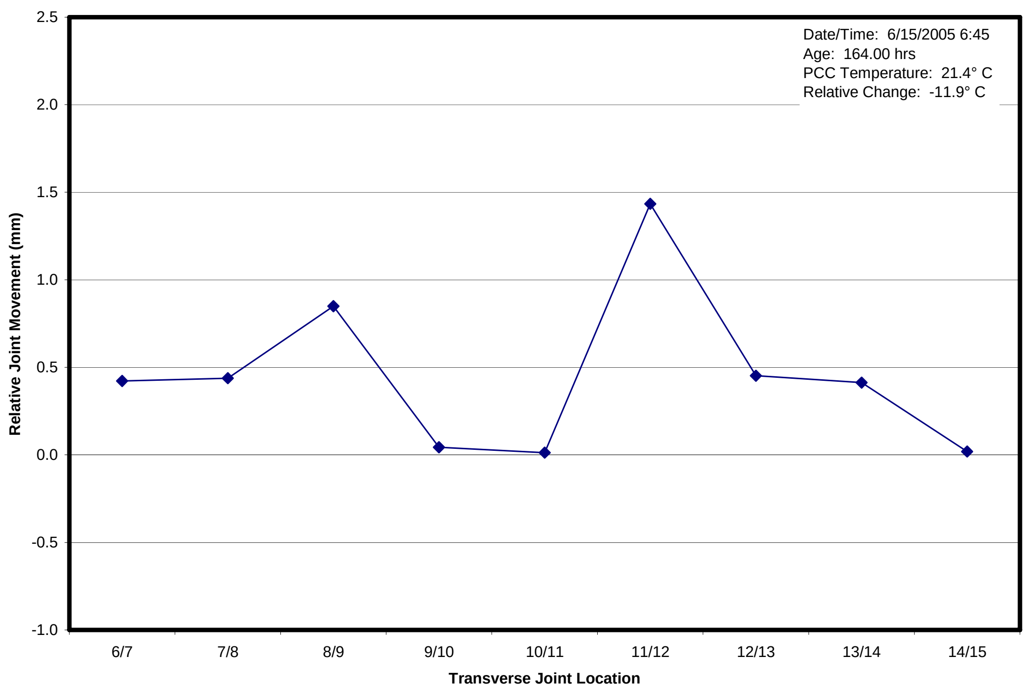


Figure E.14. Transverse joint relative opening

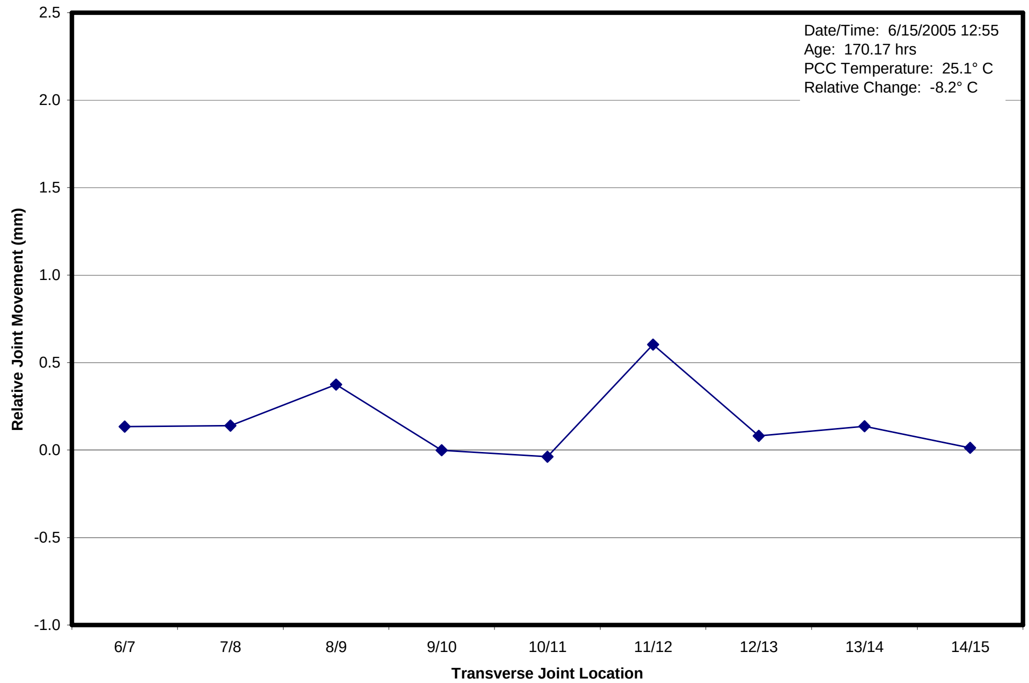


Figure E.15. Transverse joint relative opening

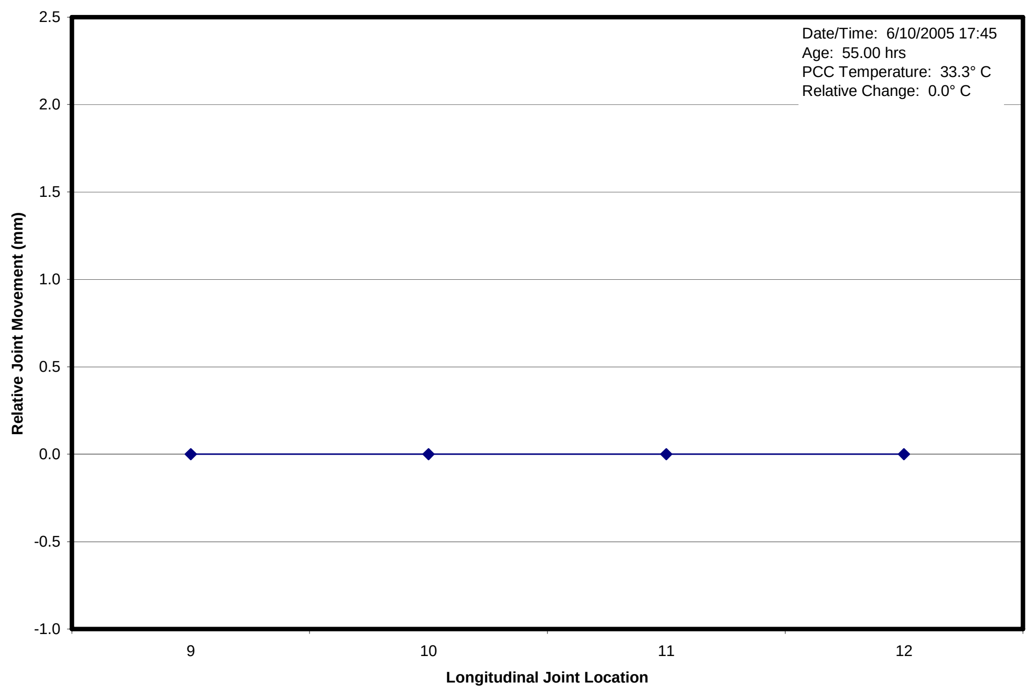


Figure E.16. Longitudinal joint relative opening

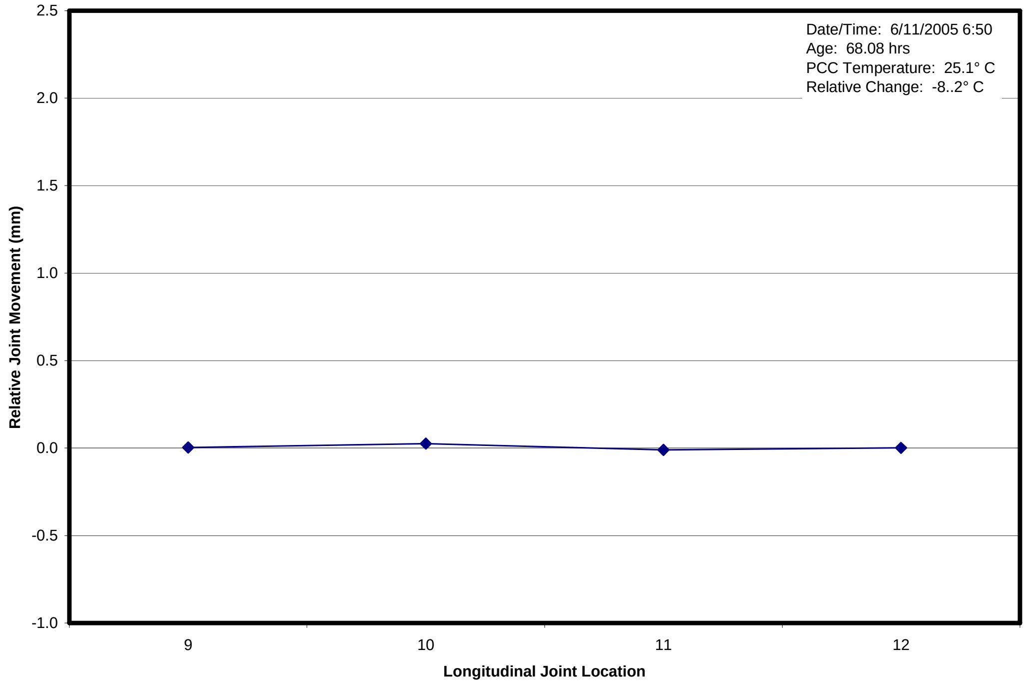


Figure E.17. Longitudinal joint relative opening

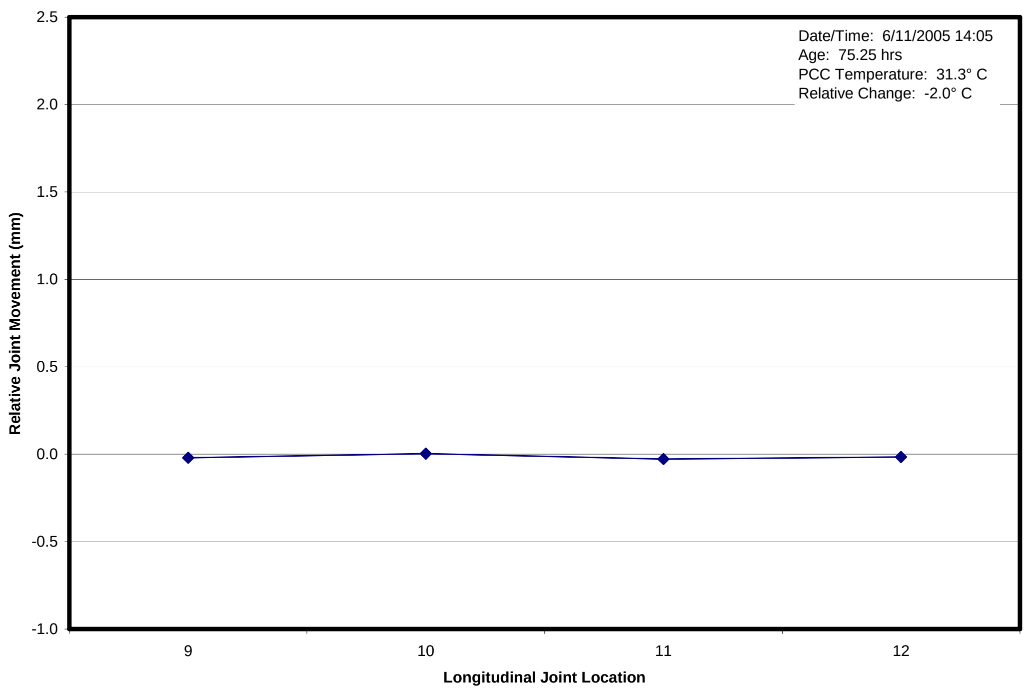


Figure E.18. Longitudinal joint relative opening

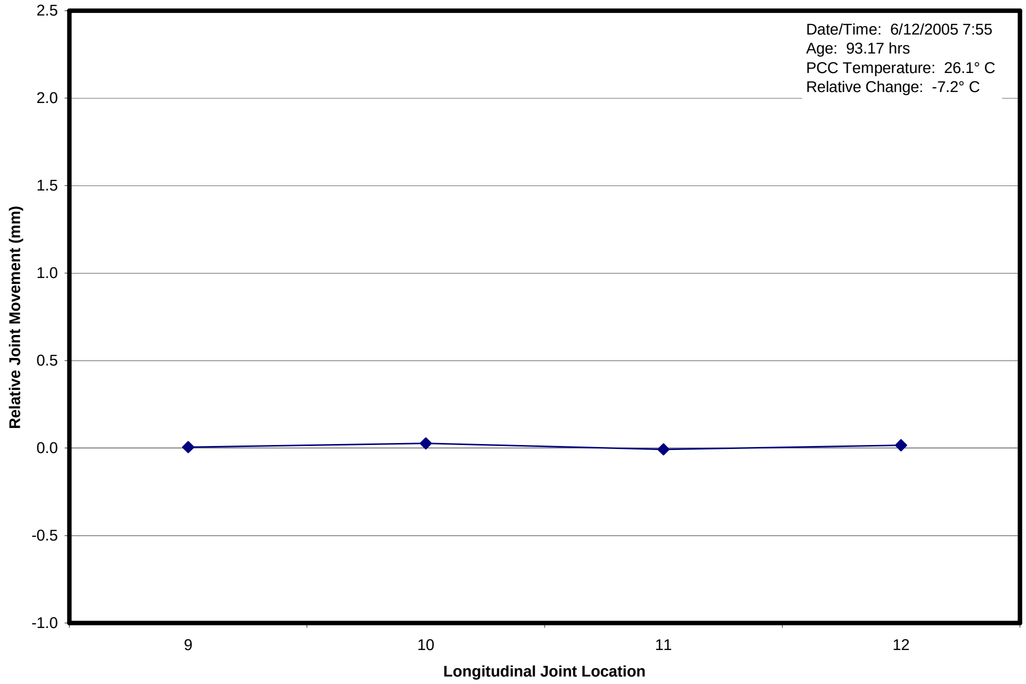


Figure E.19. Longitudinal joint relative opening

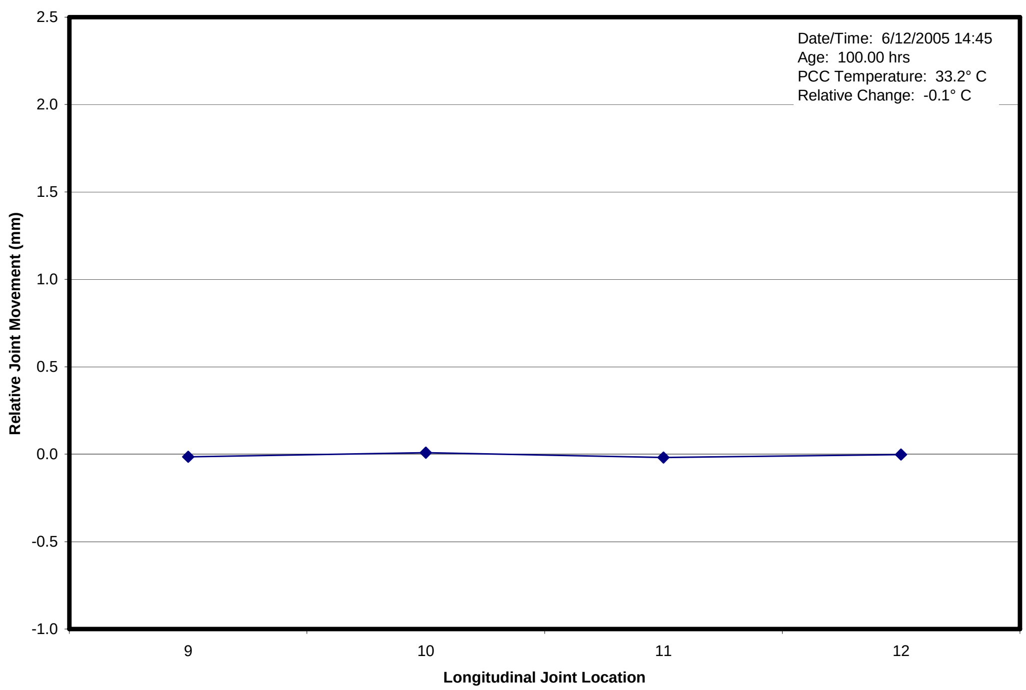


Figure E.20. Longitudinal joint relative opening

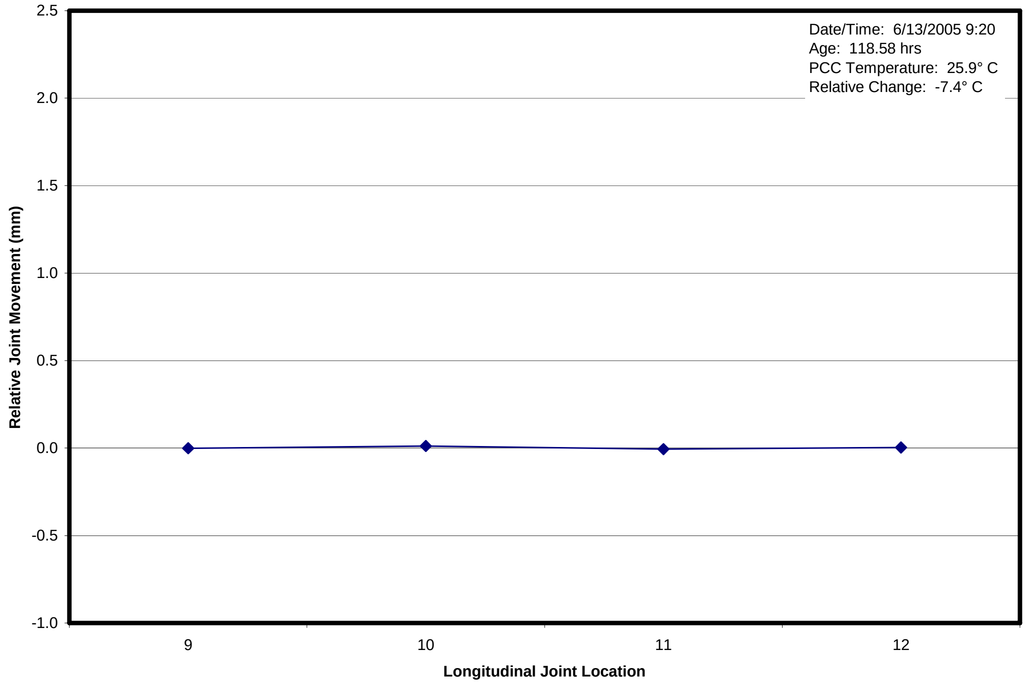


Figure E.21. Longitudinal joint relative opening

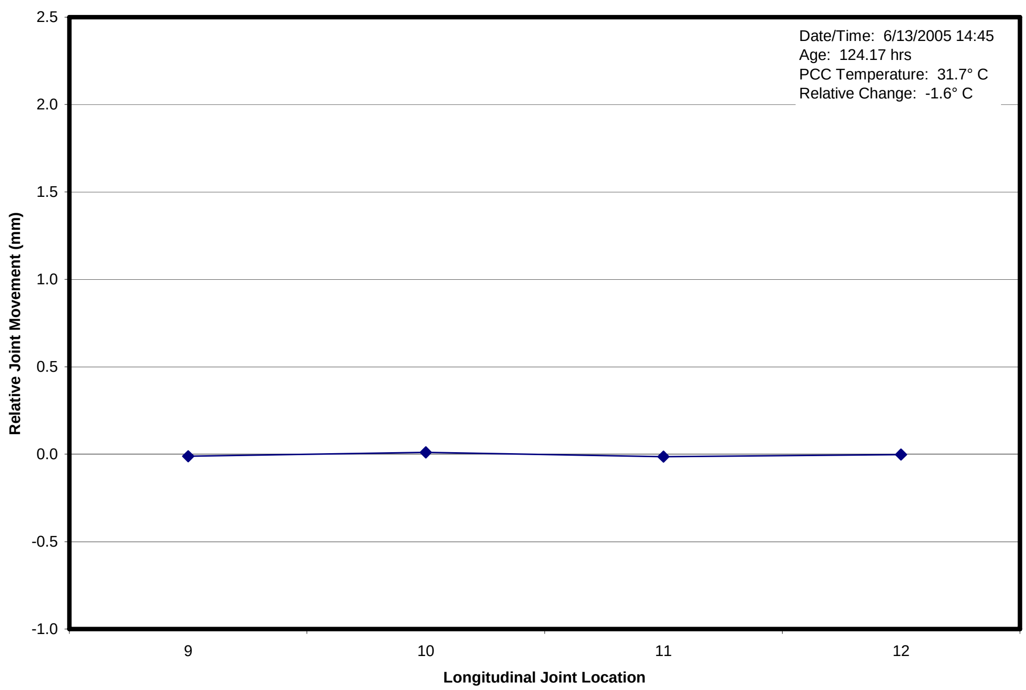


Figure E.22. Longitudinal joint relative opening

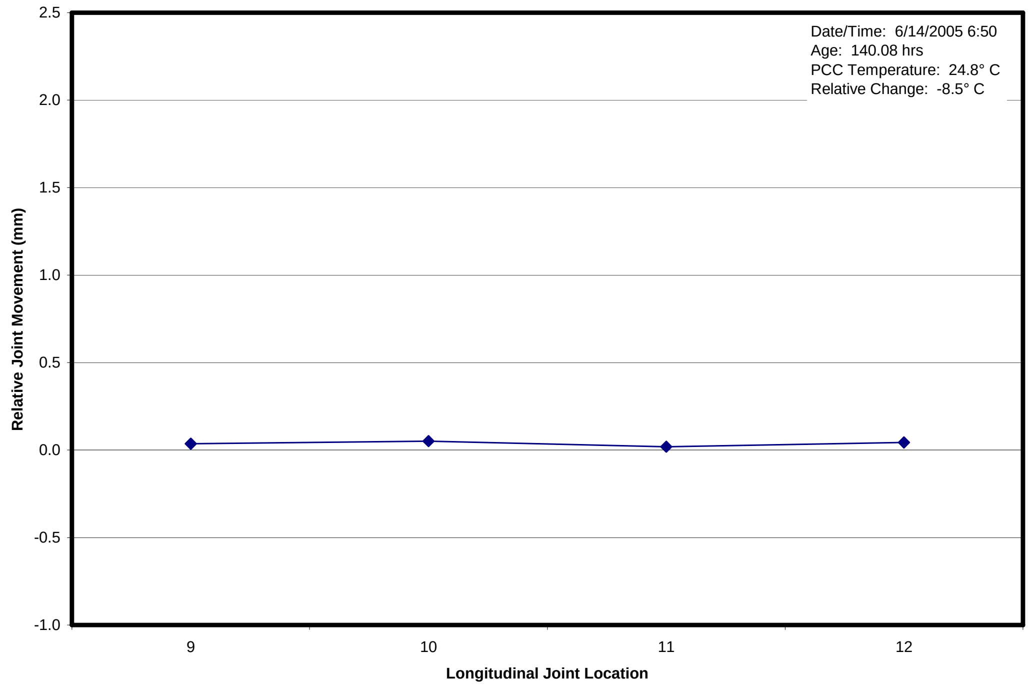


Figure E.23. Longitudinal joint relative opening

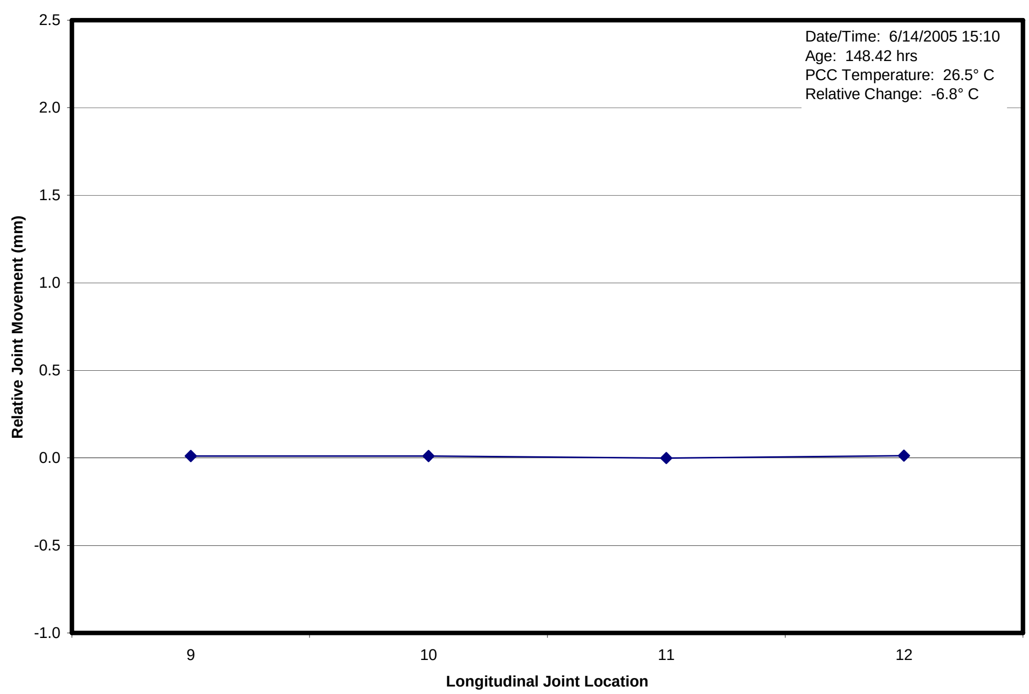


Figure E.24. Longitudinal joint relative opening

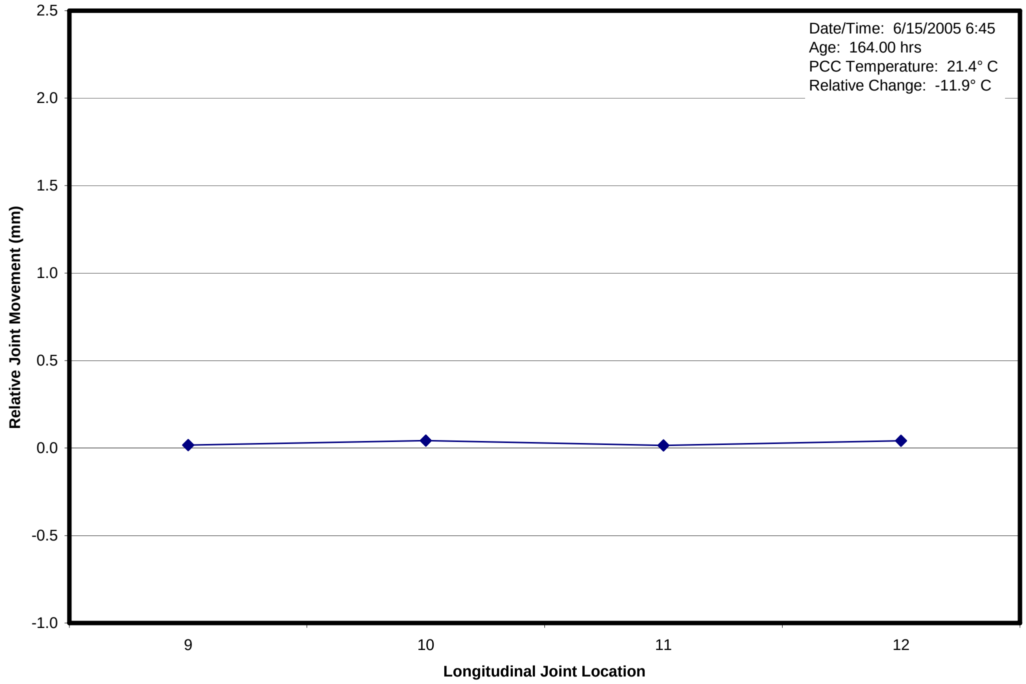


Figure E.25. Longitudinal joint relative opening

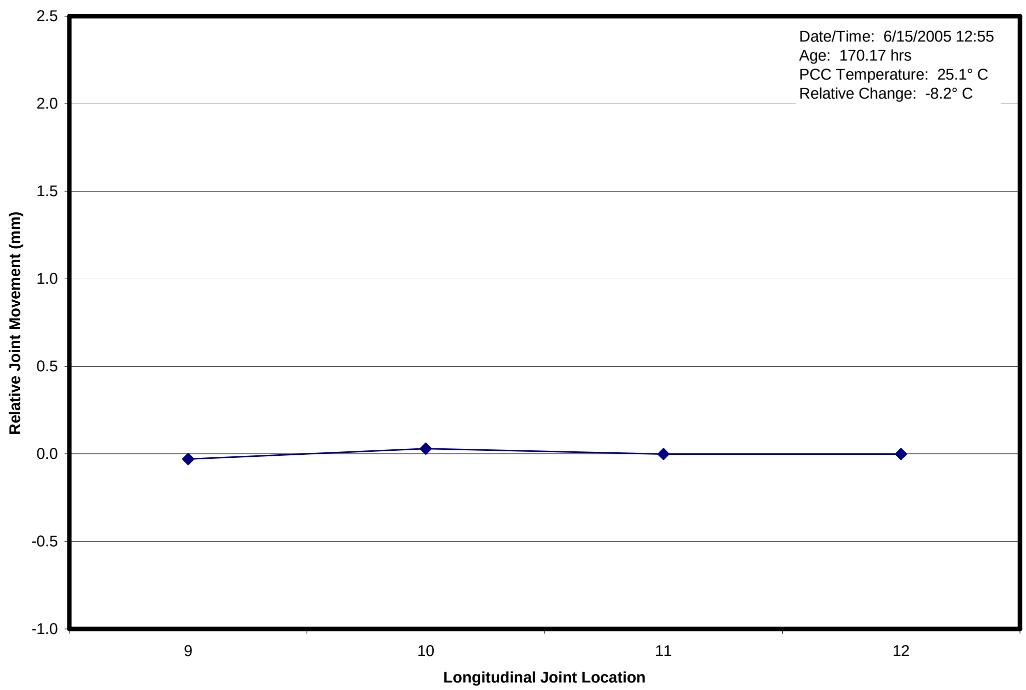


Figure E.26. Longitudinal joint relative opening

Table E.1. Level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1643	6/10/2005 16:43	54.00	33.5	29.4	110.8	250.7	2.65
11JN0645	6/11/2005 6:45	68.00	25.1	19.5	106.2	230.7	2.79
11JN1324	6/11/2005 13:24	74.67	30.5	28.2	103.7	234.8	2.76
12JN0744	6/12/2005 7:44	93.00	26.0	21.6	112.7	231.3	2.79
12JN1438	6/12/2005 14:38	99.92	33.1	29.1	112.6	241.0	2.72
13JN0958	6/13/2005 9:58	119.25	26.5	23.4	101.8	202.0	3.00
13JN1435	6/13/2005 14:35	123.83	31.4	27.3	106.6	223.1	2.85
14JN0642	6/14/2005 6:42	139.92	24.8	18.8	111.6	222.3	2.85
14JN1449	6/14/2005 14:49	148.08	26.2	22.7	107.1	228.9	2.81
15JN0633	6/15/2005 6:33	163.83	21.4	17.6	106.4	232.7	2.78
15JN1244	6/15/2005 12:44	170.00	25.0	22.5	96.6	220.0	2.87

Table E.2. Level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1651	6/10/2005 16:51	54.08	33.4	29.4	75.1	167.0	3.28
11JN0652	6/11/2005 6:52	68.08	25.1	19.5	71.3	166.3	3.29
11JN1332	6/11/2005 13:32	74.75	30.8	28.2	68.0	155.1	3.38
12JN0752	6/12/2005 7:52	93.08	26.1	21.6	63.3	147.4	3.45
12JN1446	6/12/2005 14:46	100.00	33.2	29.1	65.6	150.8	3.42
13JN0906	6/13/2005 9:06	118.33	25.9	22.4	72.0	168.1	3.27
13JN1443	6/13/2005 14:43	124.00	31.6	26.9	65.9	140.1	3.51
14JN0650	6/14/2005 6:50	140.08	24.8	18.8	67.4	160.3	3.34
14JN1456	6/14/2005 14:56	148.17	26.4	22.7	64.7	151.8	3.41
15JN0640	6/15/2005 6:40	163.92	21.4	17.9	71.4	161.5	3.33
15JN1255	6/15/2005 12:55	170.17	25.1	22.4	67.6	154.3	3.39

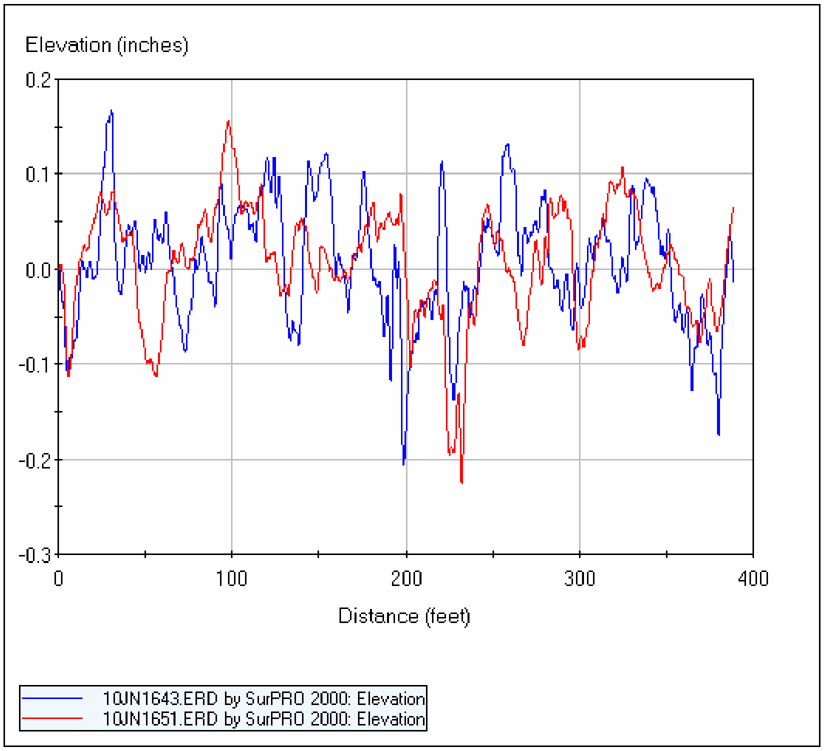


Figure E.27. Level A profile – June 10, 2005 afternoon

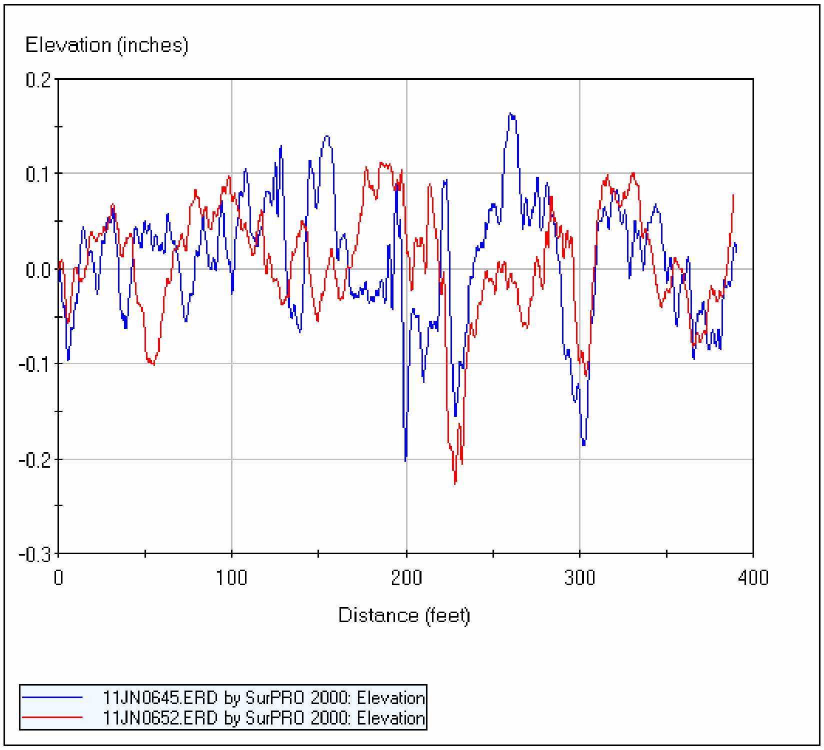


Figure E.28. Level A profile – June 11, 2005 morning

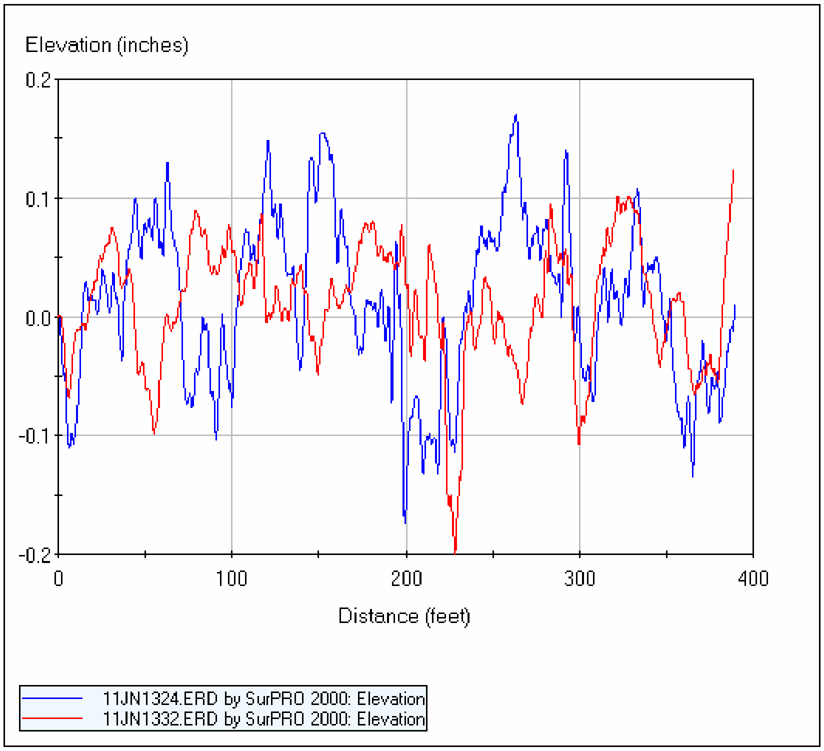


Figure E.29. Level A profile – June 11, 2005 afternoon

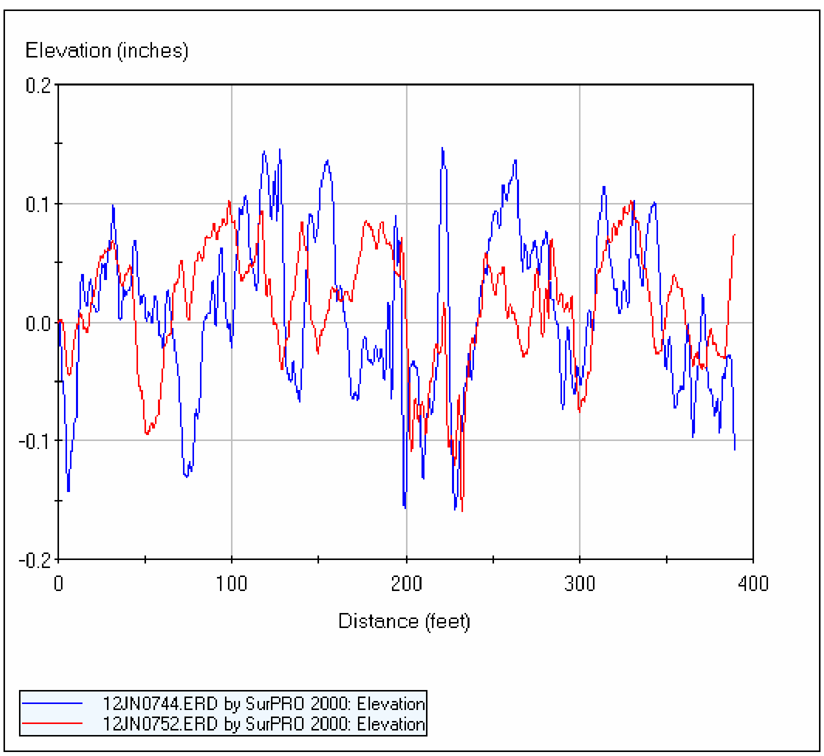


Figure E.30. Level A profile – June 12, 2005 morning

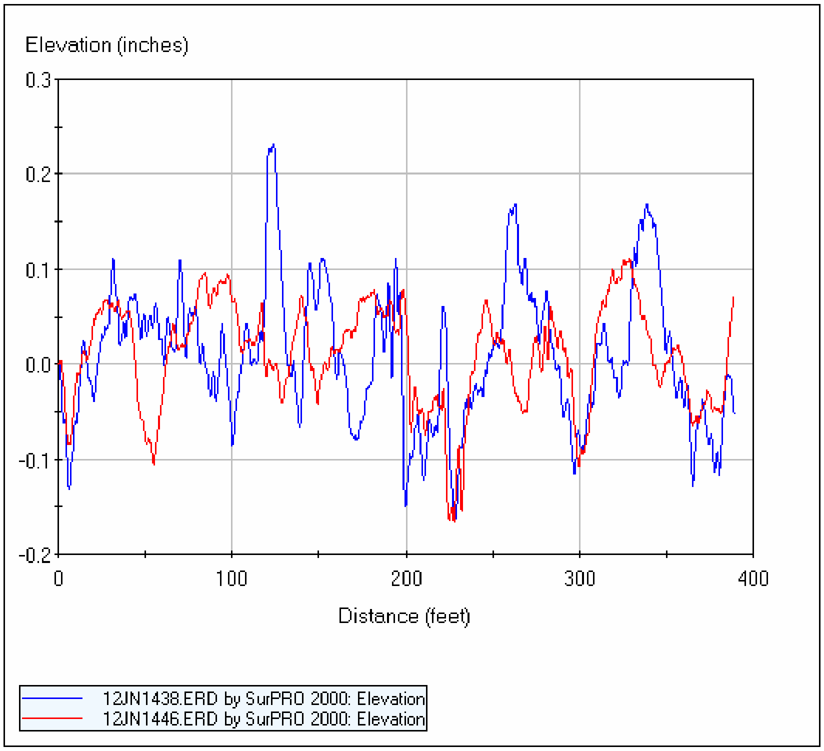


Figure E.31. Level A profile – June 12, 2005 afternoon

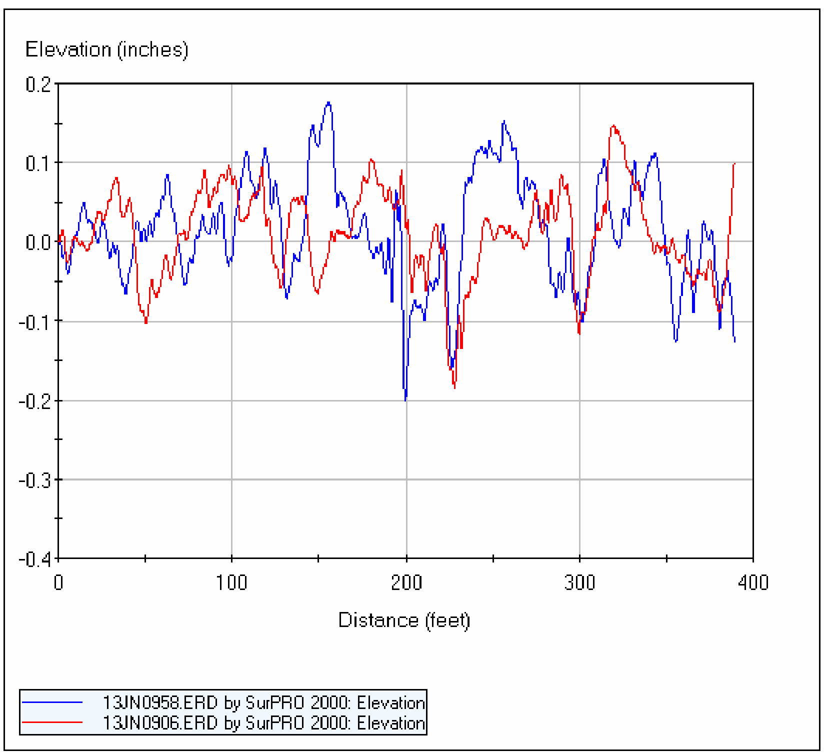


Figure E.32. Level A profile – June 13, 2005 morning

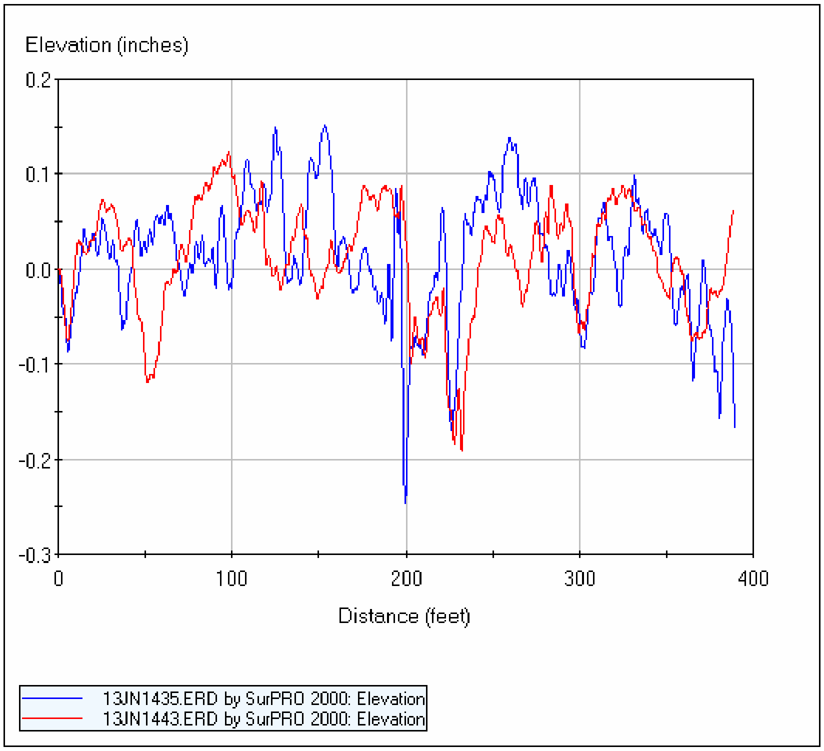


Figure E.33. Level A profile – June 13, 2005 afternoon

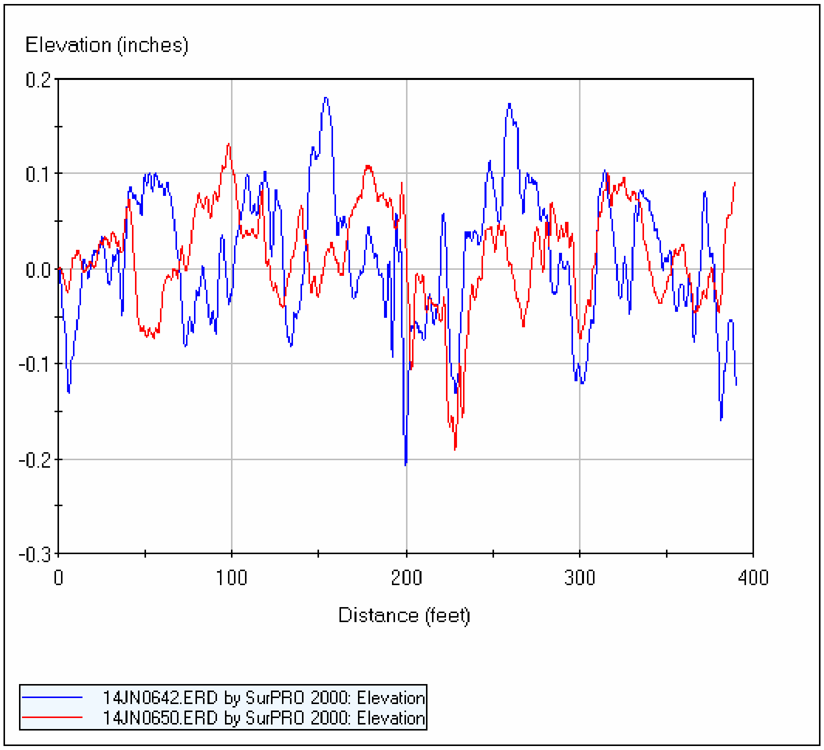


Figure E.34. Level A profile – June 14, 2005 morning

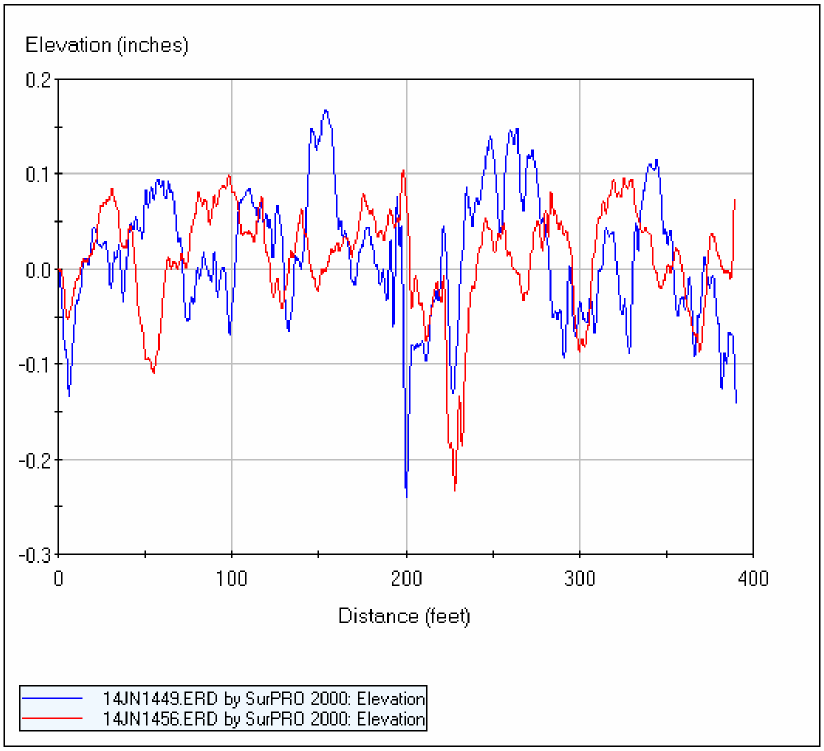


Figure E.35. Level A profile – June 14, 2005 afternoon

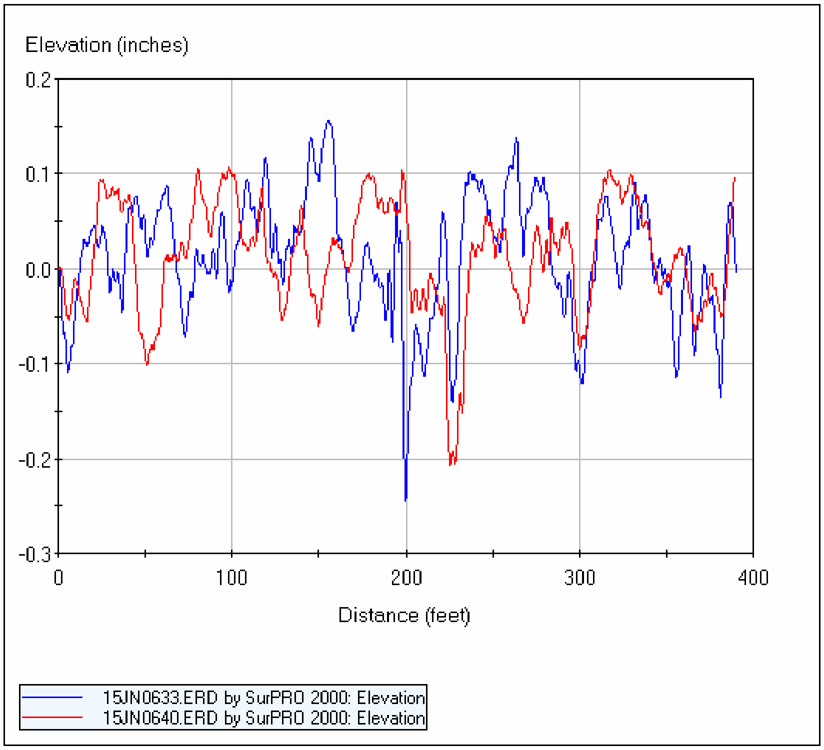


Figure E.36. Level A profile – June 15, 2005 morning

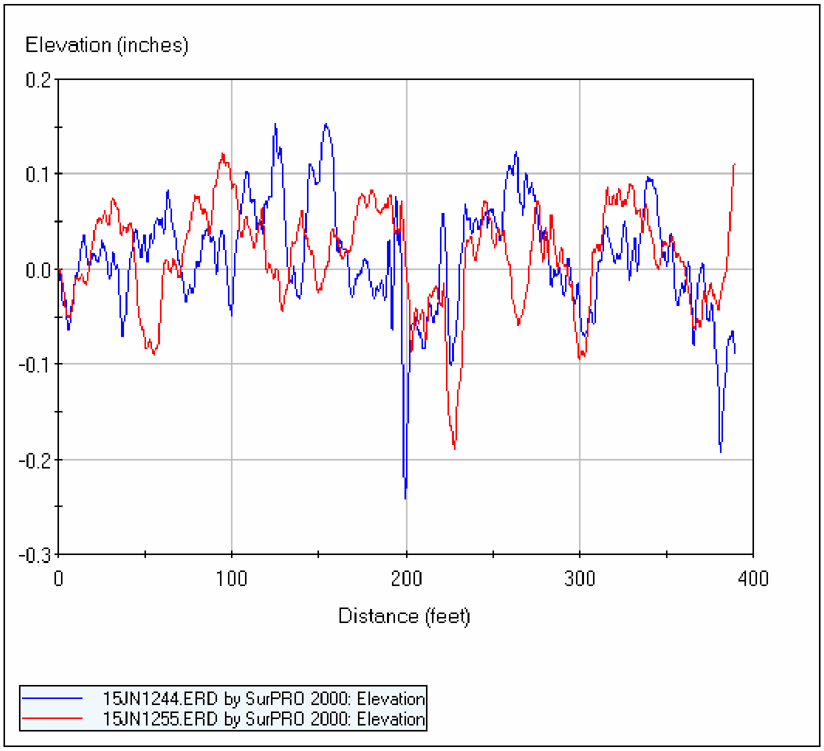


Figure E.37. Level A profile – June 15, 2005 afternoon

Table E.3. Level B profile summary (2 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1659	6/10/2005 16:59	54.25	33.5	29.2	86.6	172.4	3.24
11JN1340	6/11/2005 13:40	74.92	30.9	28.7	84.2	161.4	3.33
12JN1454	6/12/2005 14:54	100.17	33.4	29.2	83.0	165.9	3.29
13JN0913	6/13/2005 9:13	118.50	25.9	22.8	86.4	172.6	3.23
13JN1450	6/13/2005 14:50	124.08	31.6	26.9	89.1	173.0	3.23
14JN0656	6/14/2005 6:56	140.17	24.8	18.9	86.6	169.2	3.26
14JN1504	6/14/2005 15:04	148.33	26.5	22.7	85.7	162.3	3.32
15JN0648	6/15/2005 6:48	164.08	21.4	17.9	84.0	166.2	3.29
15JN1305	6/15/2005 13:05	170.33	25.3	22.4	83.8	174.1	3.22

Table E.4. Level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1706	6/10/2005 17:06	54.33	33.5	29.2	68.3	163.6	3.31
11JN1347	6/11/2005 13:47	75.08	31.1	28.7	66.5	148.3	3.44
12JN1501	6/12/2005 15:01	100.25	33.5	29.2	68.3	158.9	3.35
13JN0920	6/13/2005 9:20	118.58	25.9	22.8	69.1	169.6	3.26
13JN1457	6/13/2005 14:57	124.25	31.7	27.3	77.9	174.6	3.22
14JN0703	6/14/2005 7:03	140.33	24.7	18.9	69.3	171.1	3.25
14JN1511	6/14/2005 15:11	148.42	26.5	23.4	67.9	155.7	3.37
15JN0654	6/15/2005 6:54	164.17	21.4	18.2	67.8	152.9	3.4
15JN1312	6/15/2005 13:12	170.50	25.4	22.2	69.9	154.4	3.39

Table E.5. Level B profile summary (3 ft. from longitudinal joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1714	6/10/2005 17:14	54.50	33.6	28.9	79.5	173.9	3.22
11JN1355	6/11/2005 13:55	75.17	31.1	28.8	75.1	162.7	3.32
12JN1508	6/12/2005 15:08	100.42	33.5	29.2	70.3	182.2	3.16
13JN0928	6/13/2005 9:28	118.75	26.1	22.9	71.9	144.1	3.48
13JN1503	6/13/2005 15:03	124.33	31.8	27.3	73.7	167.1	3.28
14JN0710	6/14/2005 7:10	140.42	24.8	18.9	79.9	173.1	3.23
14JN1518	6/14/2005 15:18	148.58	26.6	23.4	75.2	165.8	3.29
15JN0701	6/15/2005 7:01	164.25	21.4	18.2	82.6	173.0	3.23

Table E.6. Level B profile summary (1 ft. from longitudinal joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
10JN1721	6/10/2005 17:21	54.58	33.6	28.9	93.3	210.9	2.94
11JN1404	6/11/2005 14:04	75.33	31.3	28.8	89.2	204.8	2.98
12JN1515	6/12/2005 15:15	100.50	33.6	29.2	93.0	233.3	2.77
13JN0935	6/13/2005 9:35	118.83	26.1	22.9	84.7	196.9	3.04
13JN1510	6/13/2005 15:10	124.42	31.8	26.7	90.9	211.8	2.93
14JN0718	6/14/2005 7:18	140.58	24.7	18.9	73.8	165.2	3.29
14JN1525	6/14/2005 15:25	148.67	26.9	23.3	85.2	184.8	3.14
15JN0708	6/15/2005 7:08	164.42	21.4	18.6	83.8	191.7	3.08

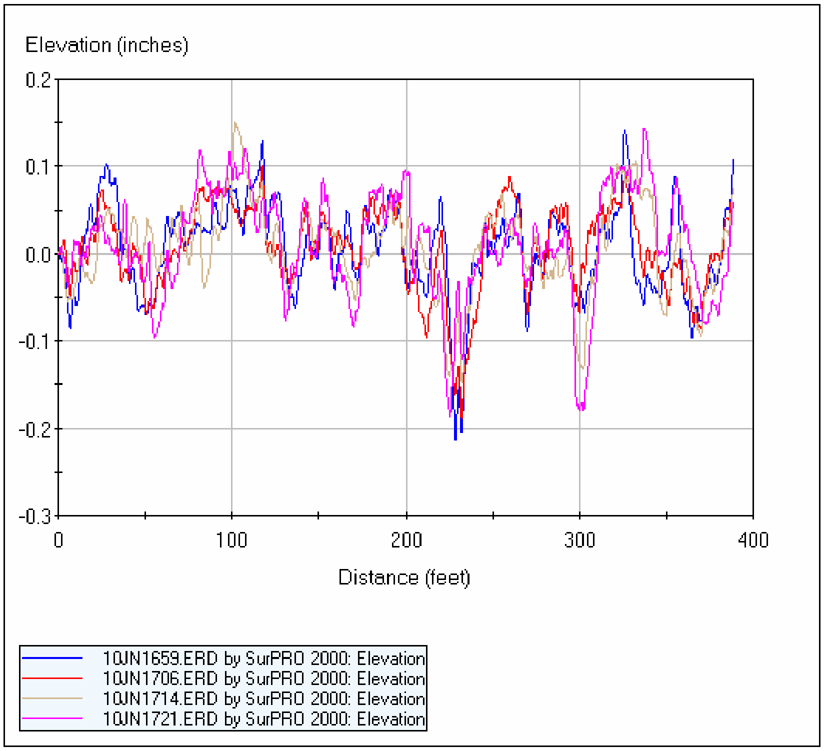


Figure E.38. Level B profile – June 10, 2005 afternoon

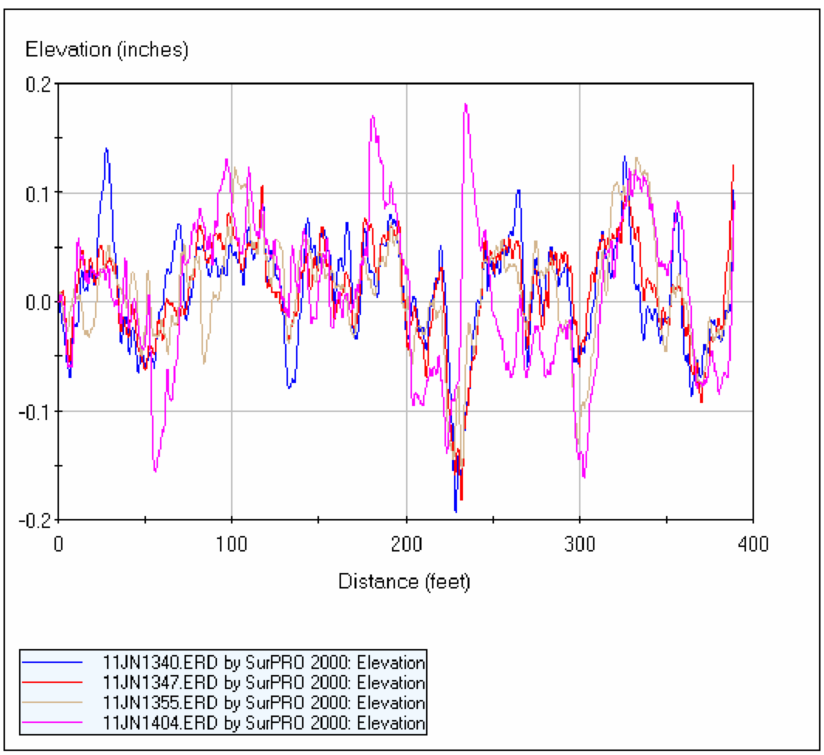


Figure E.39. Level B profile – June 11, 2005 afternoon

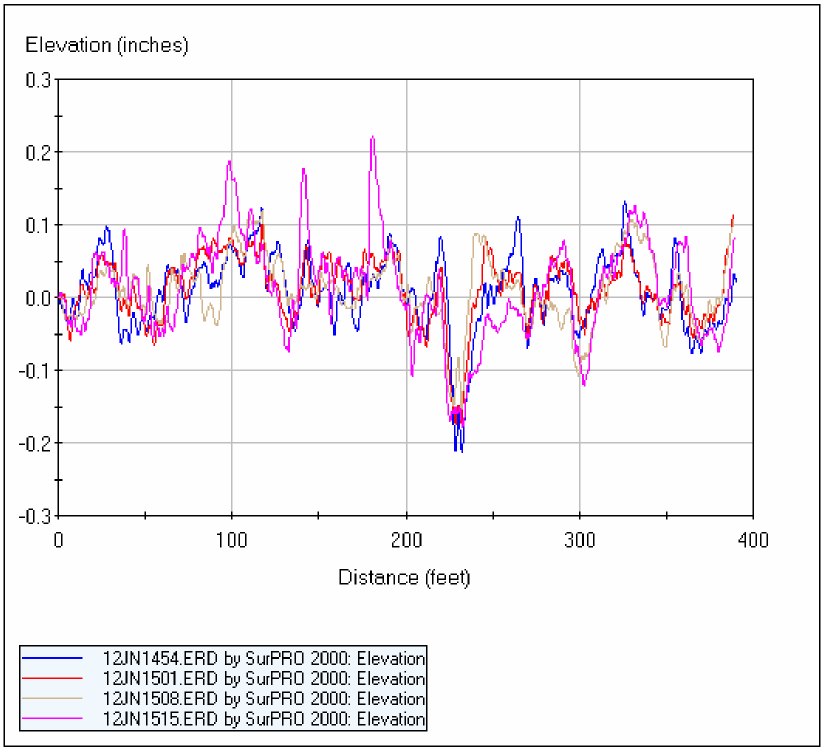


Figure E.40. Level B profile – June 12, 2005 afternoon

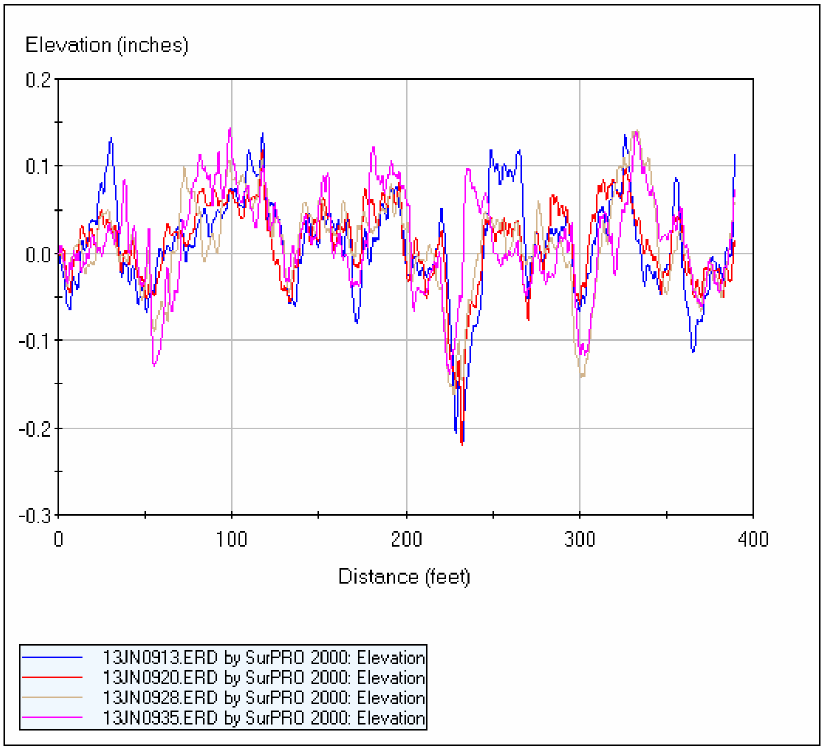


Figure E.41. Level B profile – June 13, 2005 morning

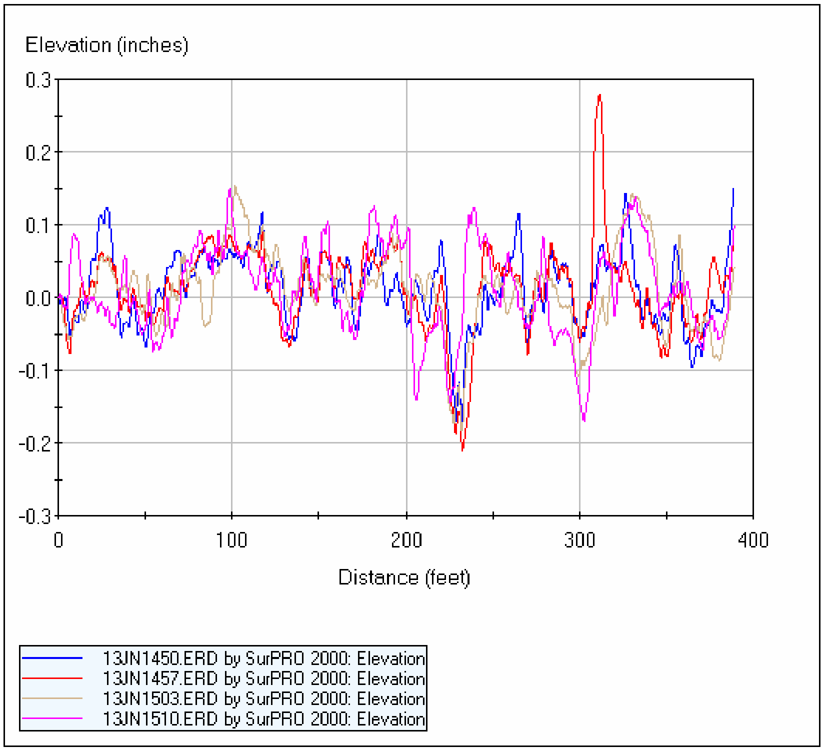


Figure E.42. Level B profile – June 13, 2005 afternoon

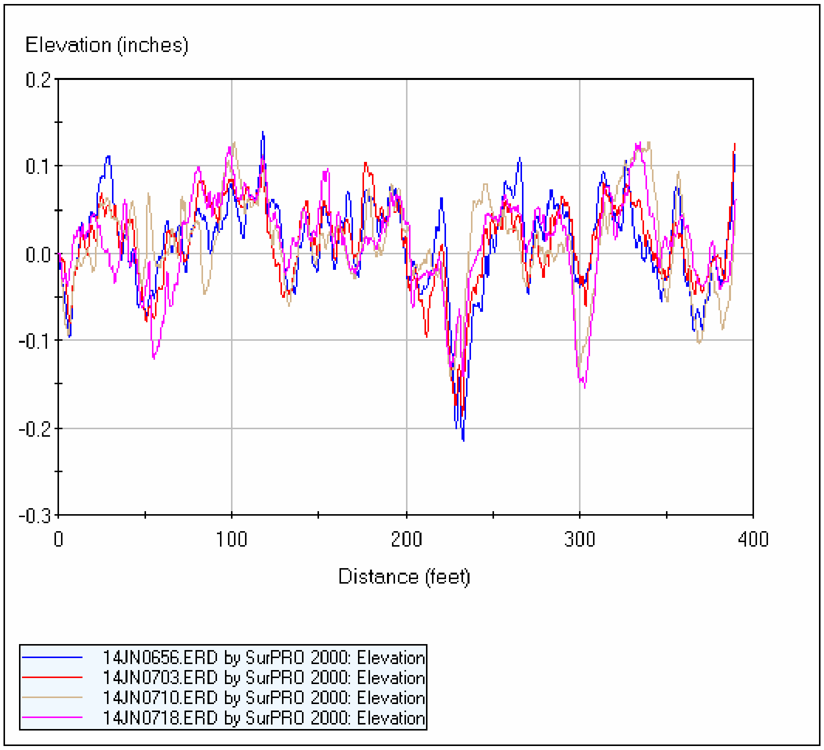


Figure E.43. Level B profile – June 14, 2005 morning

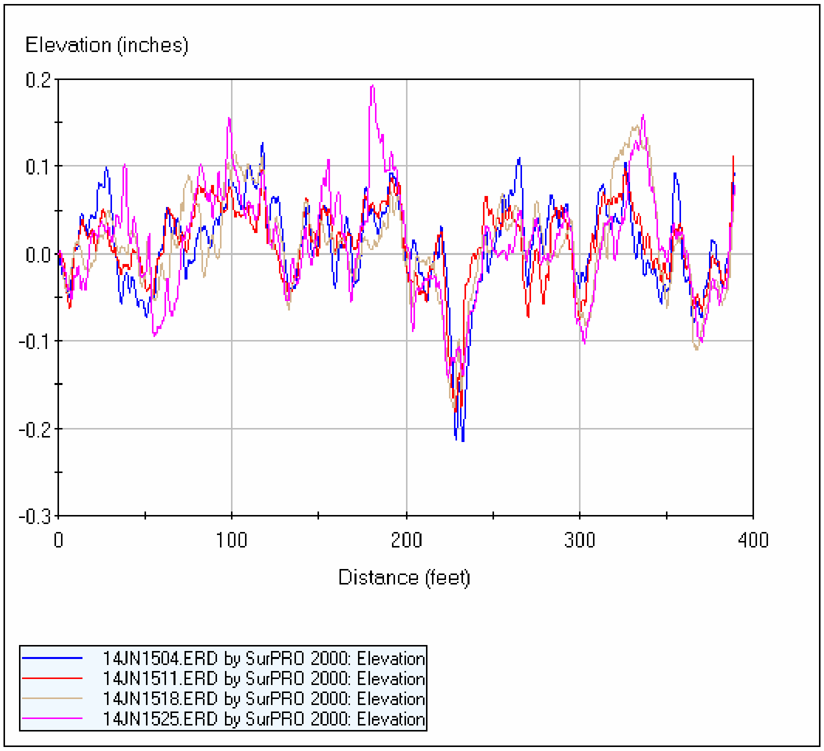


Figure E.44. Level B profile – June 14, 2005 afternoon

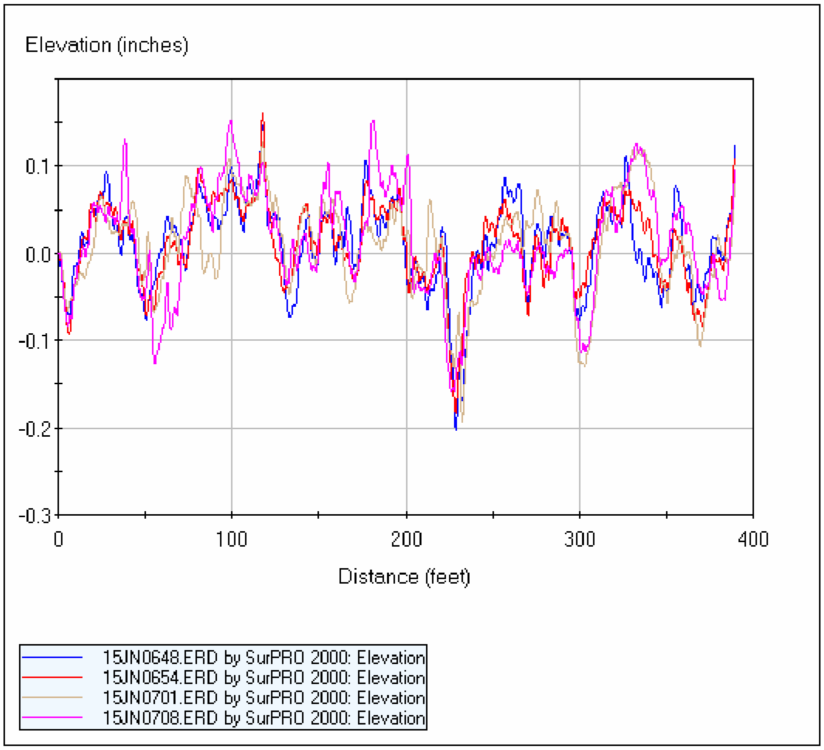


Figure E.45. Level B profile – June 15, 2005 morning

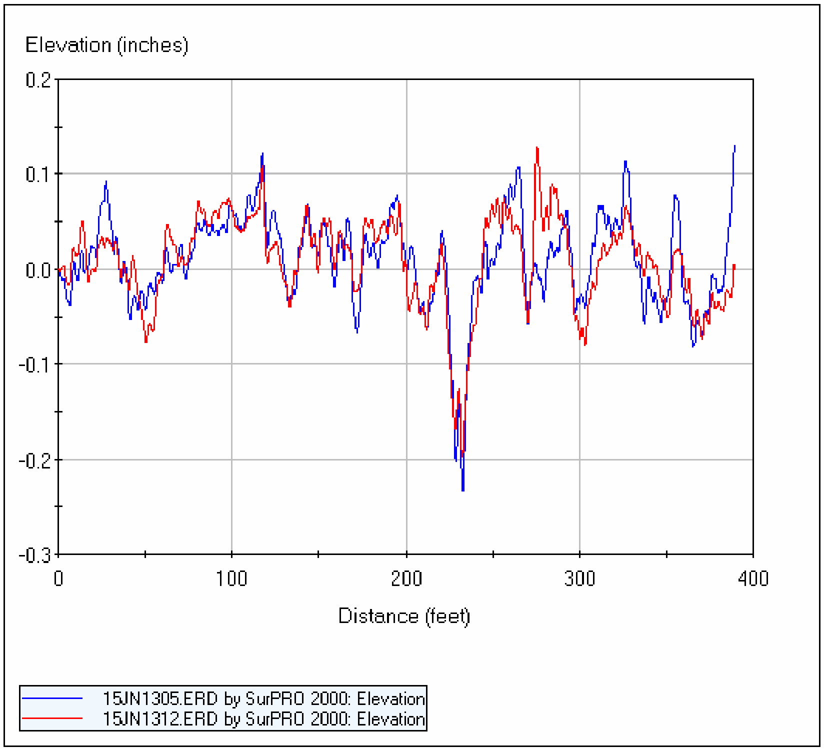


Figure E.46. Level B profile – June 15, 2005 afternoon

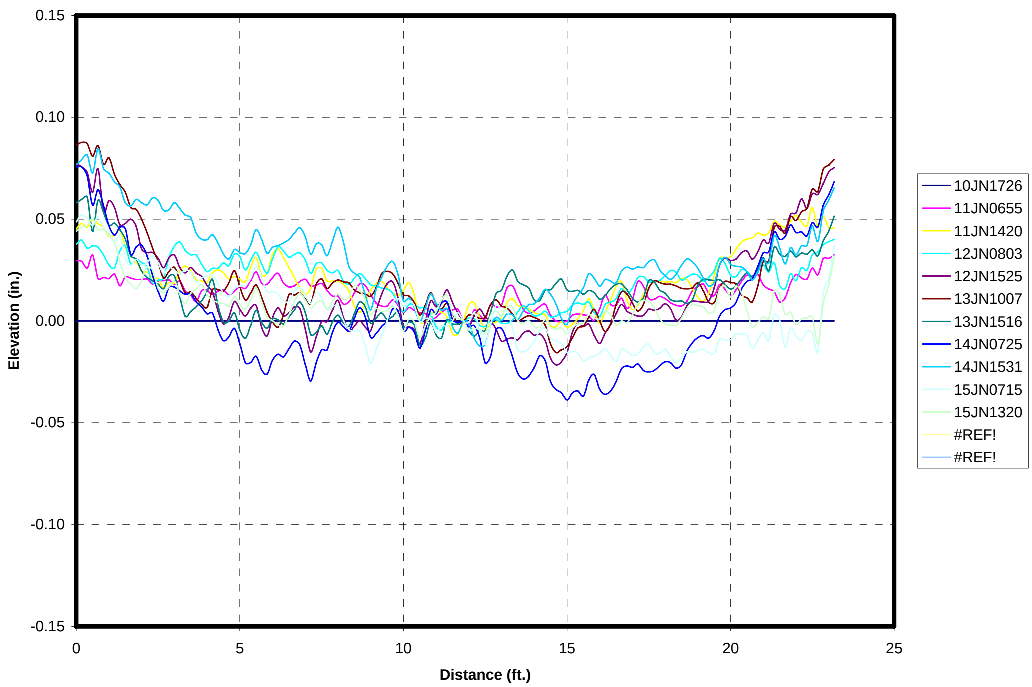


Figure E.47. Level C profiles path 1 – Slab 9

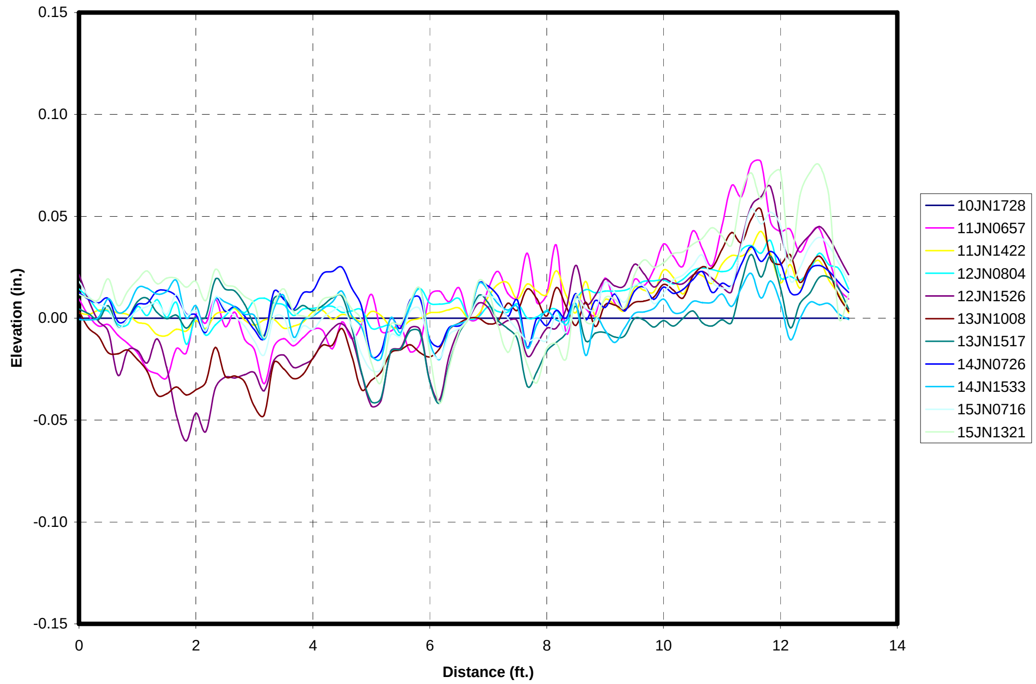


Figure E.48. Level C profiles path 2 – slab 9

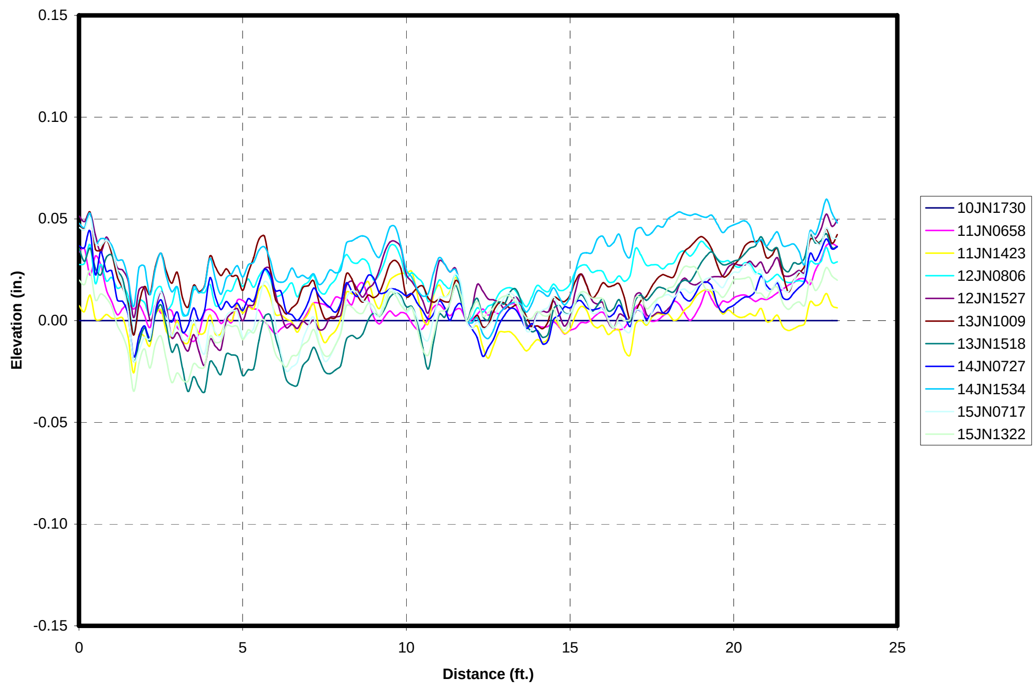


Figure E.49. Level C profiles path 3 – slab 9

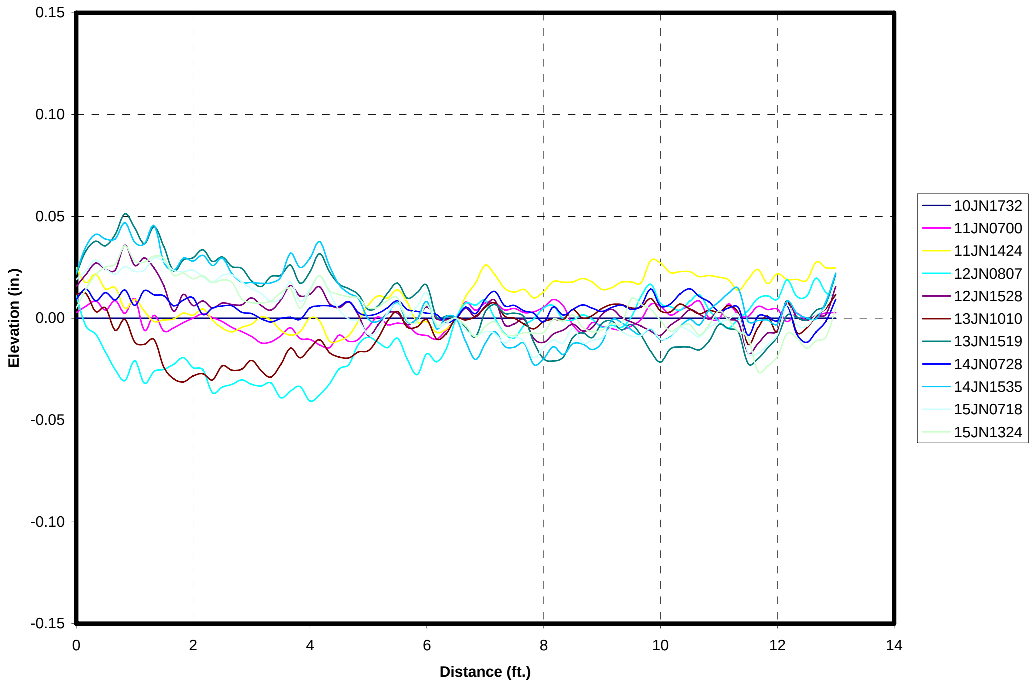


Figure E.50. Level C profiles path 4 – slab 9

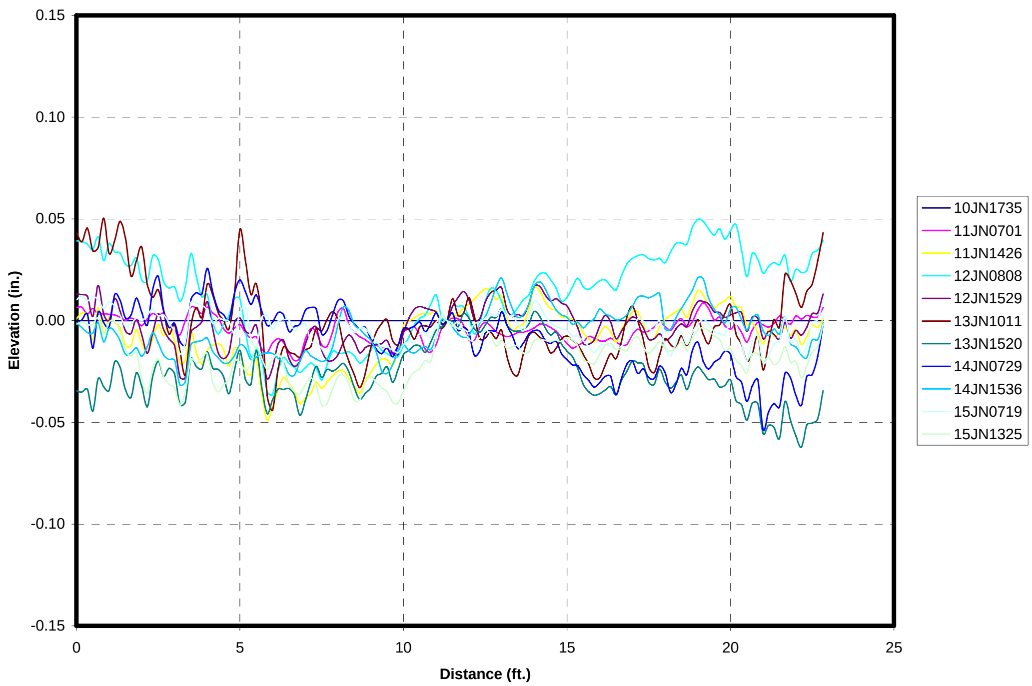


Figure E.51. Level C profiles path 1 – slab 10

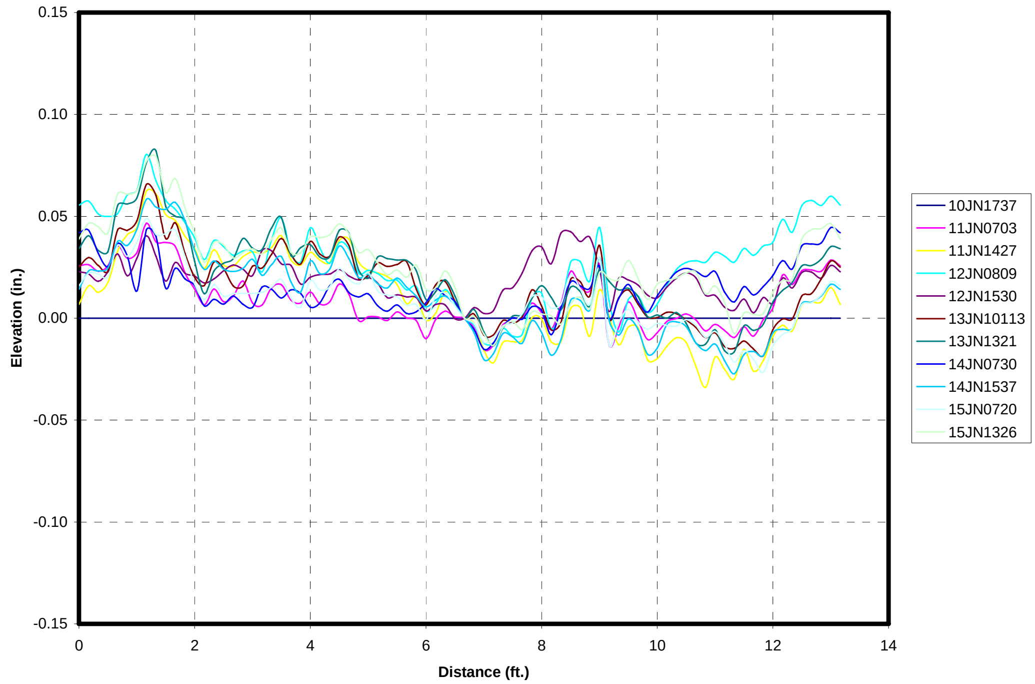


Figure E.52. Level C profiles path 2 – slab 10

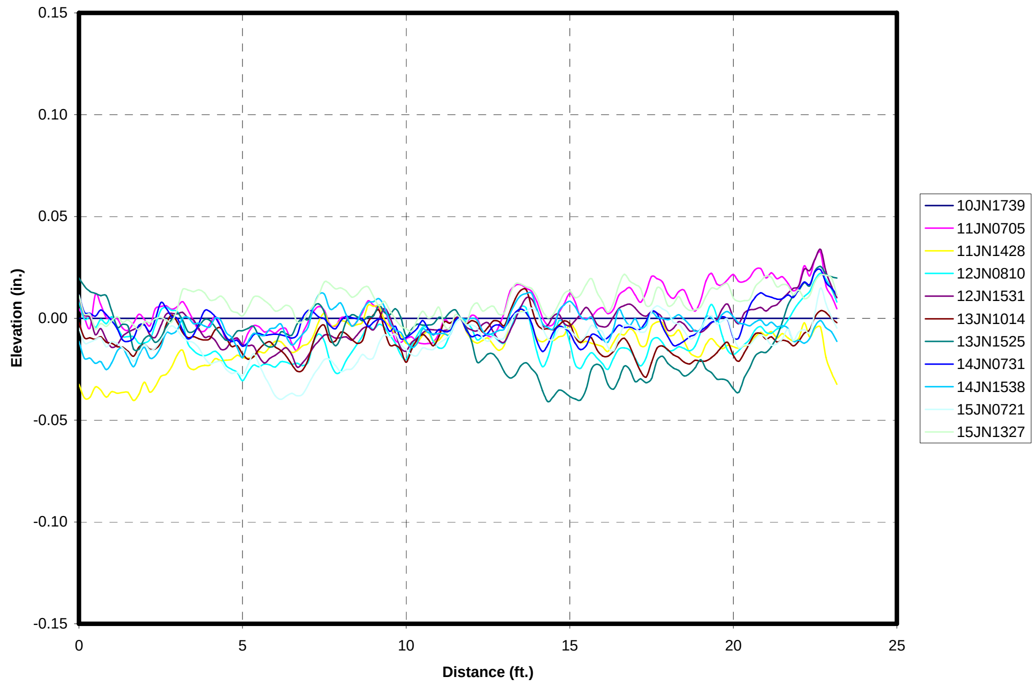


Figure E.53. Level C profiles path 3 – slab 10

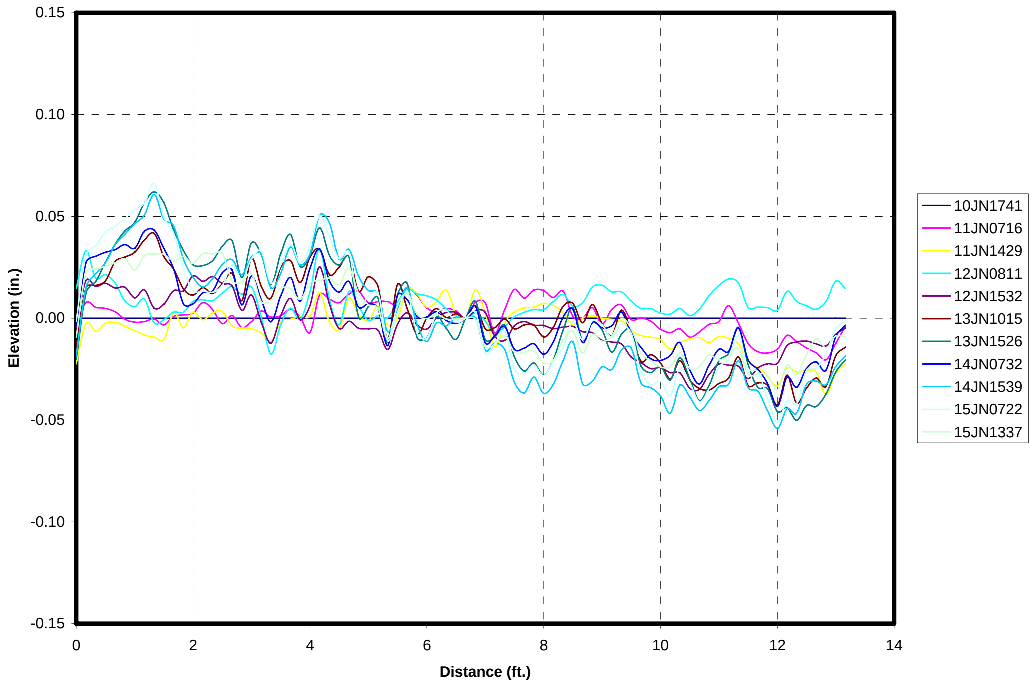


Figure E.54. Level C profiles path 4 – slab 10

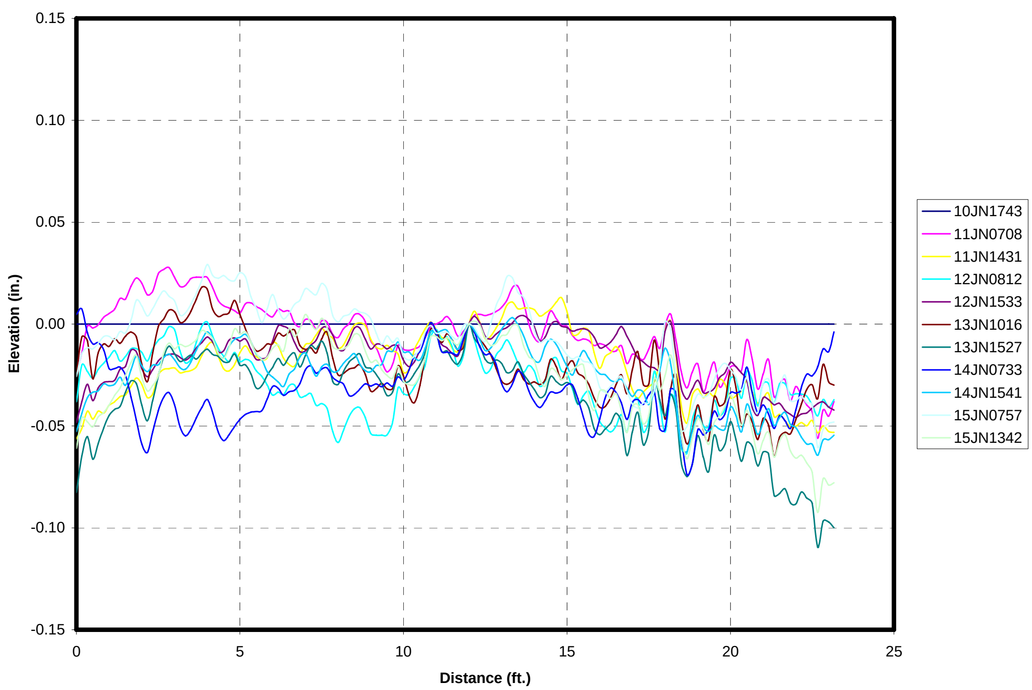


Figure E.55. Level C profiles path 1 – slab 11

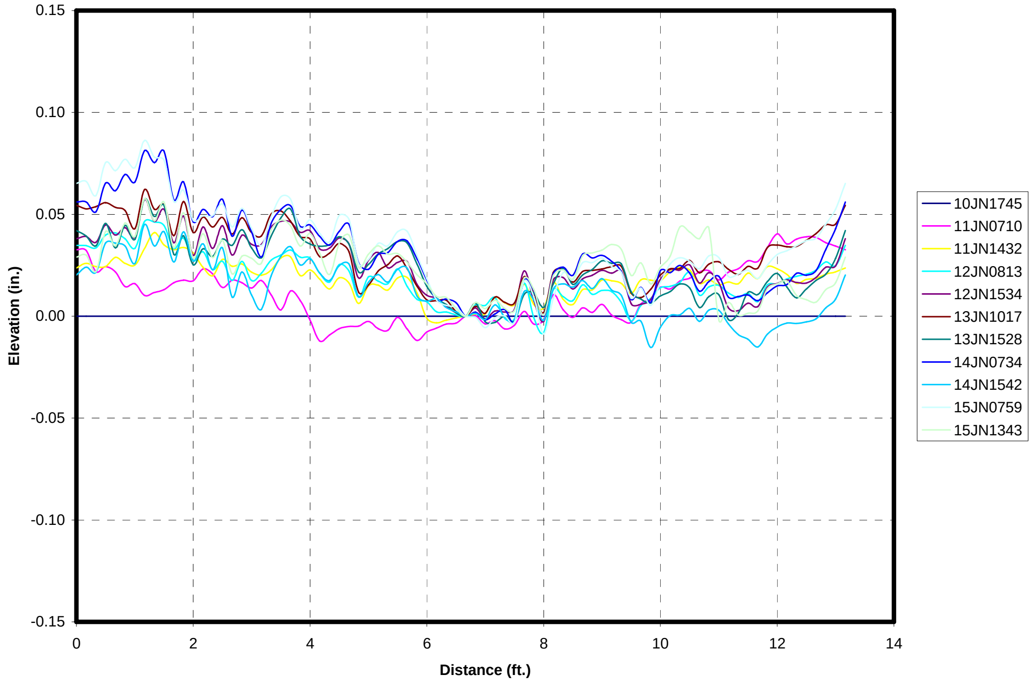


Figure E.56. Level C profiles path 2 – slab 11

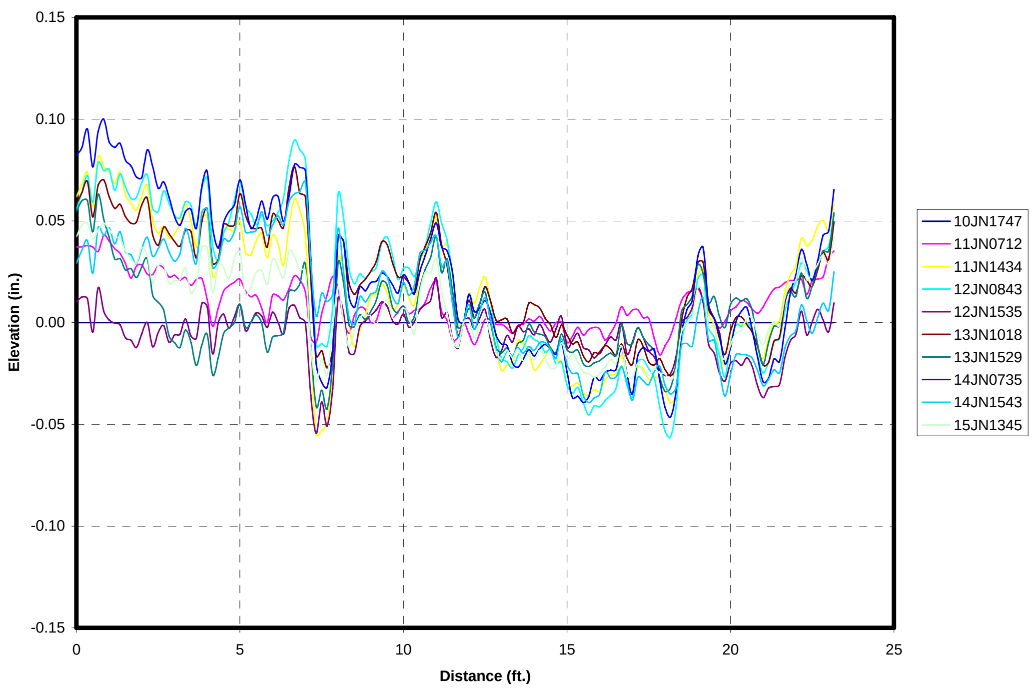


Figure E.57. Level C profiles path 3 – slab 11

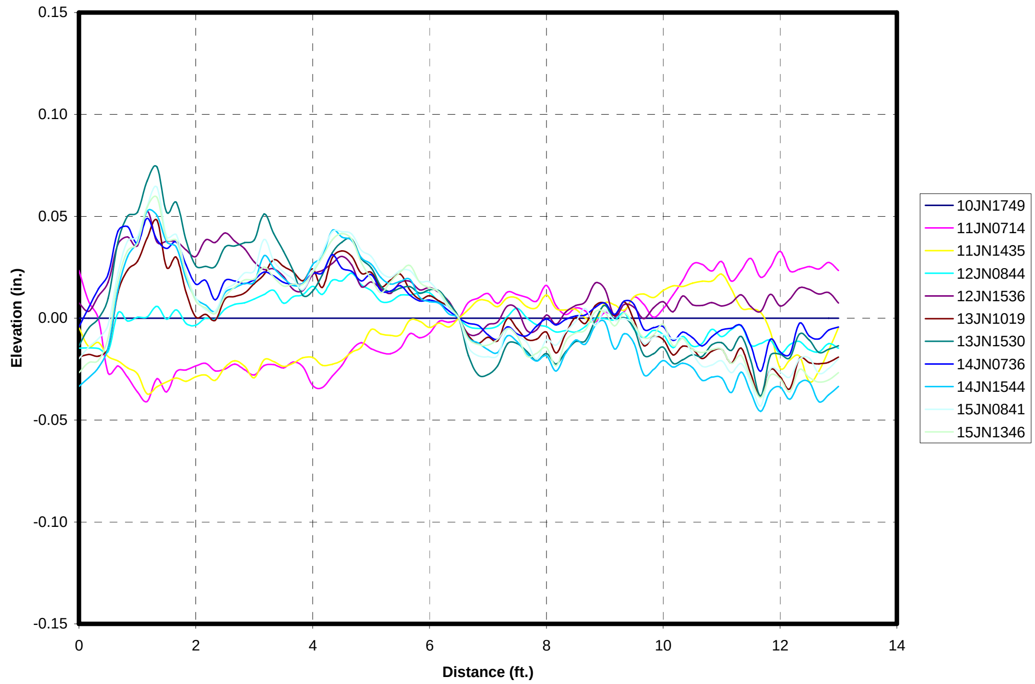


Figure E.58. Level C profiles path 4 – slab 11

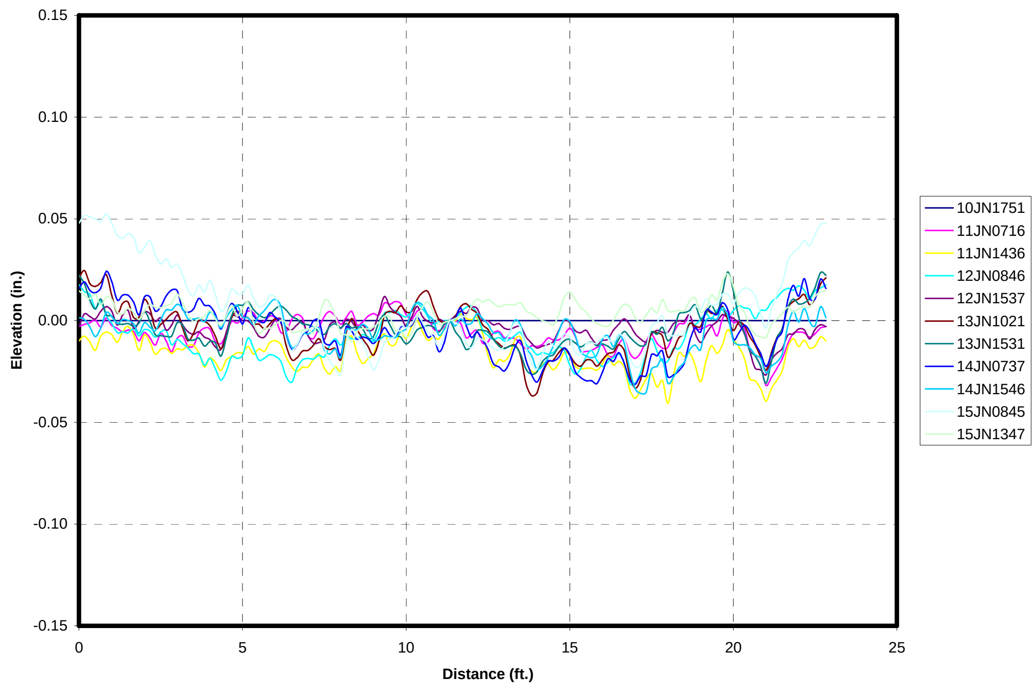


Figure E.59. Level C profiles path 1 – slab 12

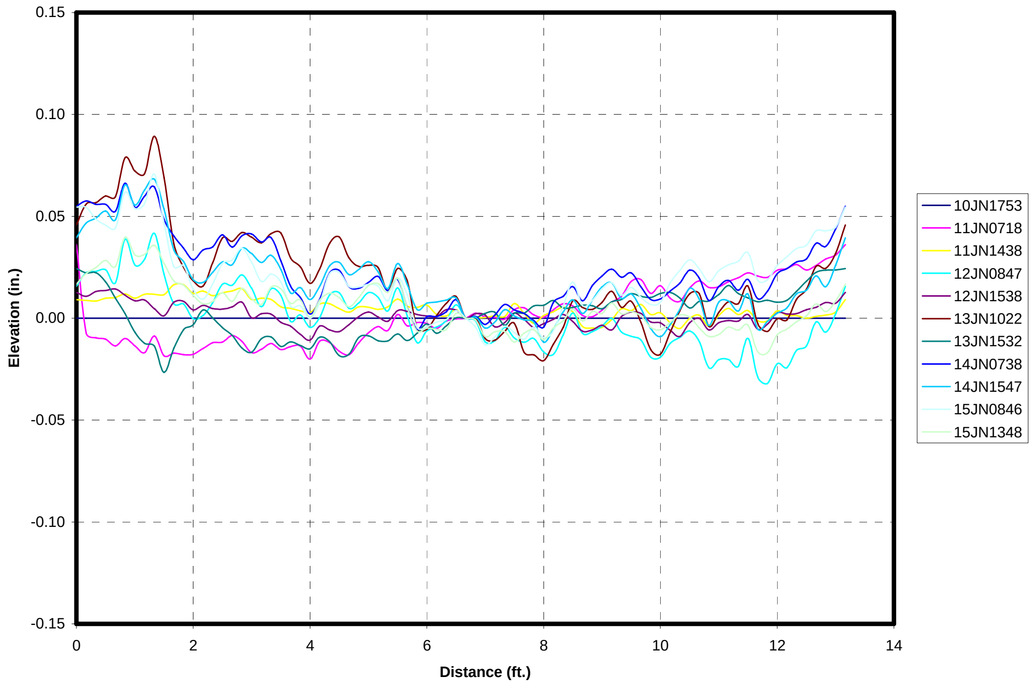


Figure E.60. Level C profiles path 2 – slab 12

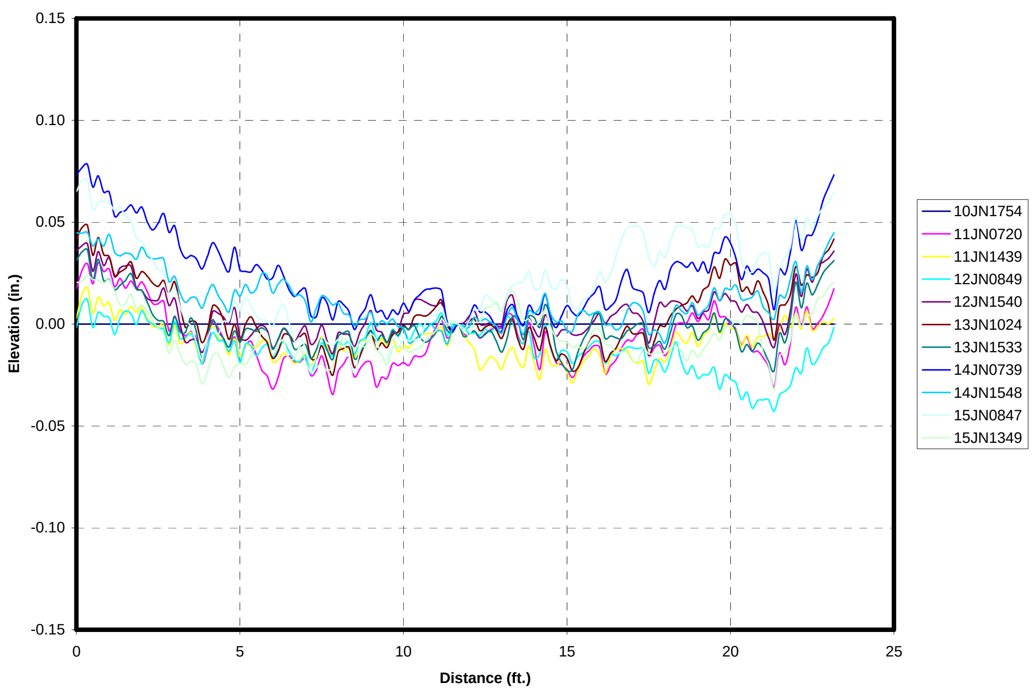


Figure E.61. Level C profiles path 3 – slab 12

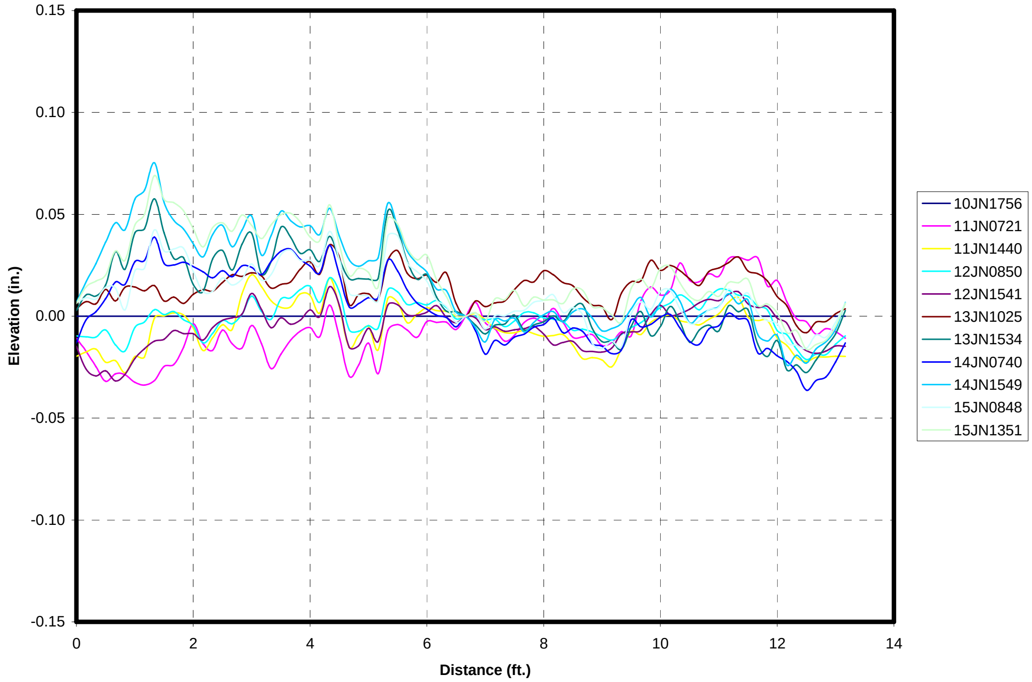


Figure E.62. Level C profiles path 4 – slab 12

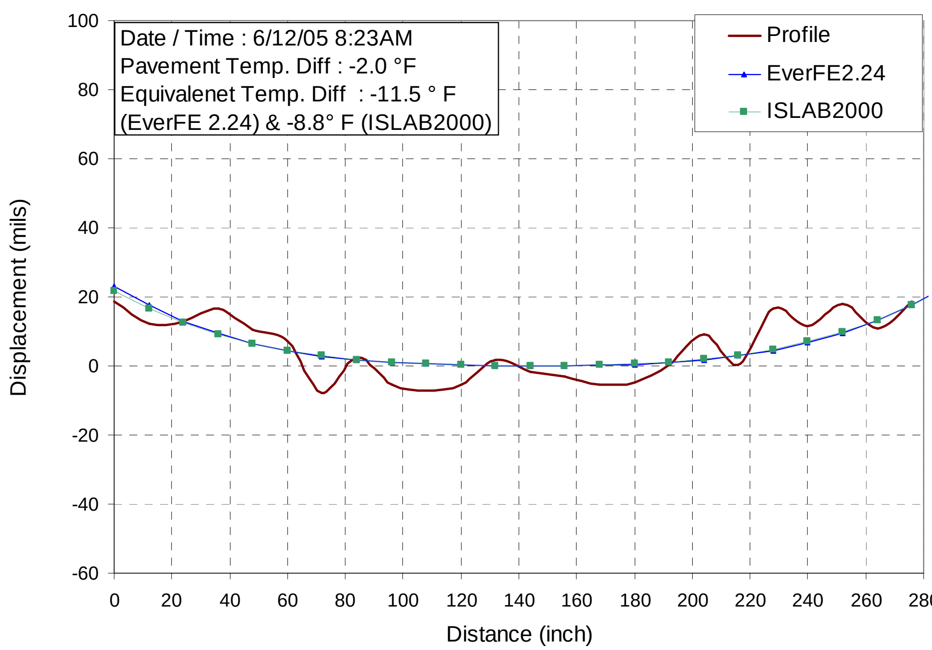


Figure E.63. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 12 morning

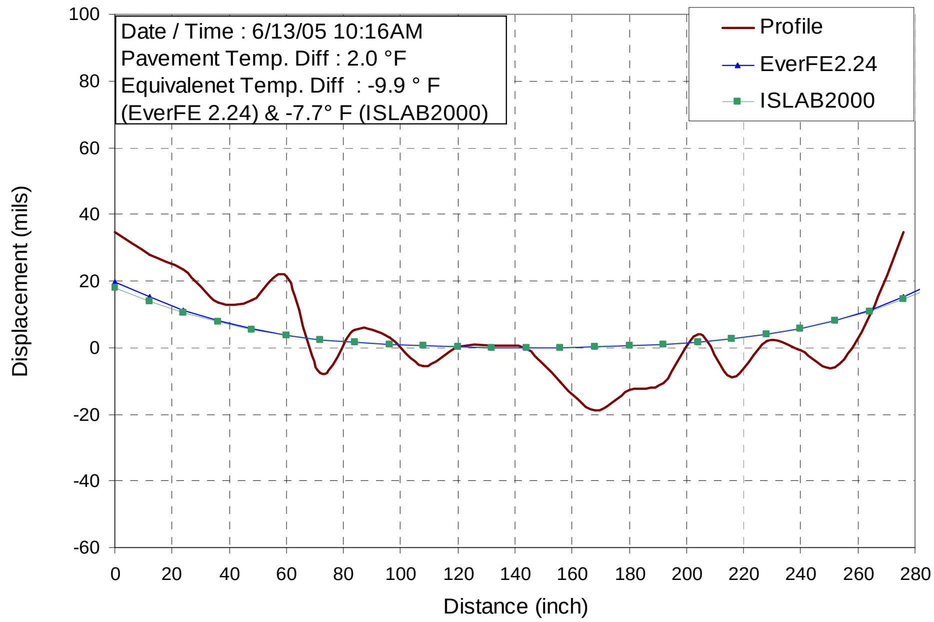


Figure E.64. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 13 morning

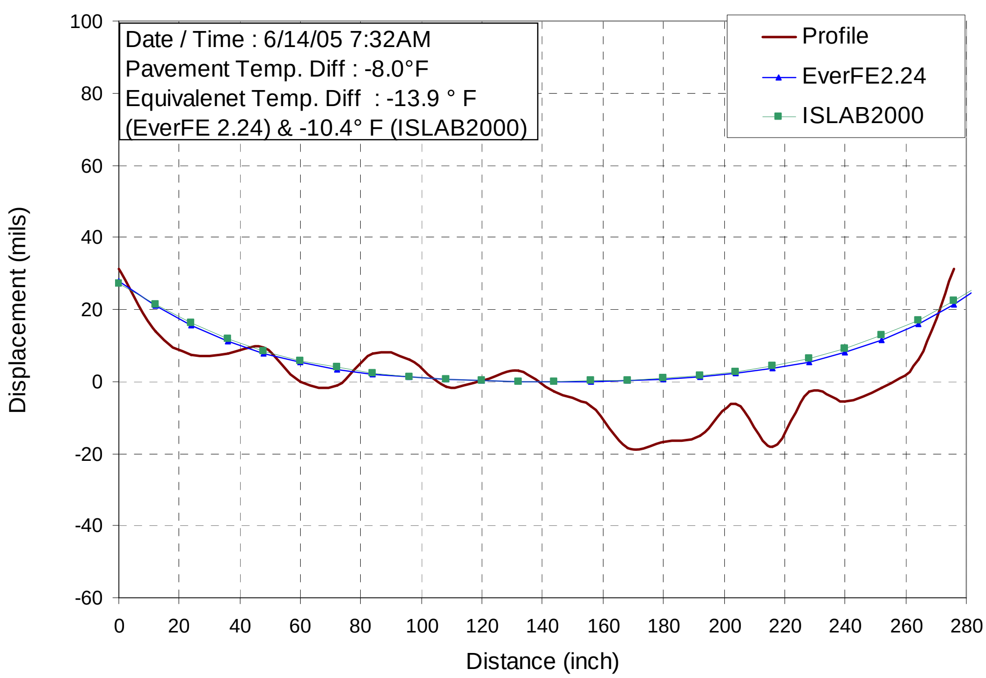


Figure E.65. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 14 morning

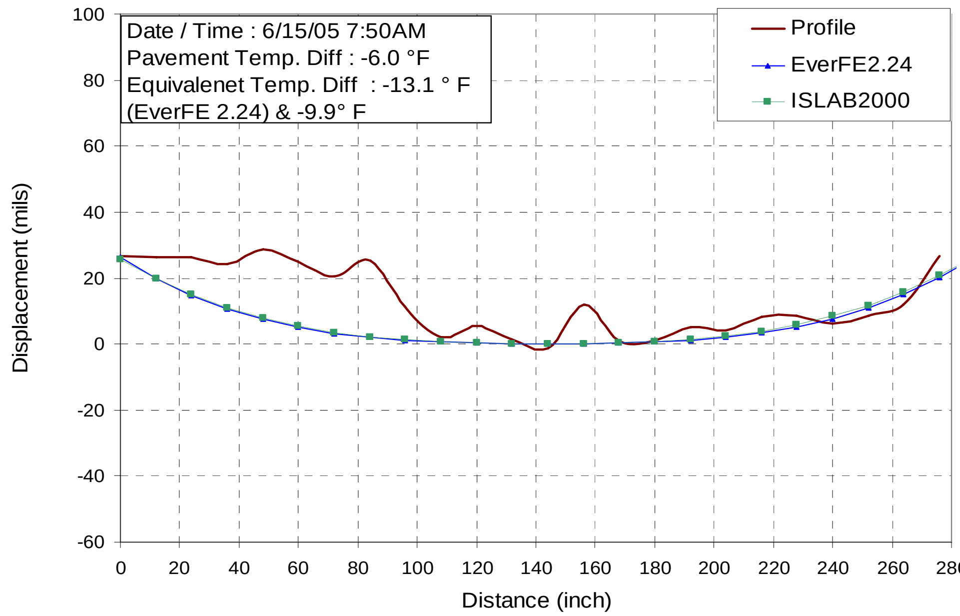


Figure E.66. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 15 morning

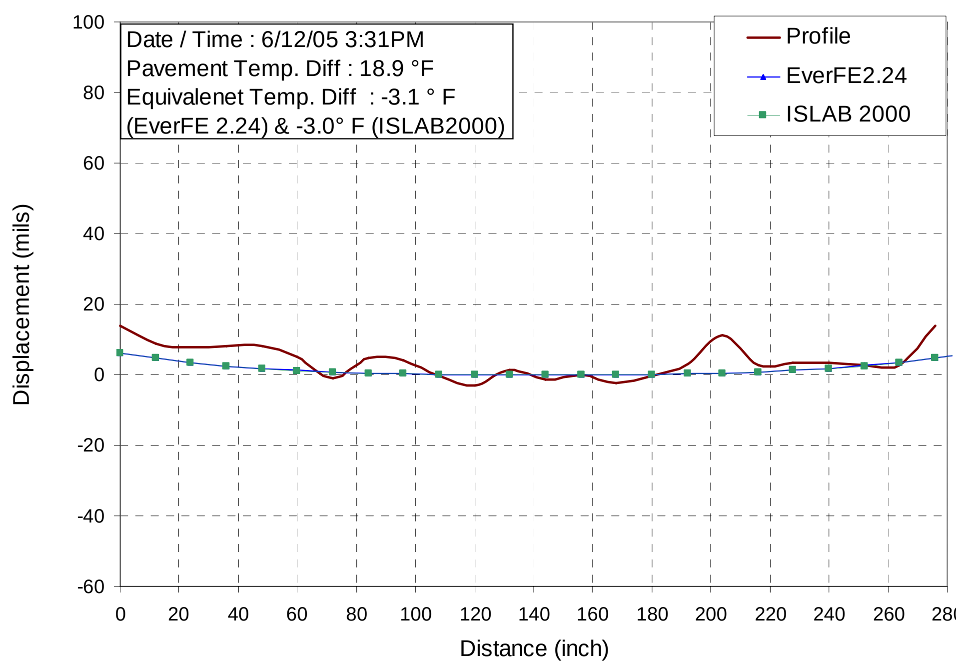


Figure E.67. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 12 afternoon

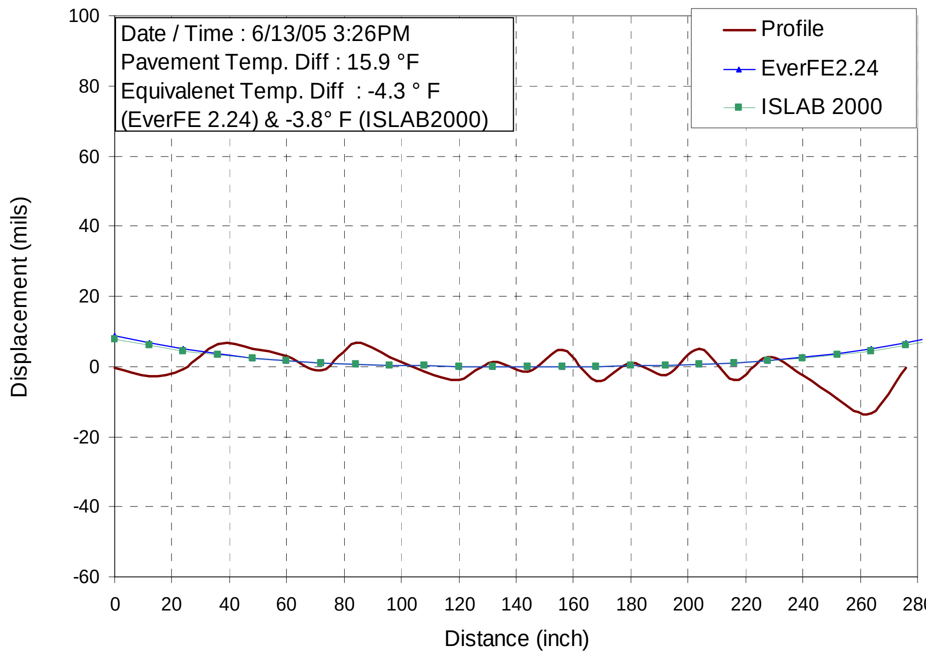


Figure E.68. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 13 afternoon

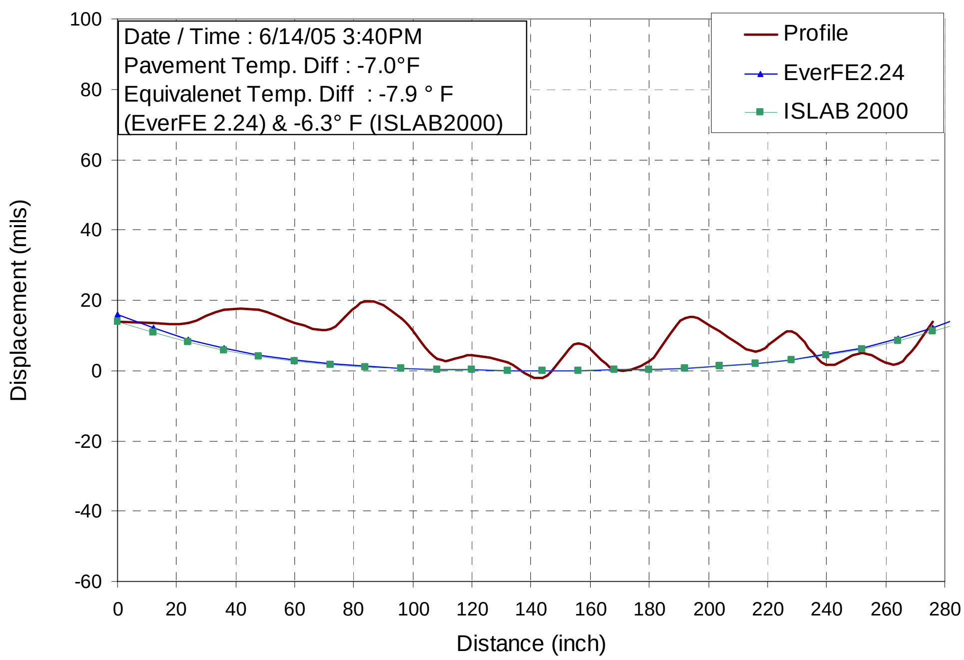


Figure E.69. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 14 afternoon

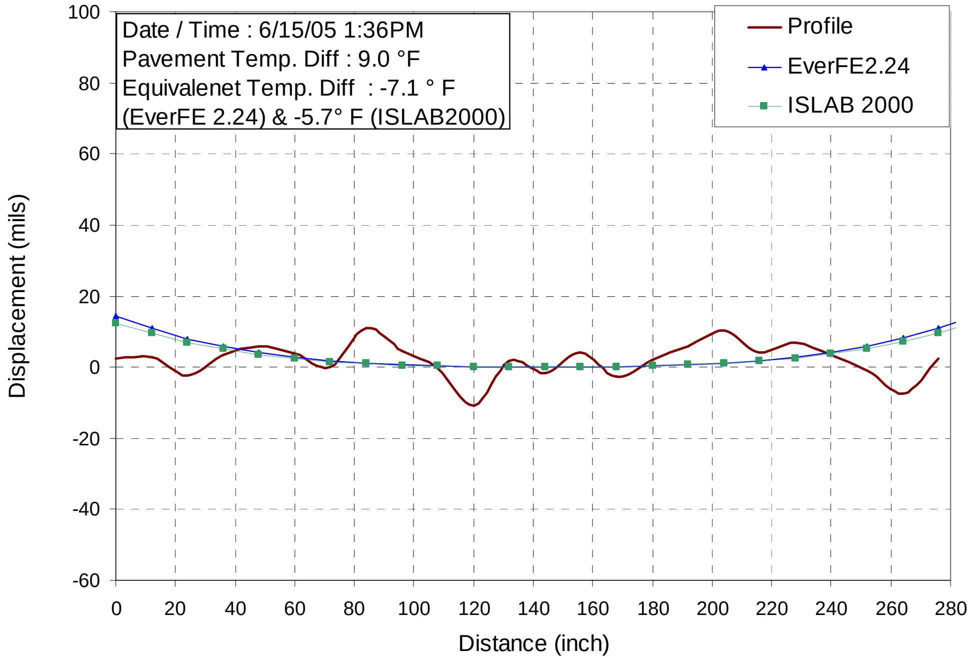


Figure E.70. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 15 afternoon

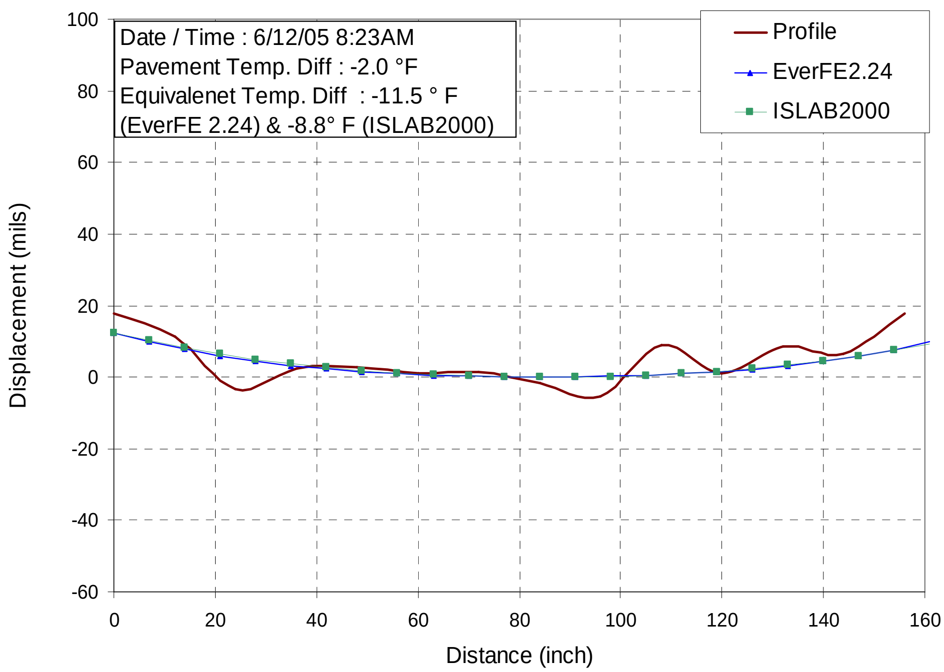


Figure E.71. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 12 morning

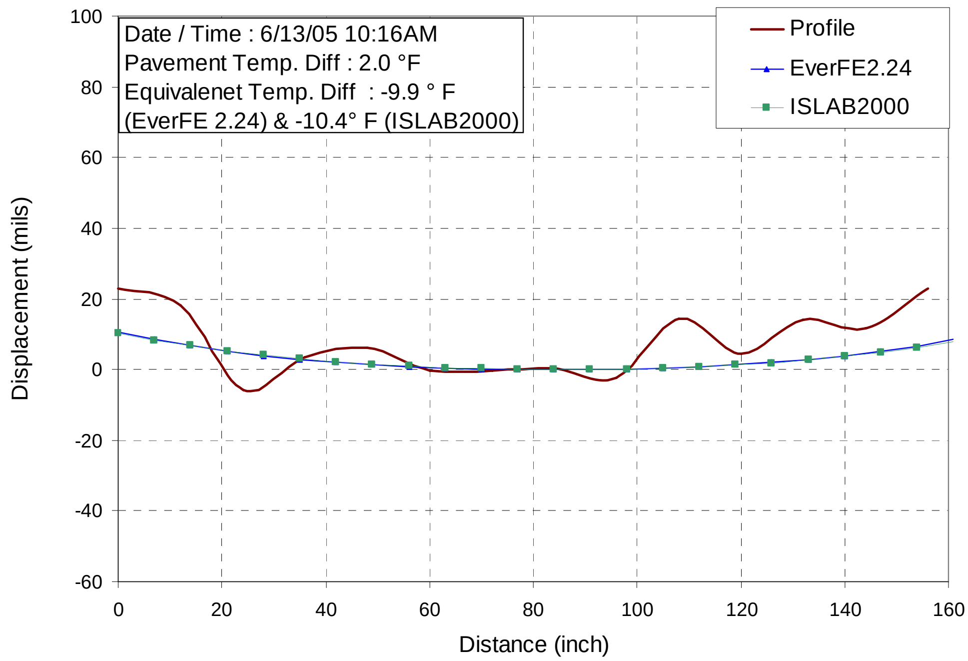


Figure E.72. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 13 morning

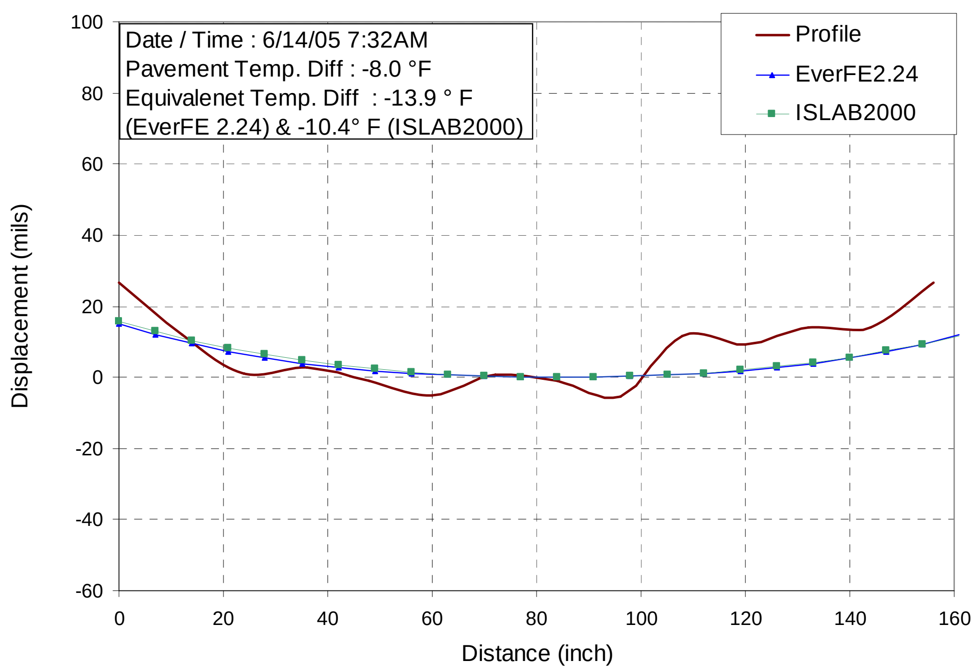


Figure E.73. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 14 morning

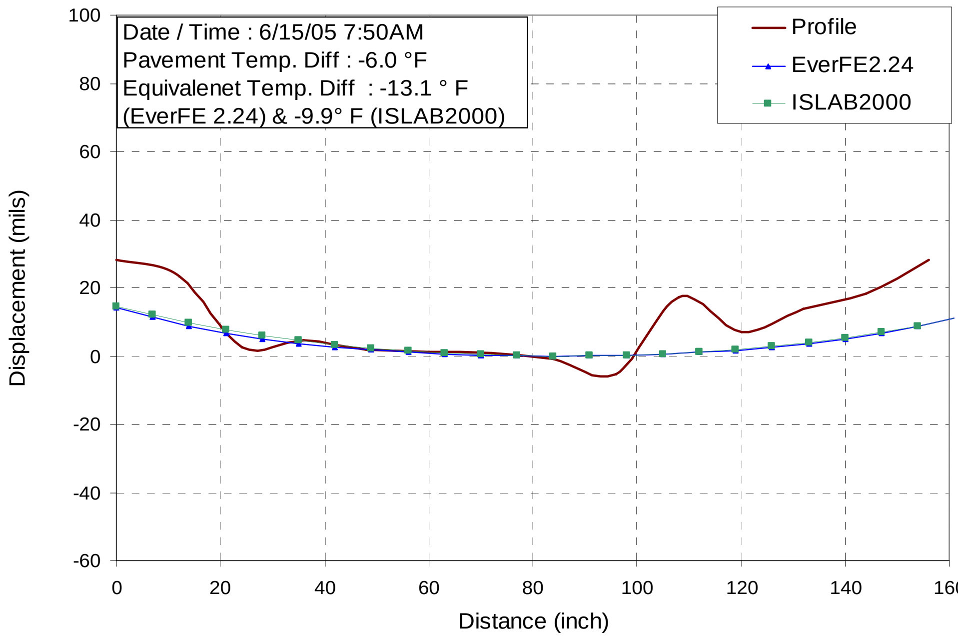


Figure E.74. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 15 morning

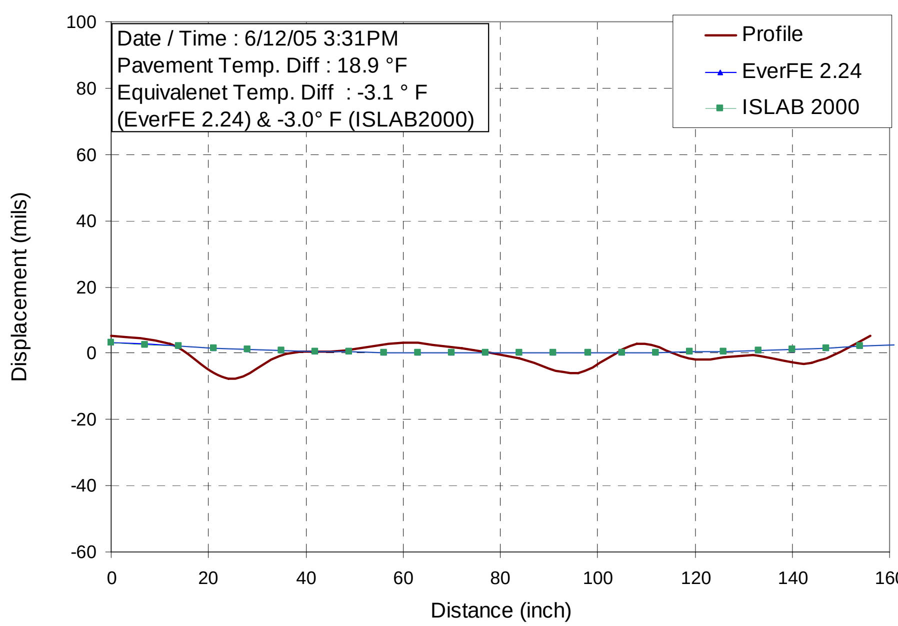


Figure E.75. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 12 afternoon

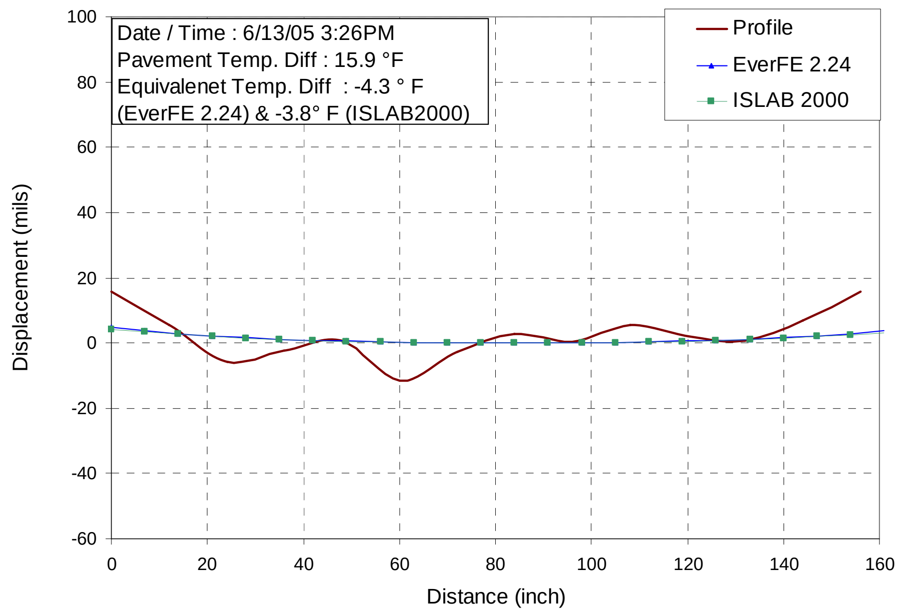


Figure E.76. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 13 afternoon

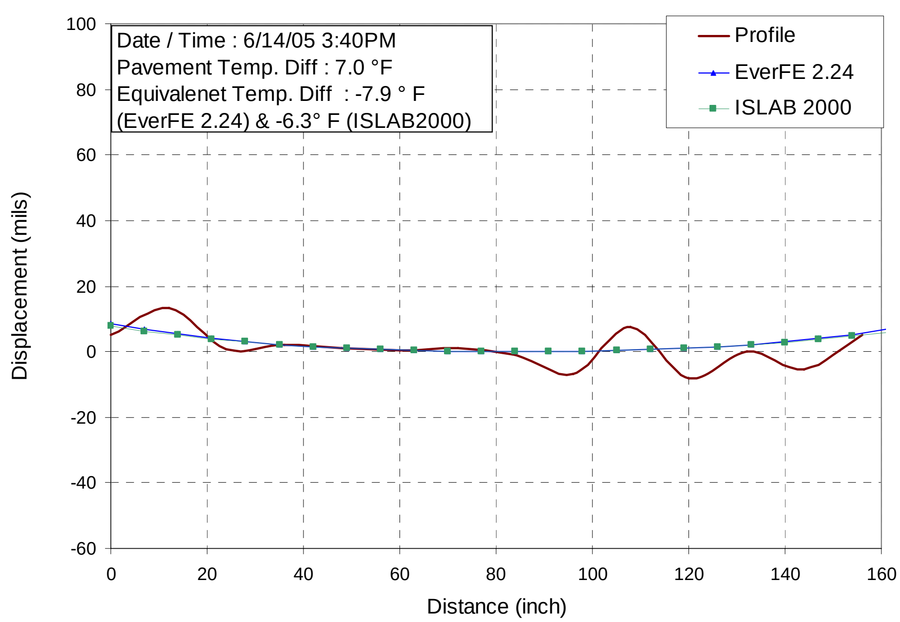


Figure E.77. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 14 afternoon

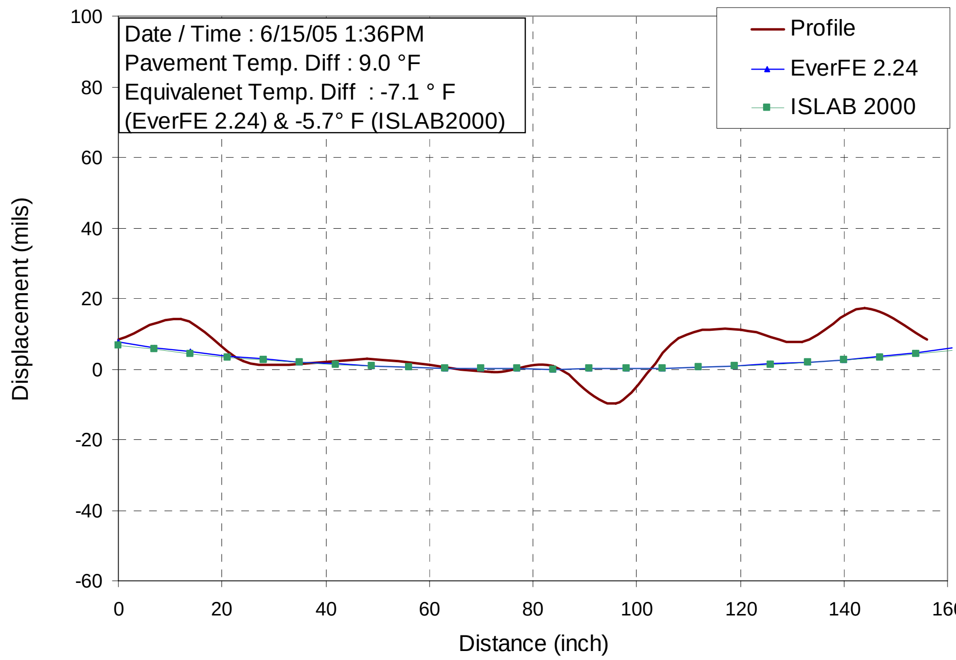


Figure E.78. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 15 afternoon

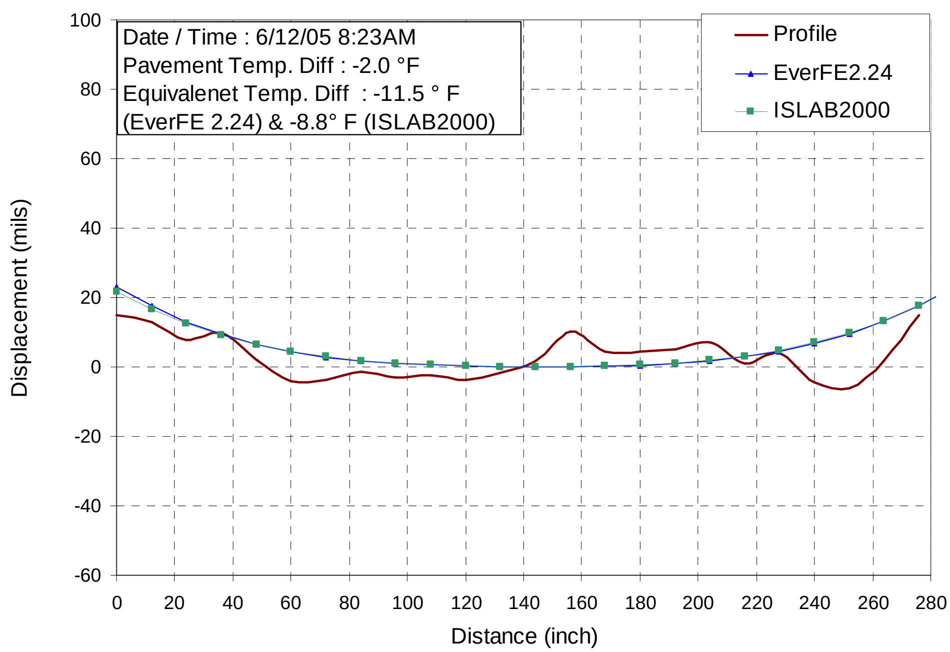


Figure E.79. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 12 morning

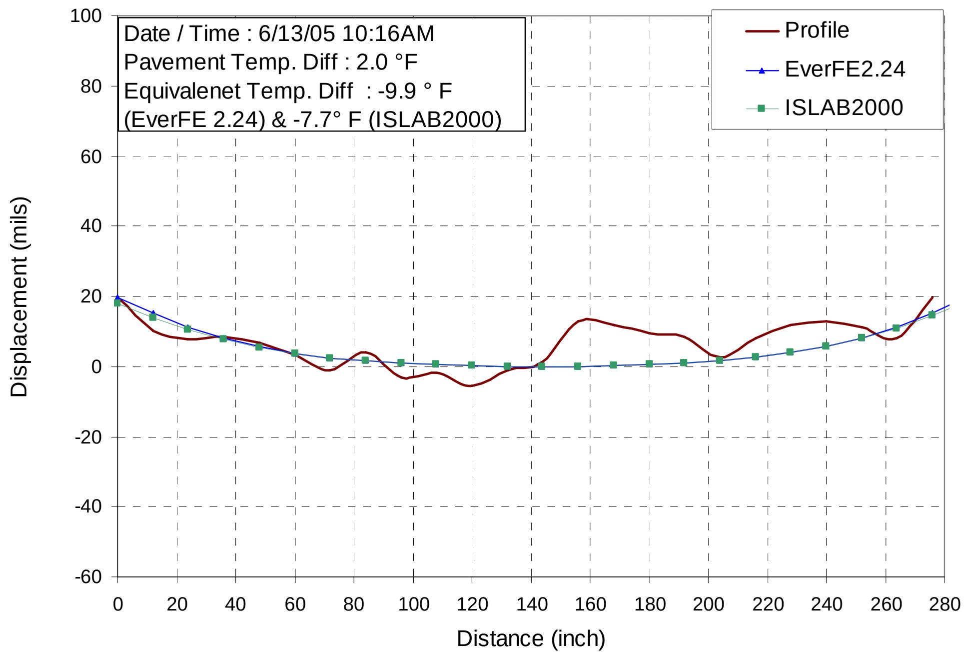


Figure E.80. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 13 morning

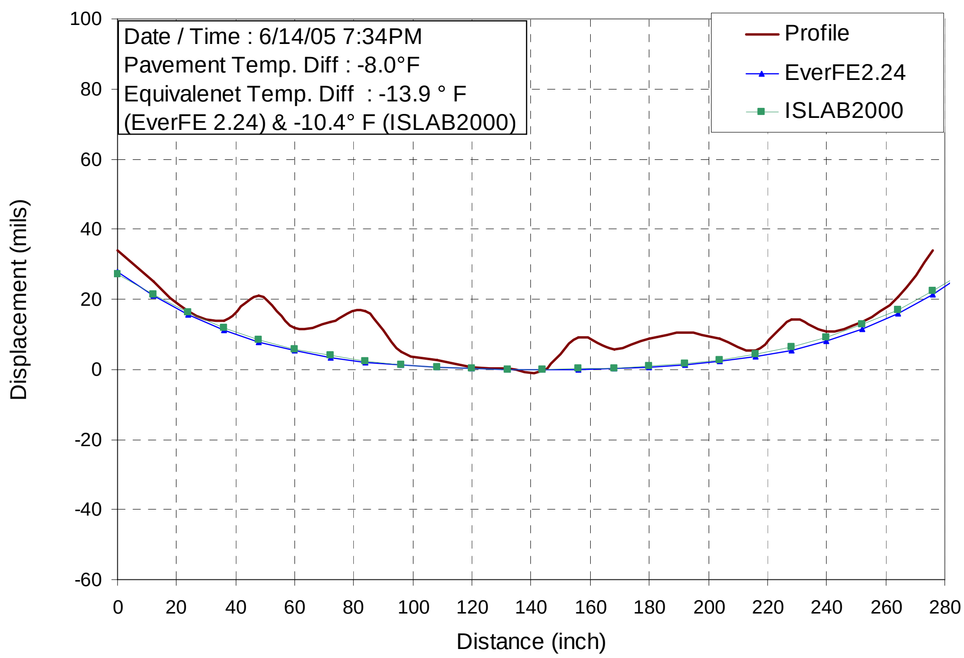


Figure E.81. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 14 morning

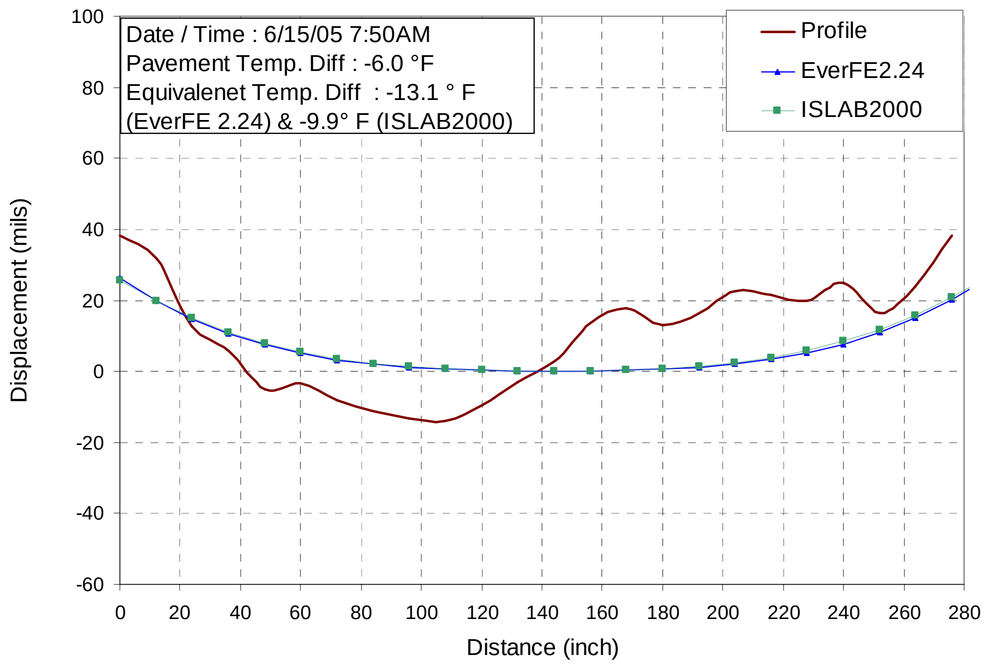


Figure E.82. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 15 morning

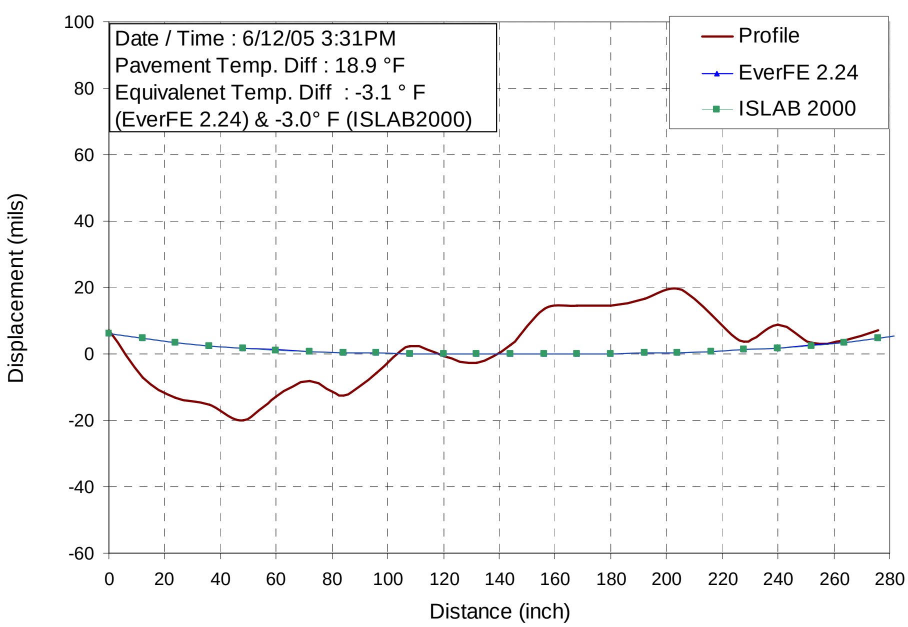


Figure E.83. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 12 afternoon

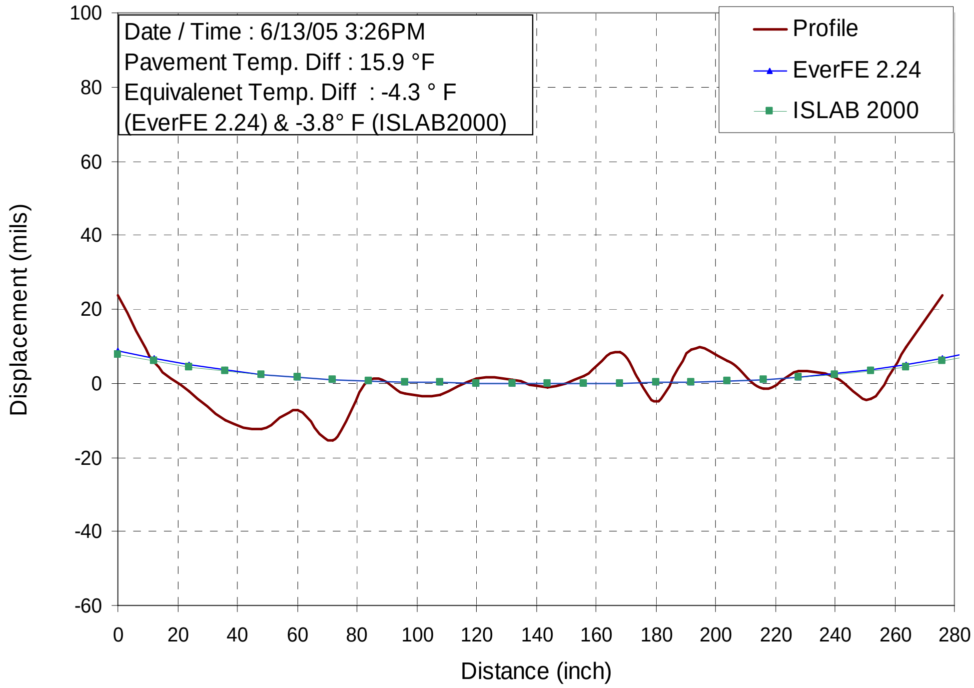


Figure E.84. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 13 afternoon

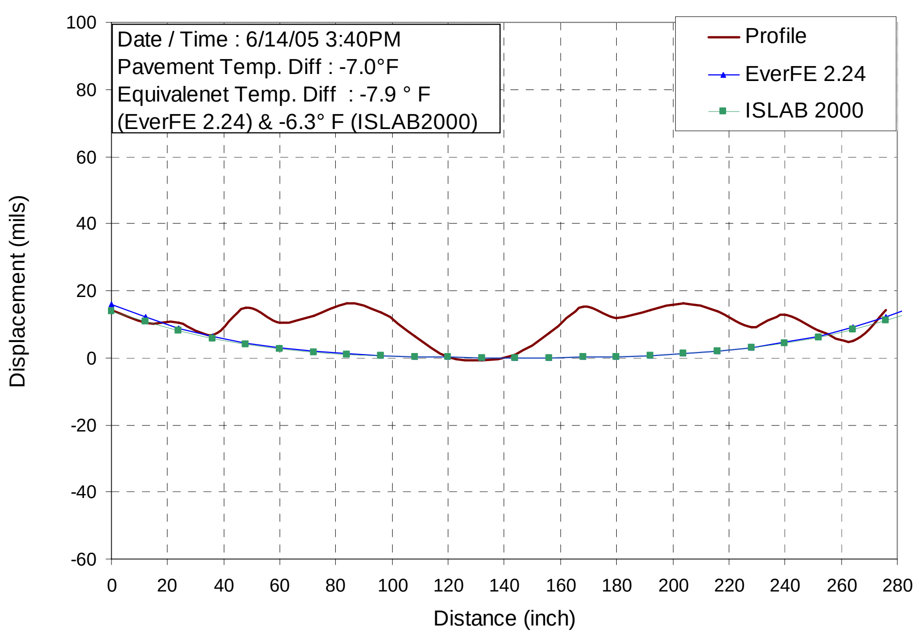


Figure E.85. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 14 afternoon

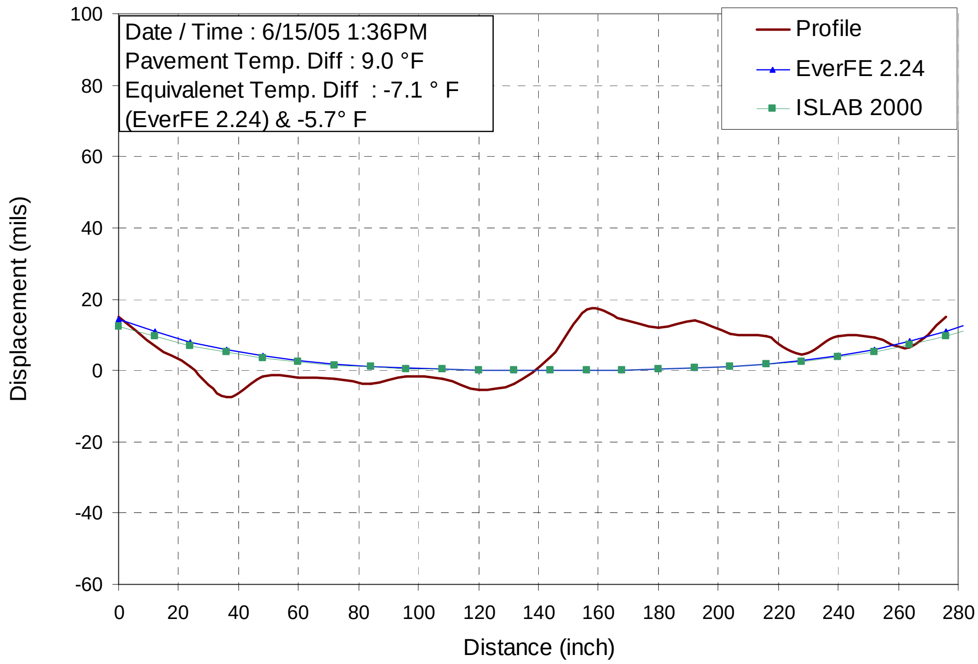


Figure E.86. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 15 afternoon

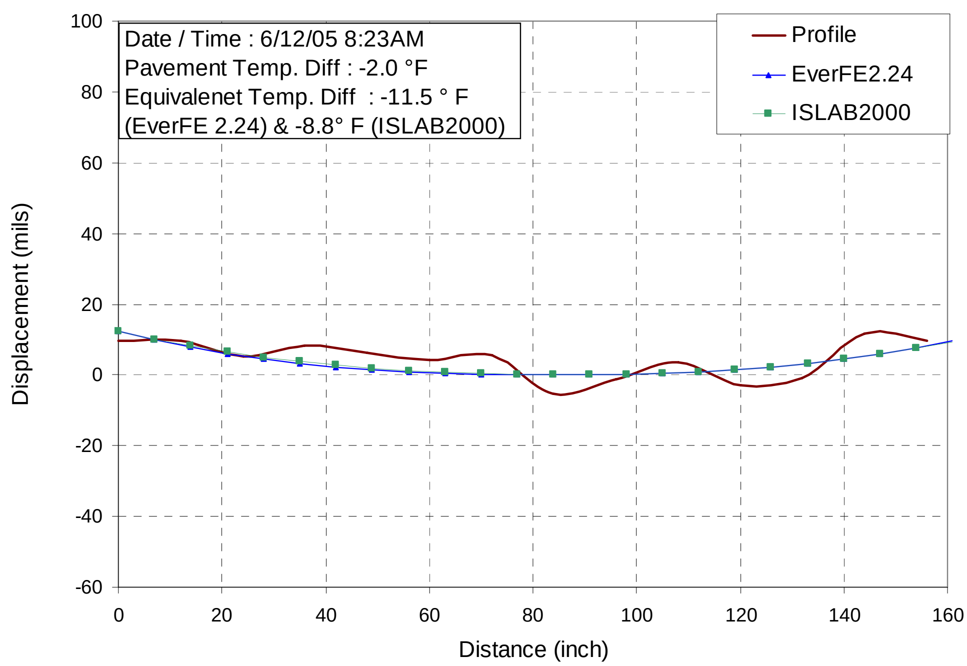


Figure E.87. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 12 morning

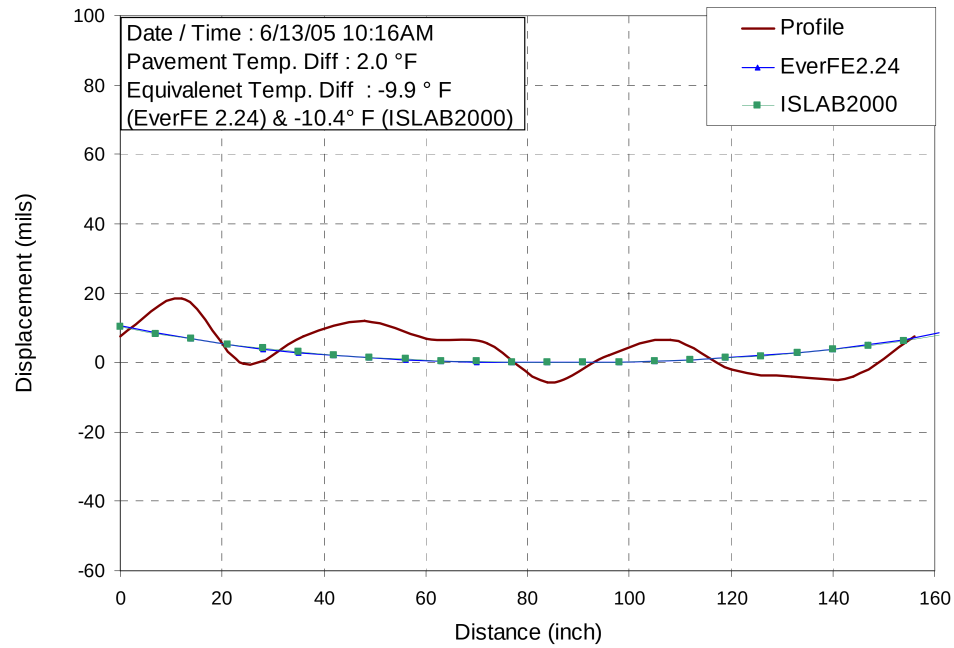


Figure E.88. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 13 morning

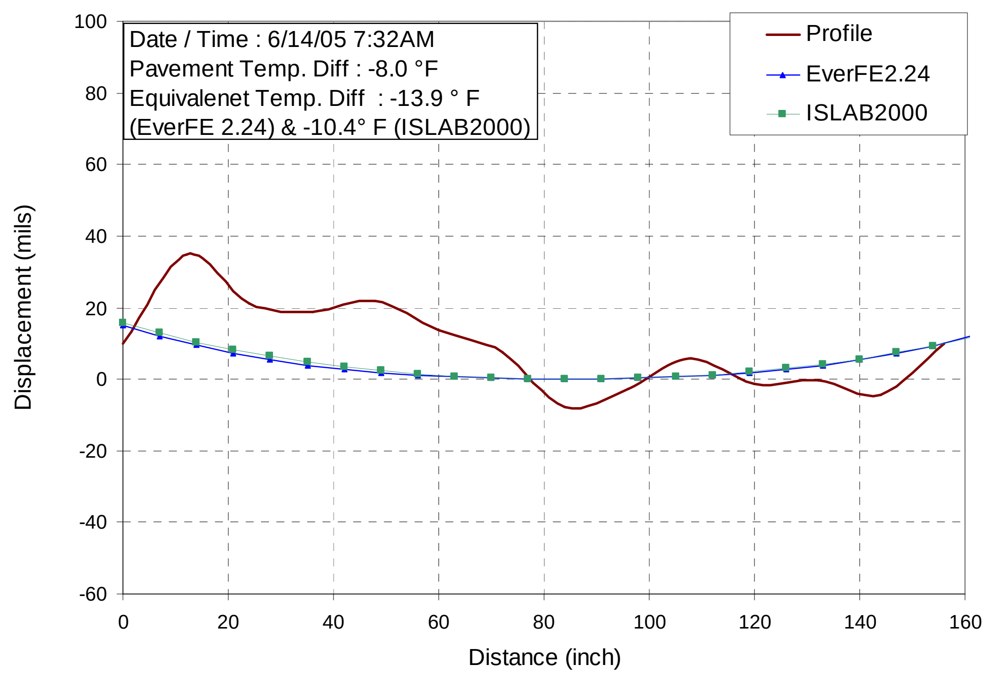


Figure E.89. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 14 morning

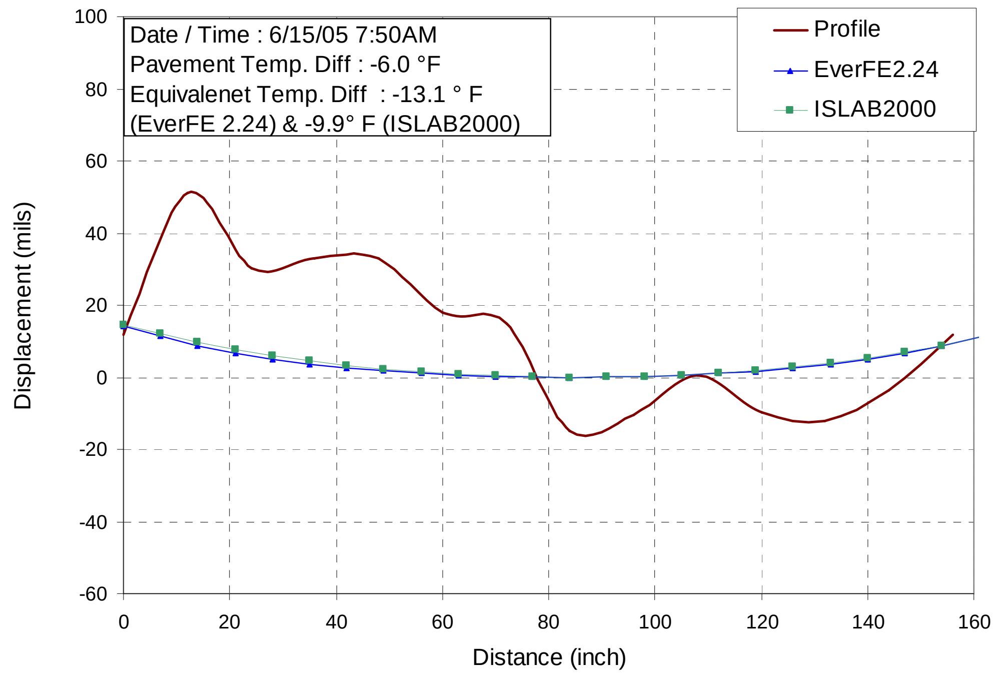


Figure E.90. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 15 morning

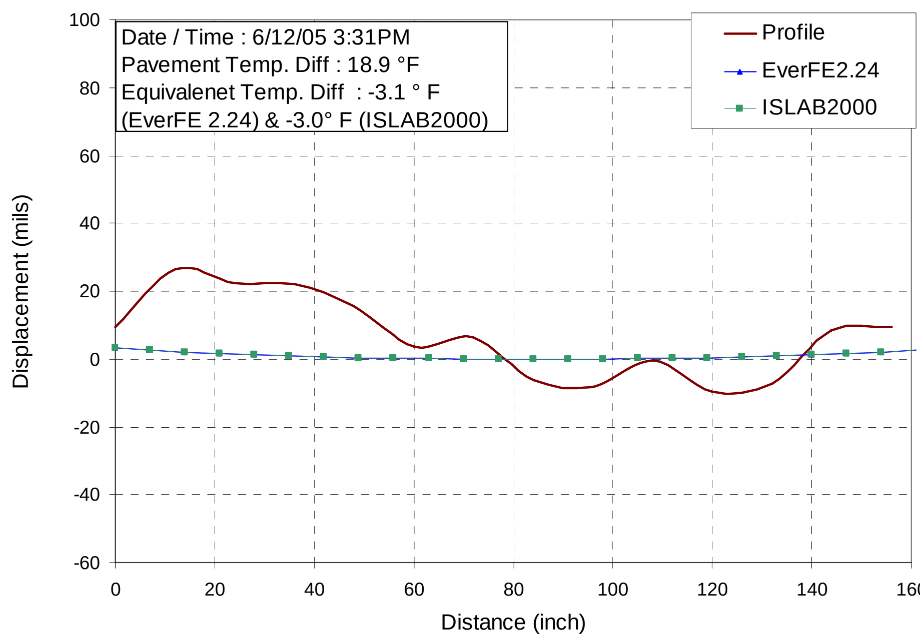


Figure E.91. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 12 afternoon

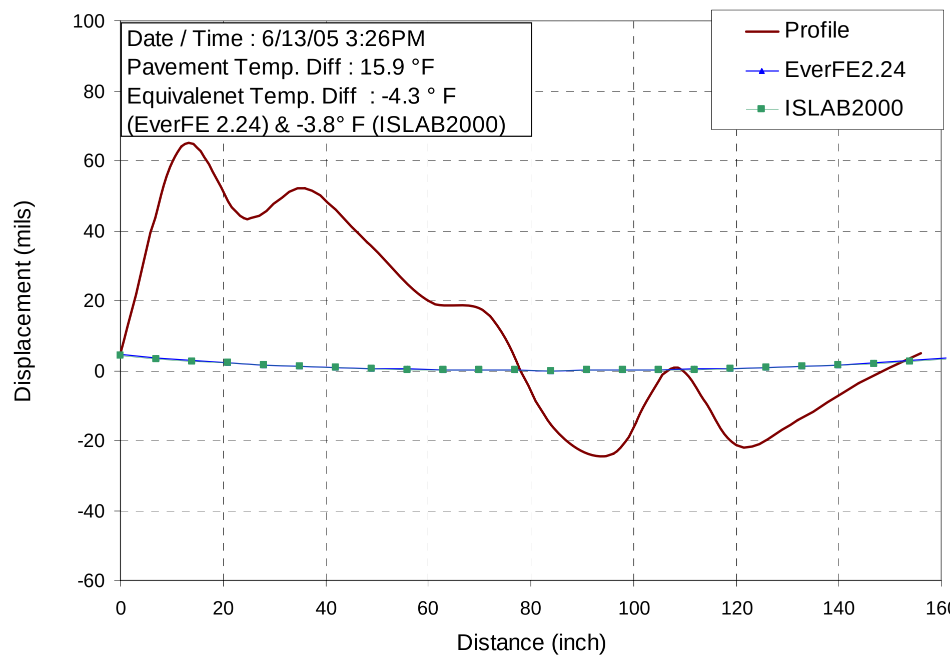


Figure E.92. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 13 afternoon

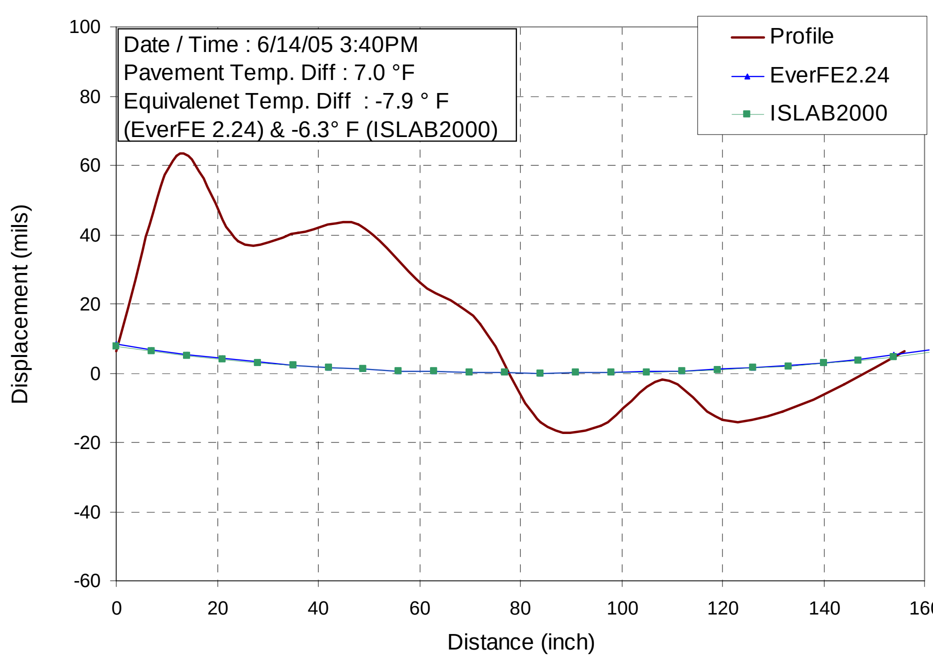


Figure E.93. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 14 afternoon

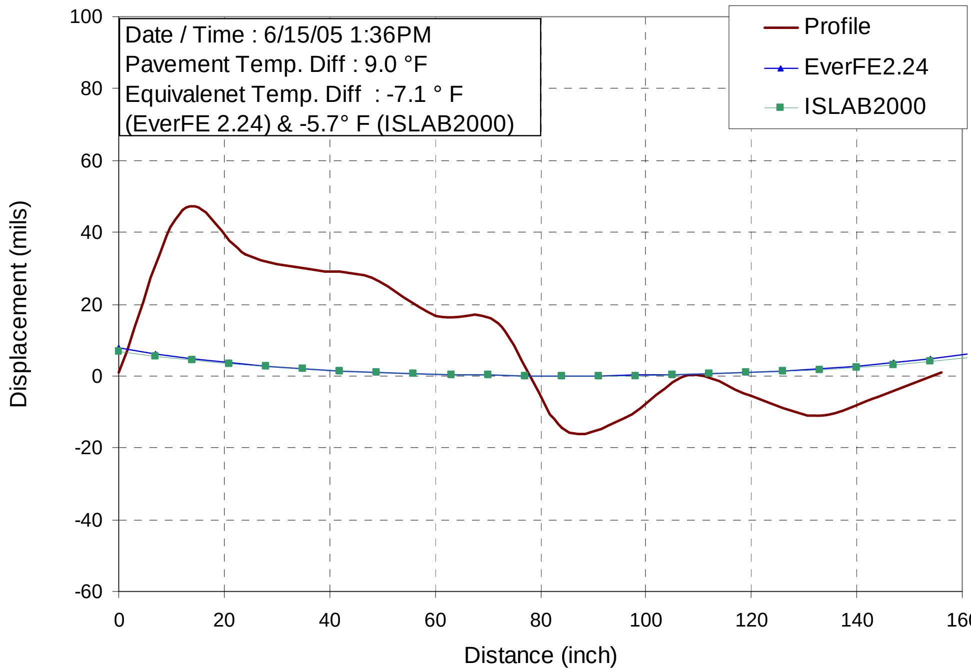


Figure E.94. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 15 afternoon

APPENDIX F: BURLINGTON SITE AFTERNOON PAVING TEST SECTION

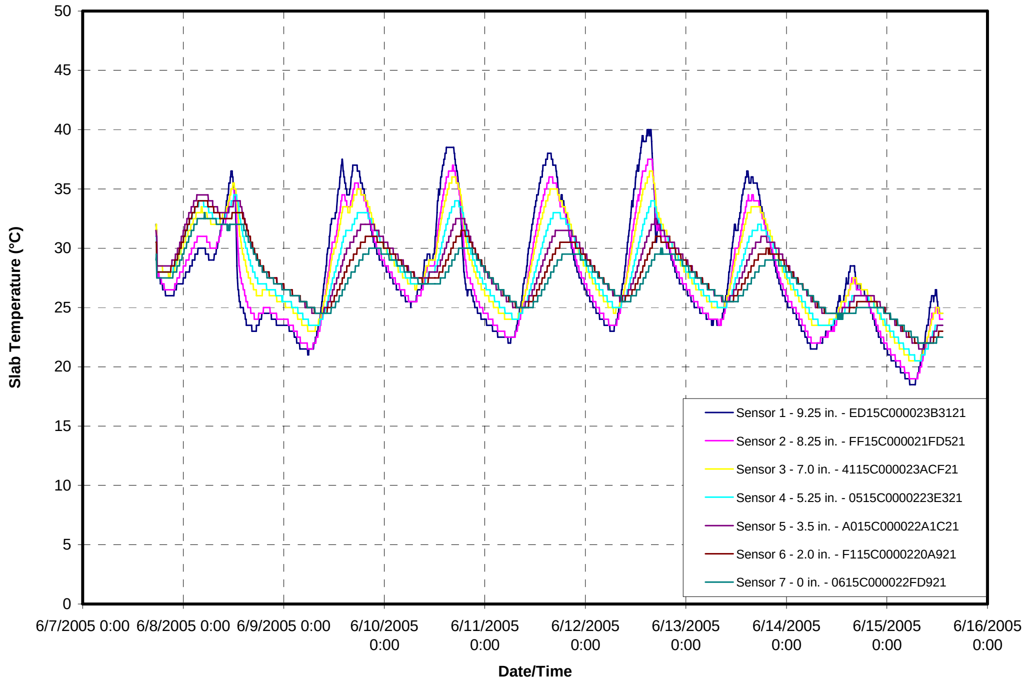


Figure F.1. Slab temperature data

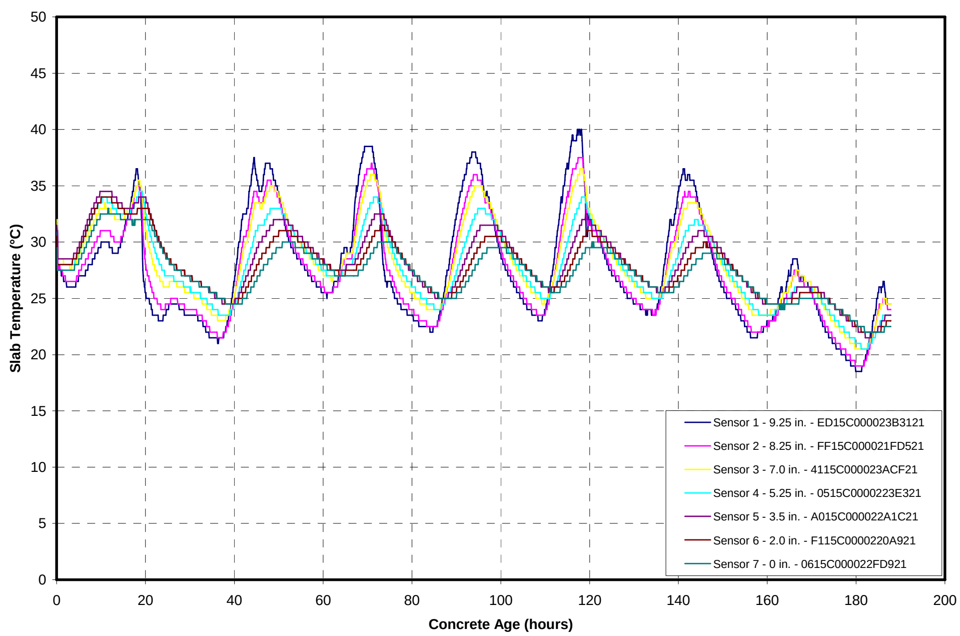


Figure F.2. Slab temperature data

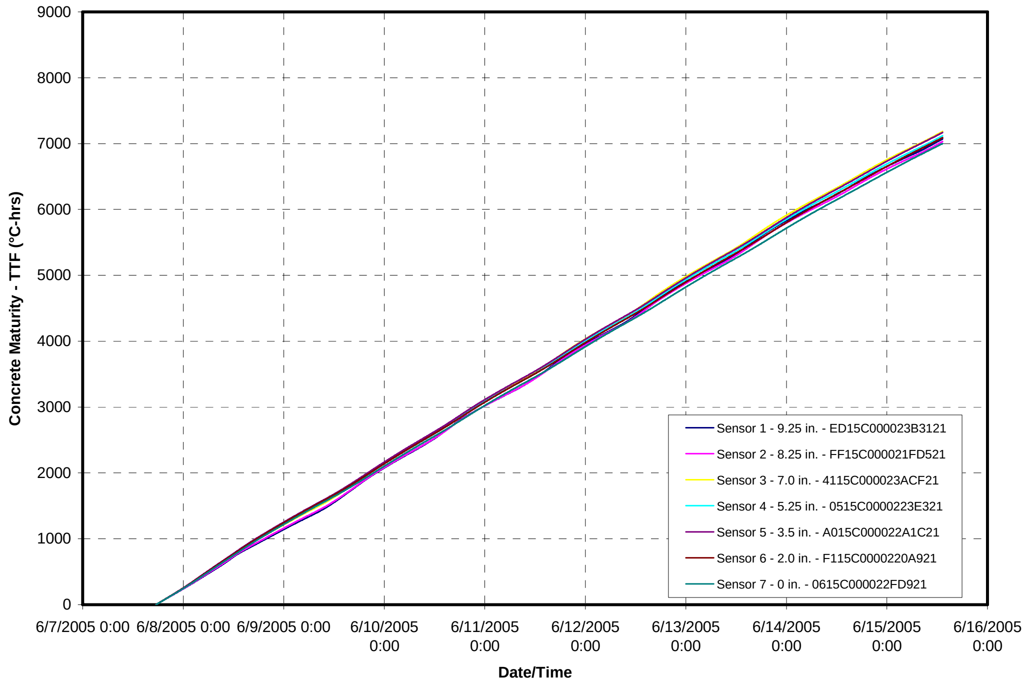


Figure F.3. Slab maturity data

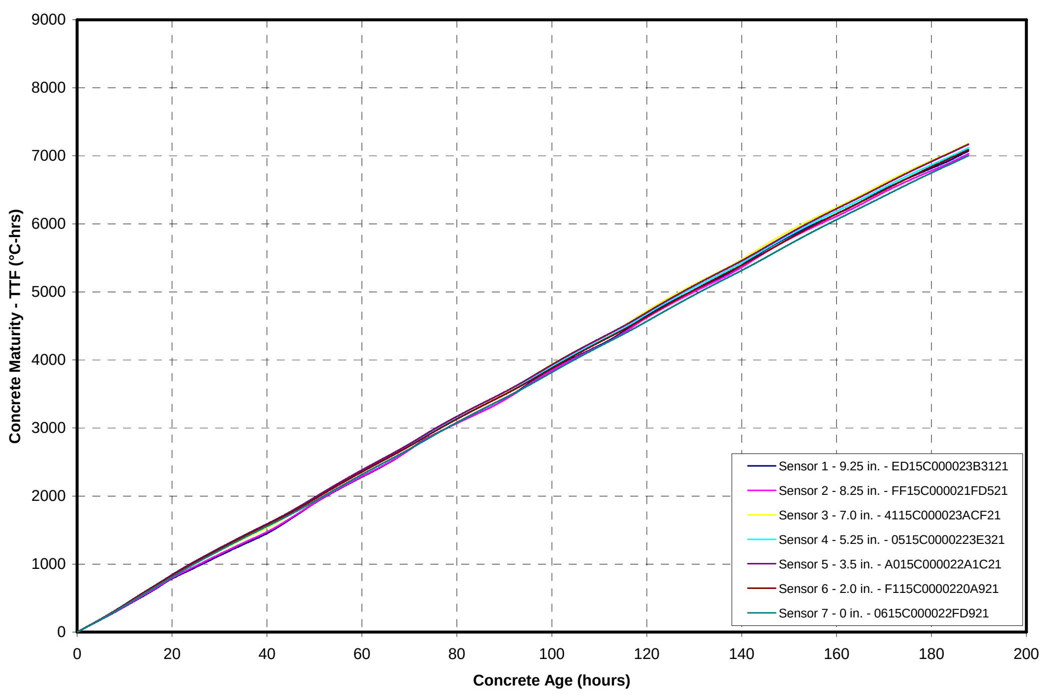


Figure F.4. Slab maturity data

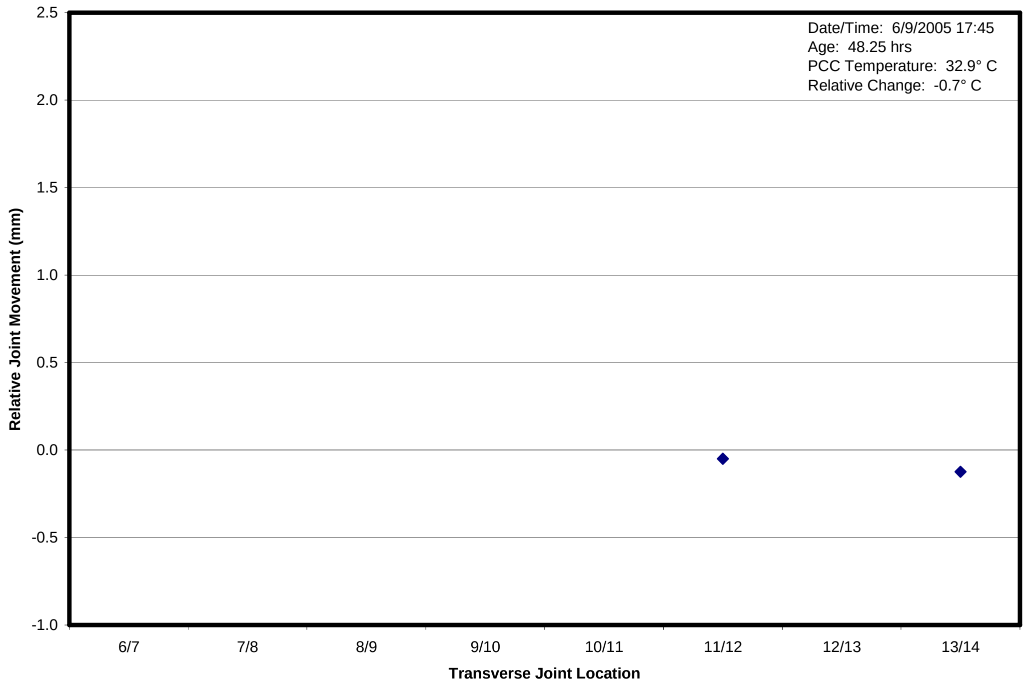


Figure F.5. Transverse joint relative opening

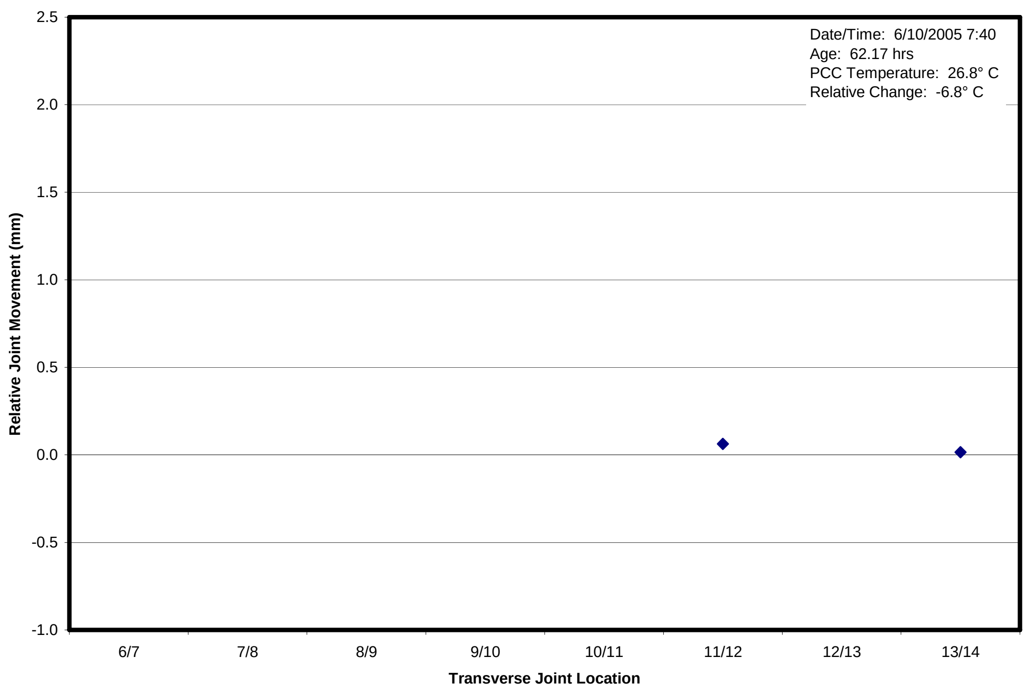


Figure F.6. Transverse joint relative opening

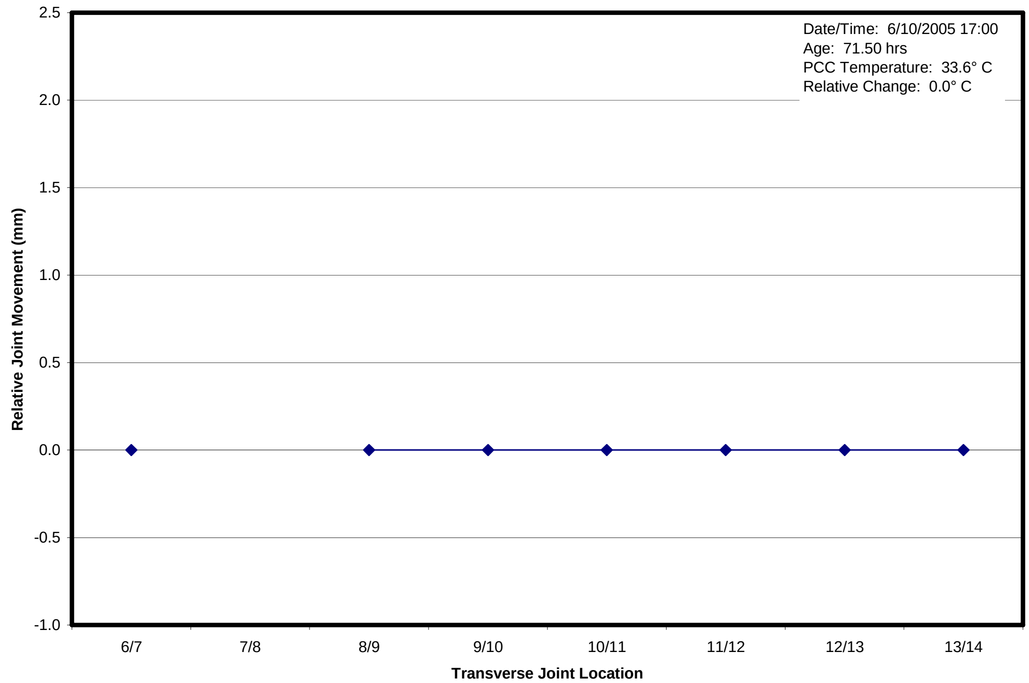


Figure F.7. Transverse joint relative opening

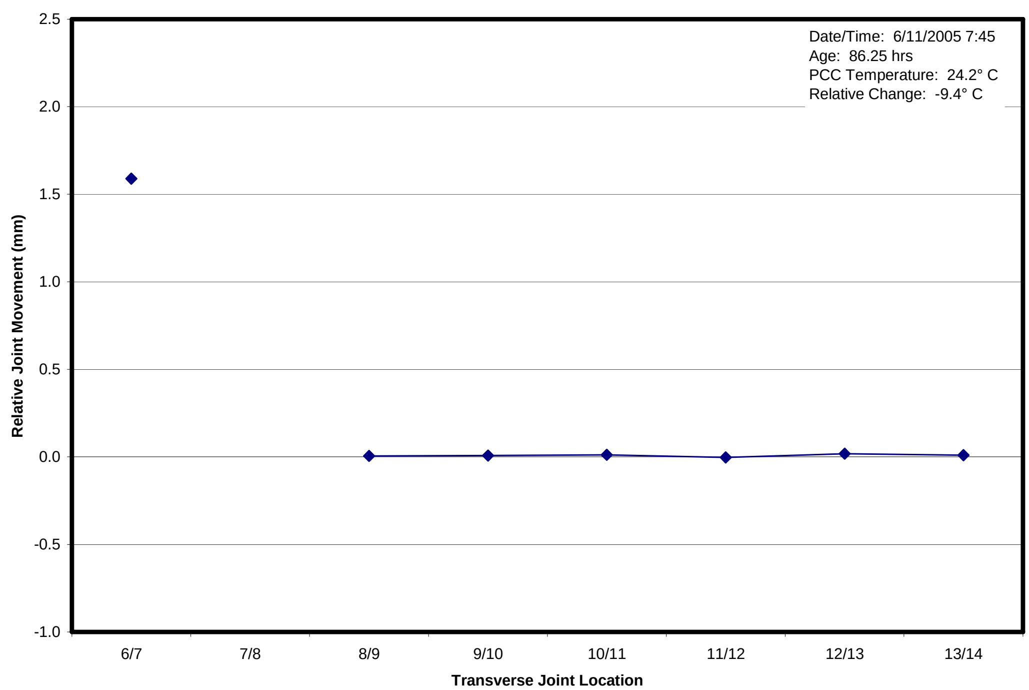


Figure F.8. Transverse joint relative opening

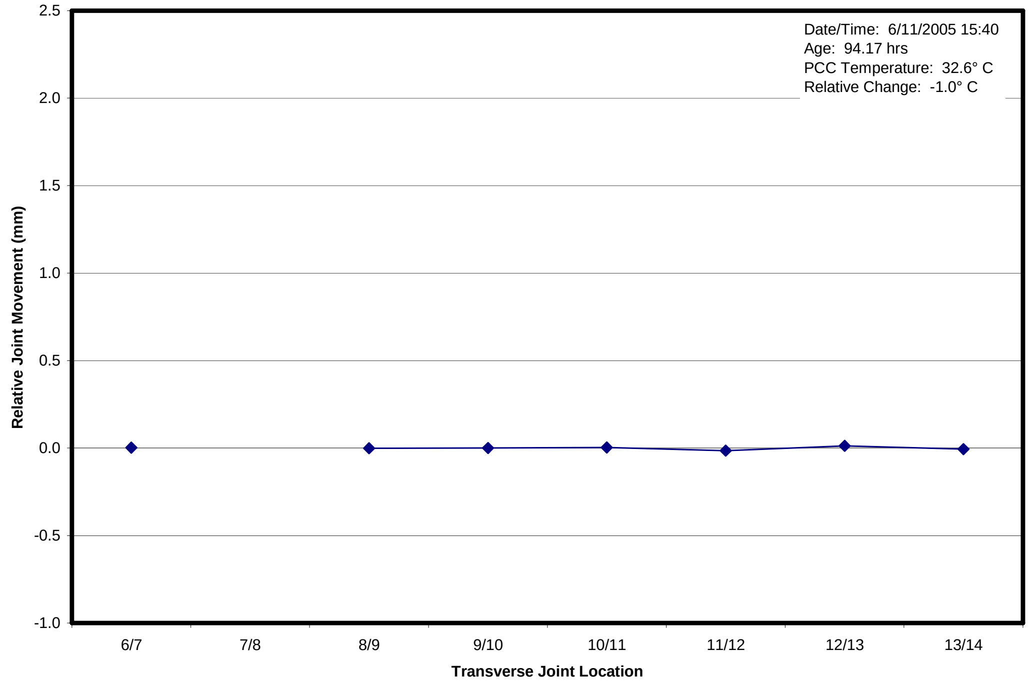


Figure F.9. Transverse joint relative opening

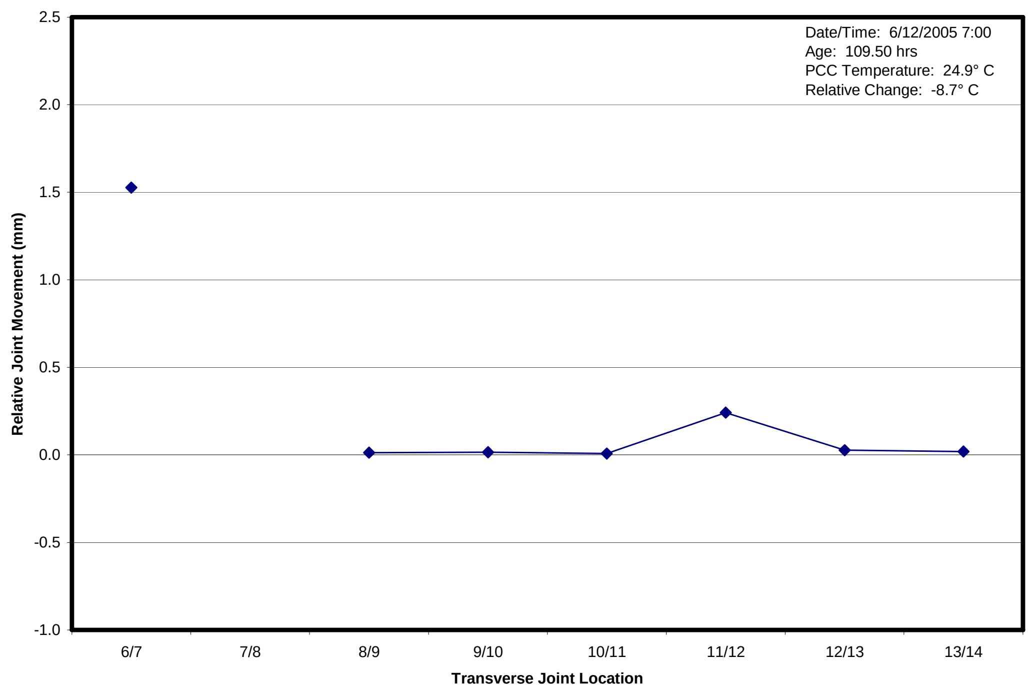


Figure F.10. Transverse joint relative opening

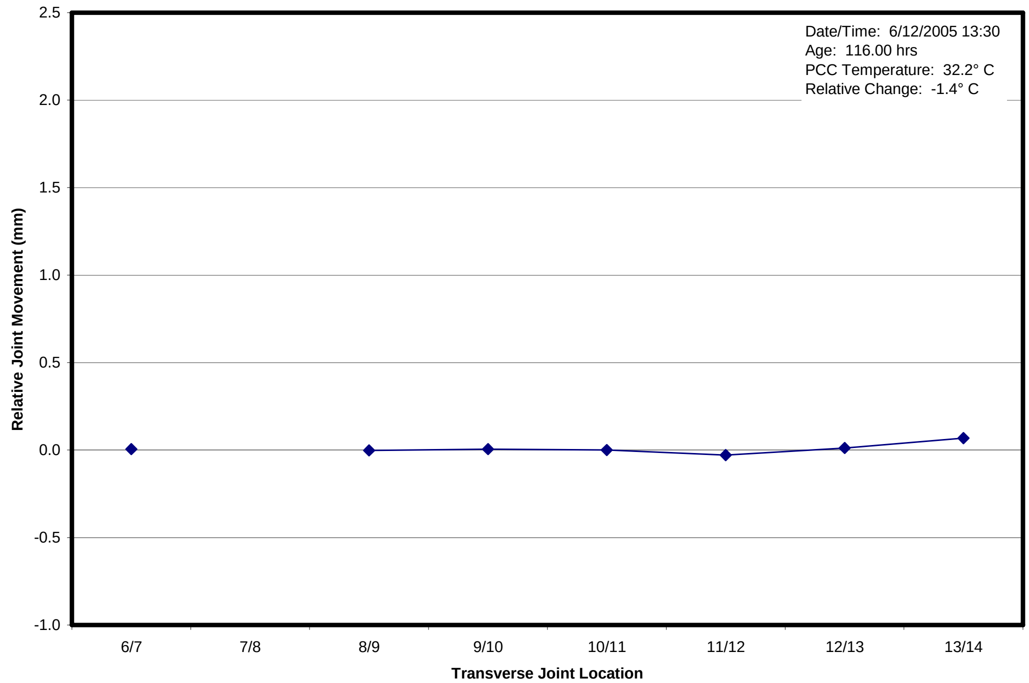


Figure F.11. Transverse joint relative opening

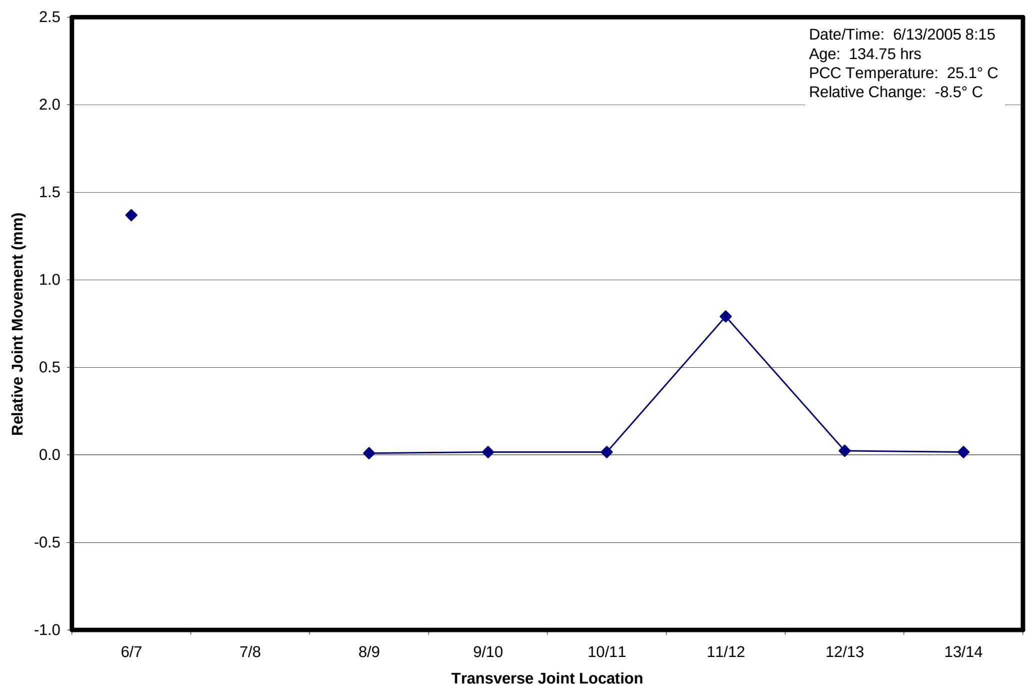


Figure F.12. Transverse joint relative opening

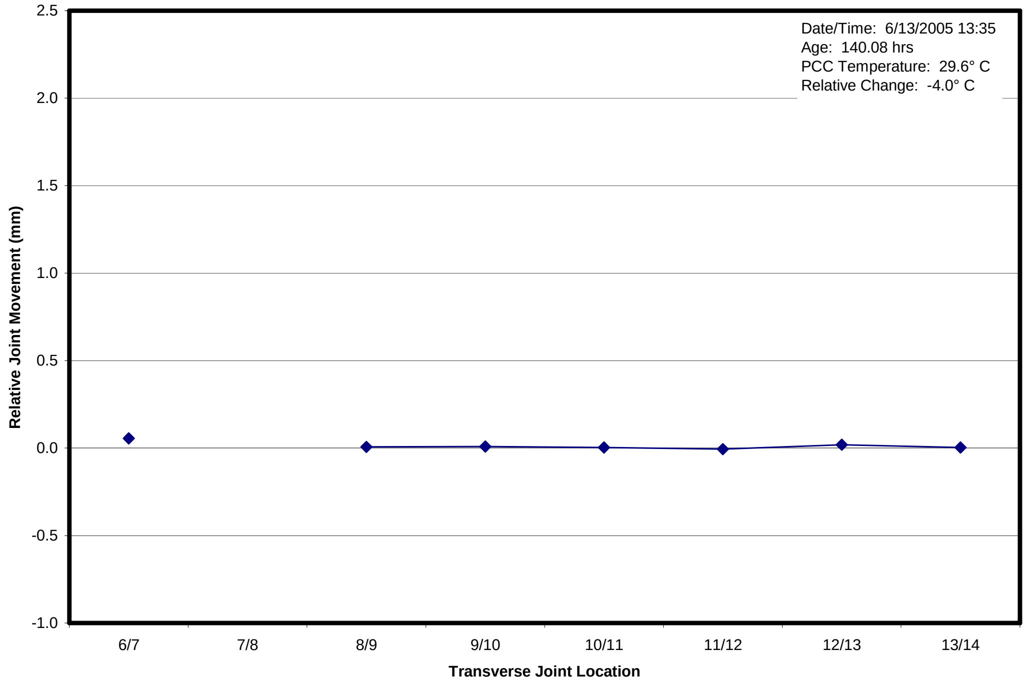


Figure F.13. Transverse joint relative opening

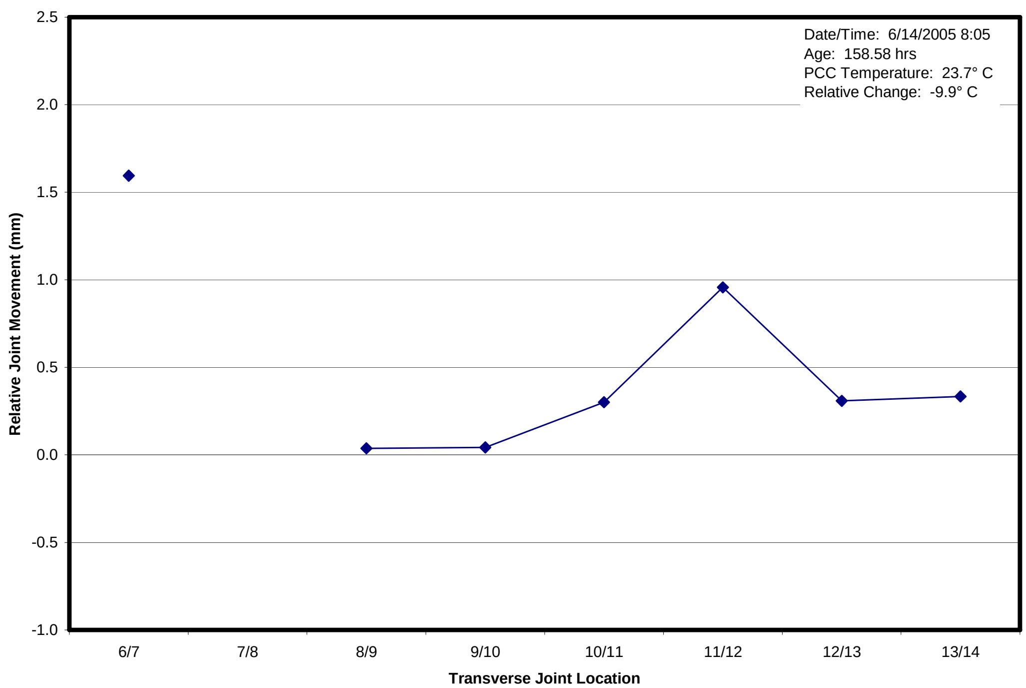


Figure F.14. Transverse joint relative opening

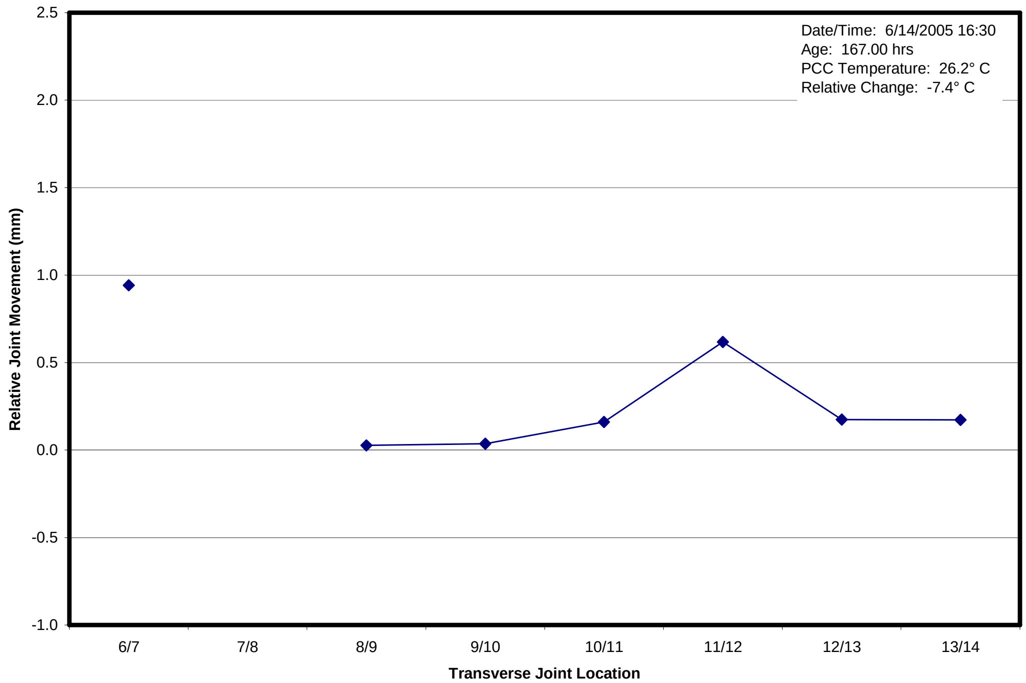


Figure F.15. Transverse joint relative opening

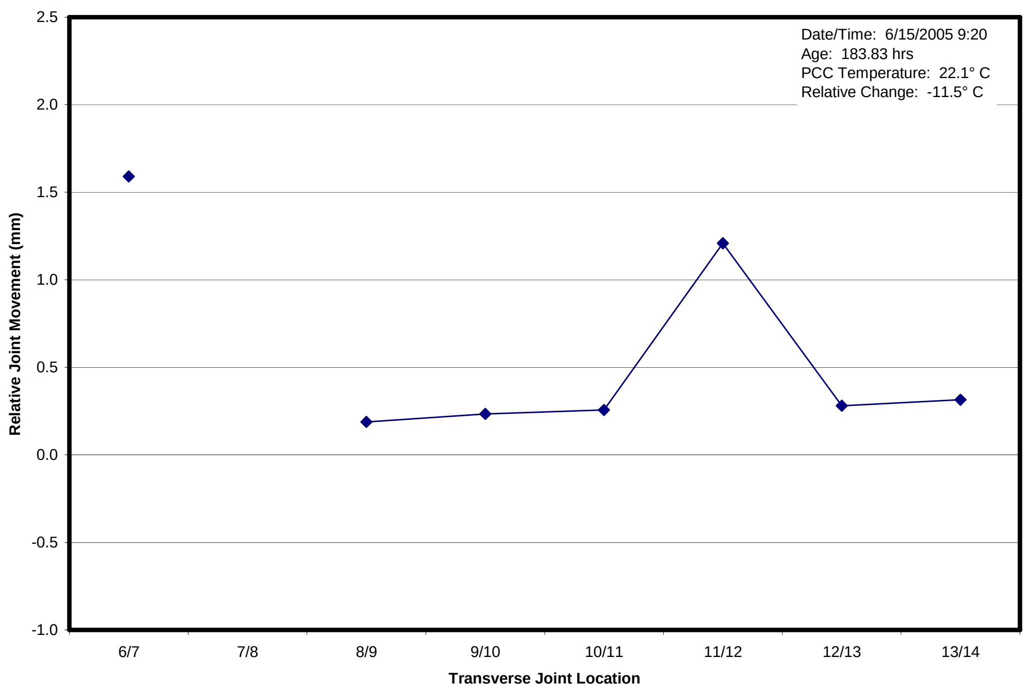


Figure F.16. Transverse joint relative opening

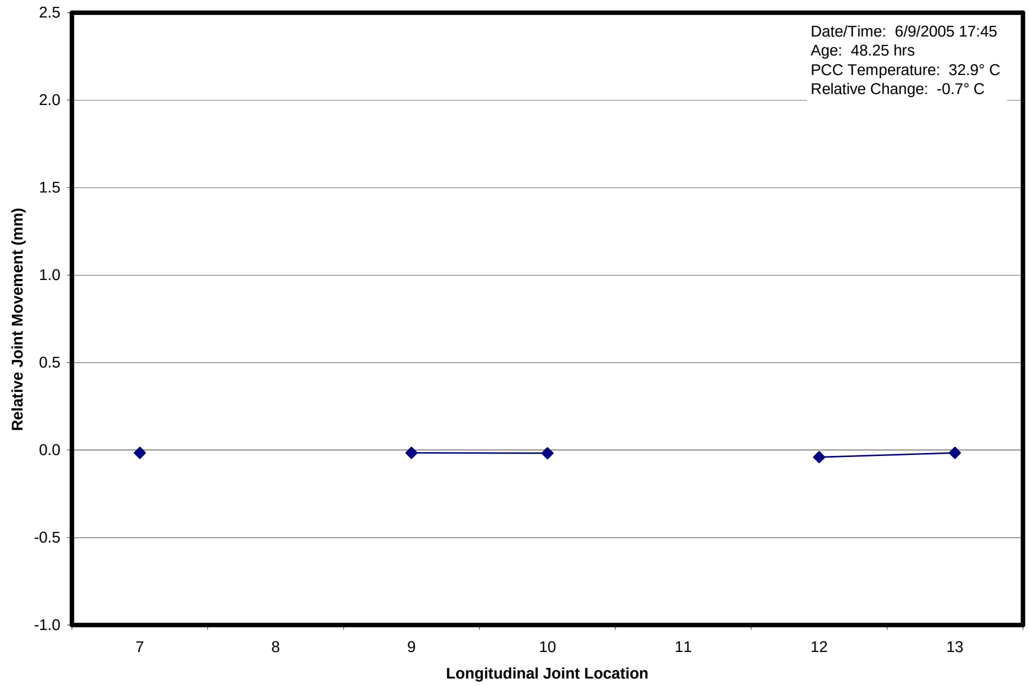


Figure F.17. Longitudinal joint relative opening

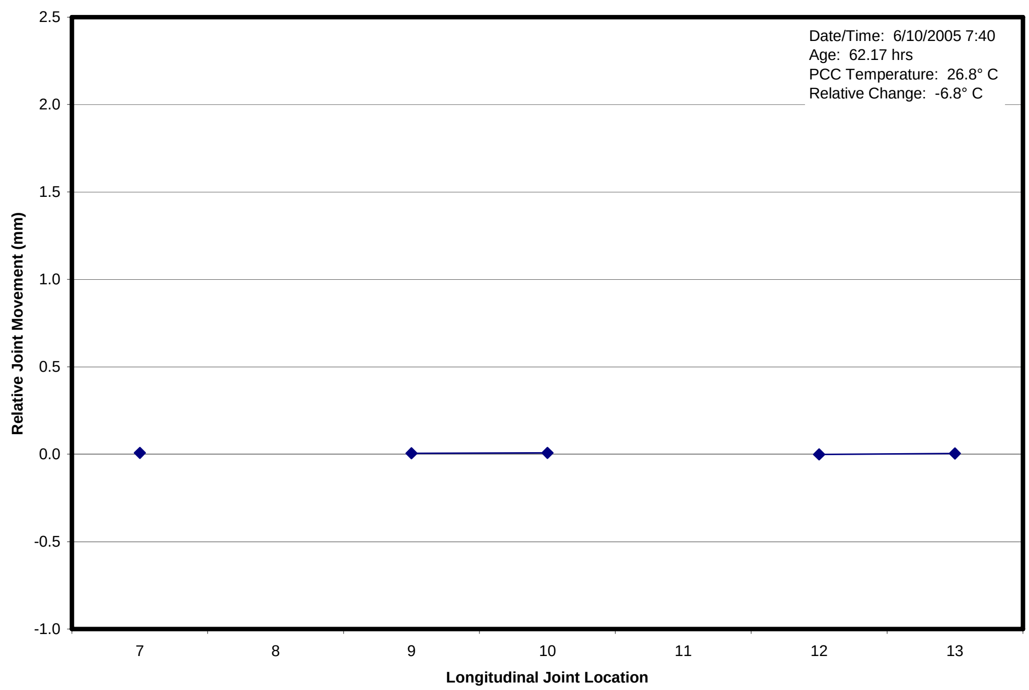


Figure F.18. Longitudinal joint relative opening

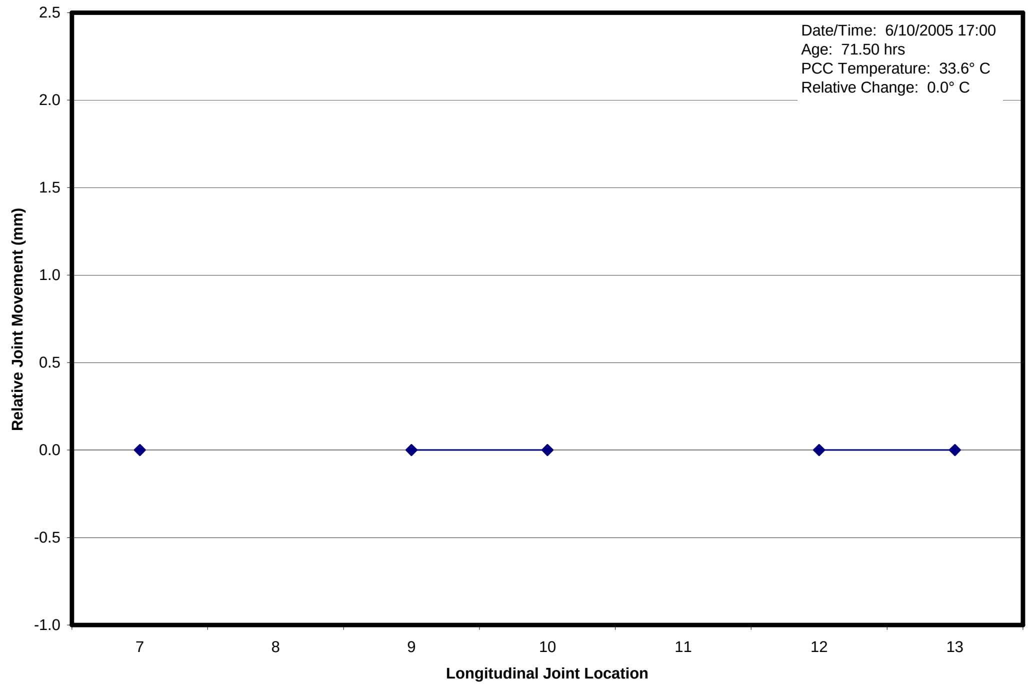


Figure F.19. Longitudinal joint relative opening

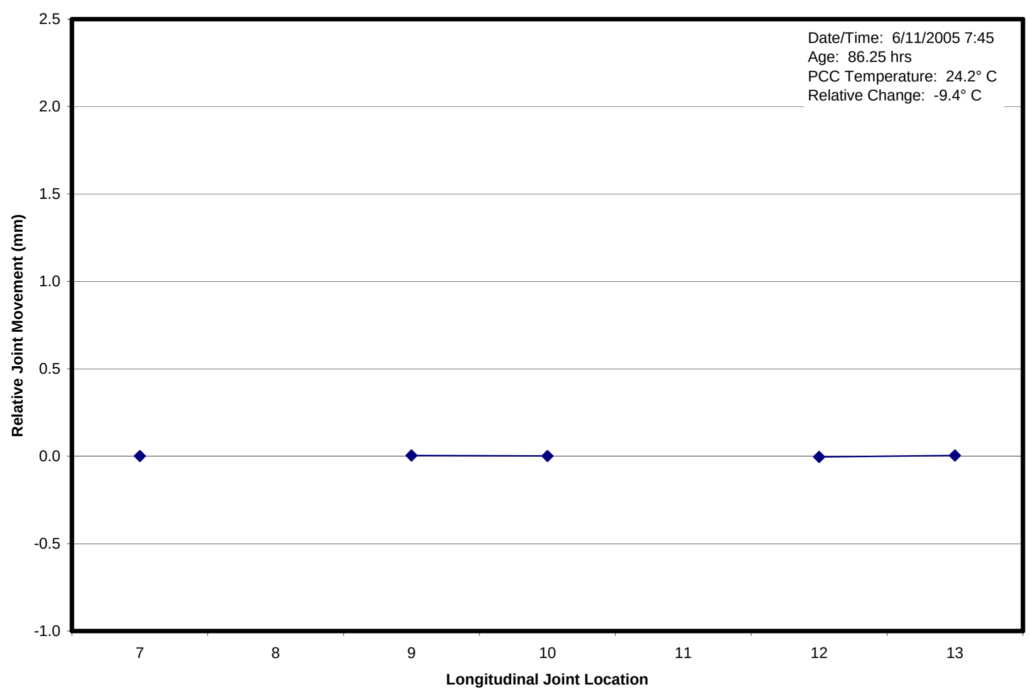


Figure F.20. Longitudinal joint relative opening

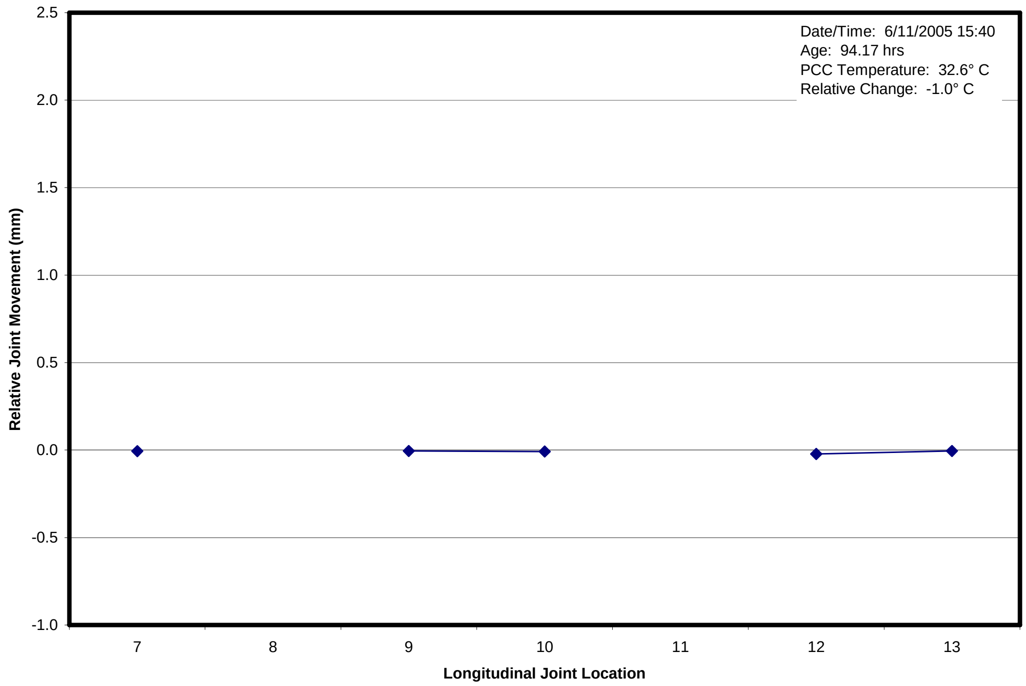


Figure F.21. Longitudinal joint relative opening

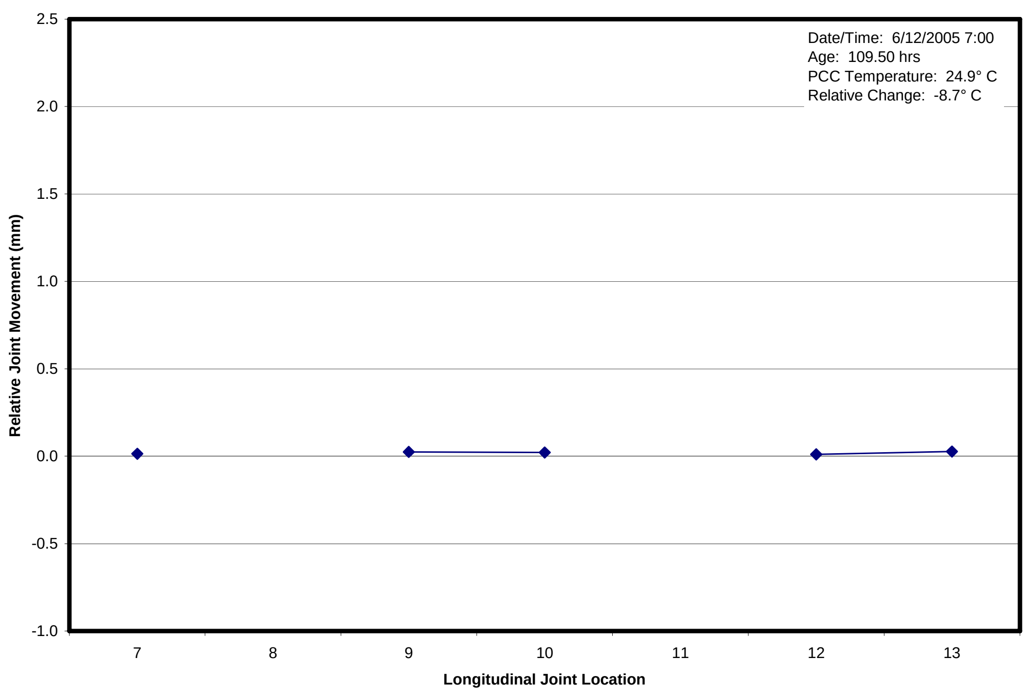


Figure F.22. Longitudinal joint relative opening

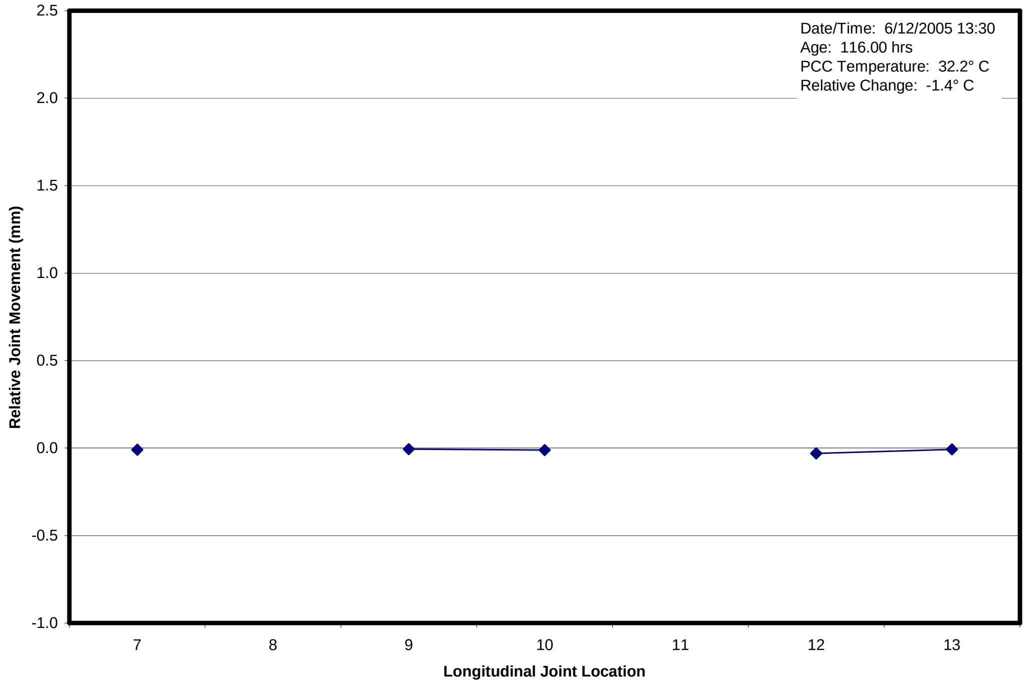


Figure F.23. Longitudinal joint relative opening

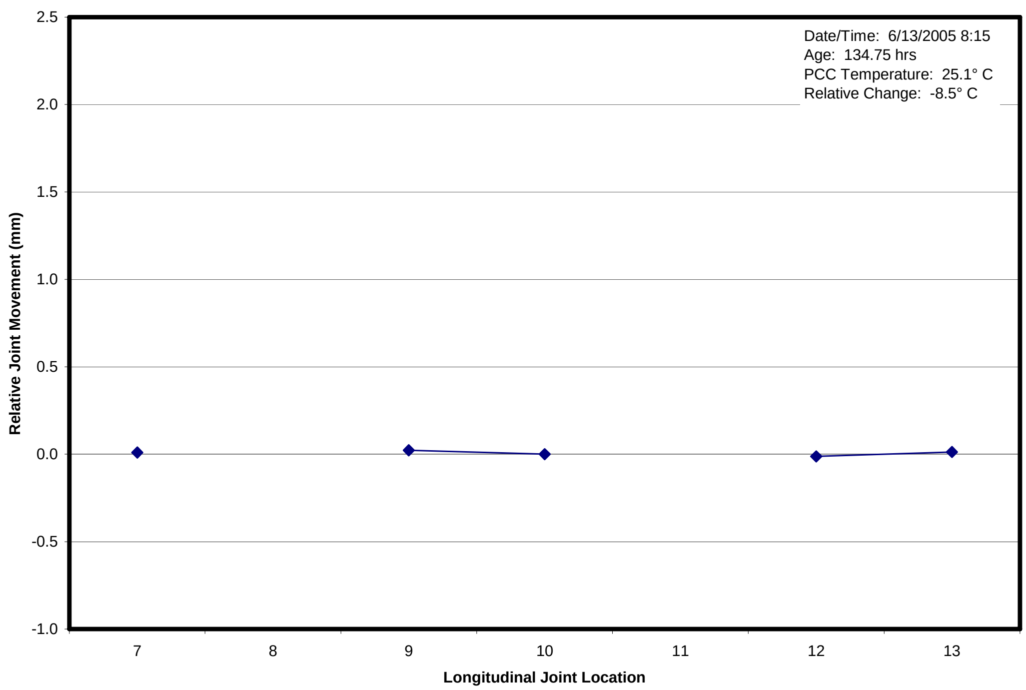


Figure F.24. Longitudinal joint relative opening

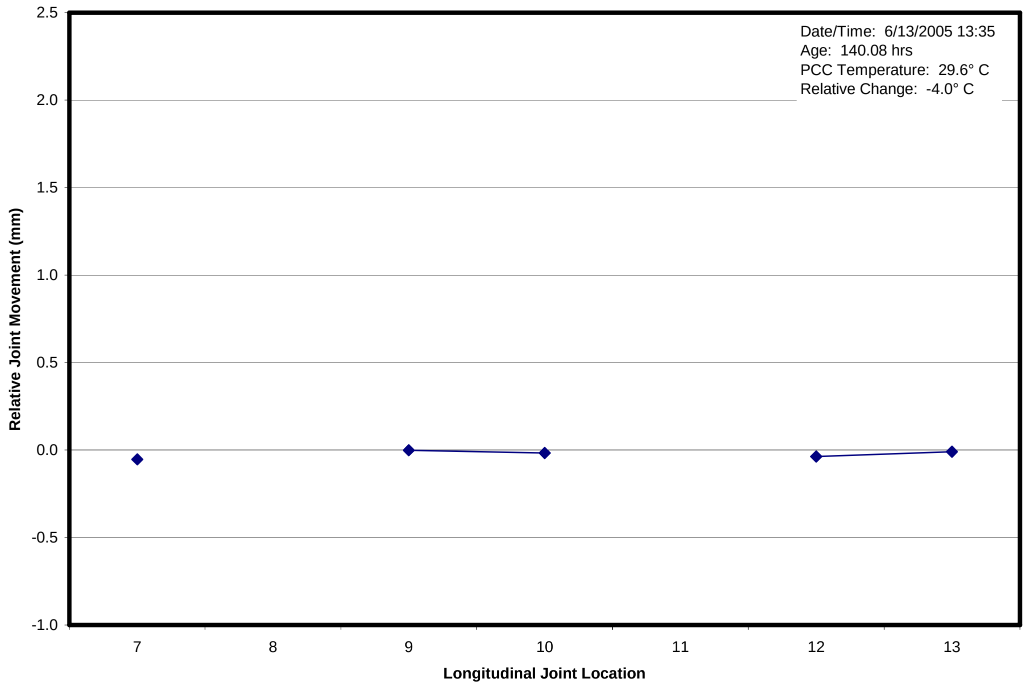


Figure F.25. Longitudinal joint relative opening

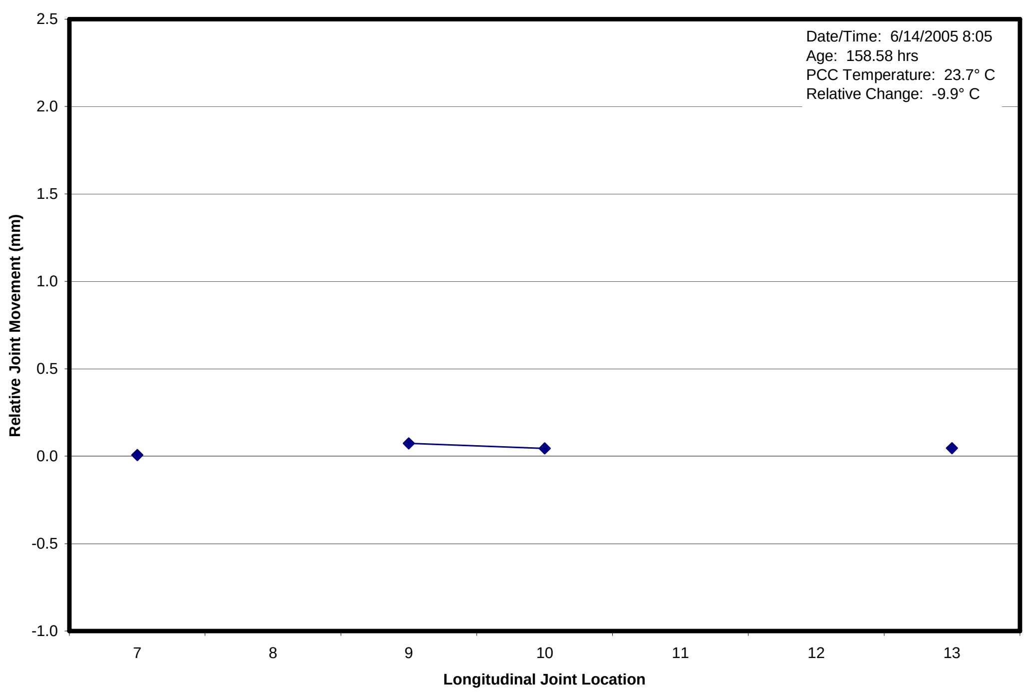


Figure F.26. Longitudinal joint relative opening

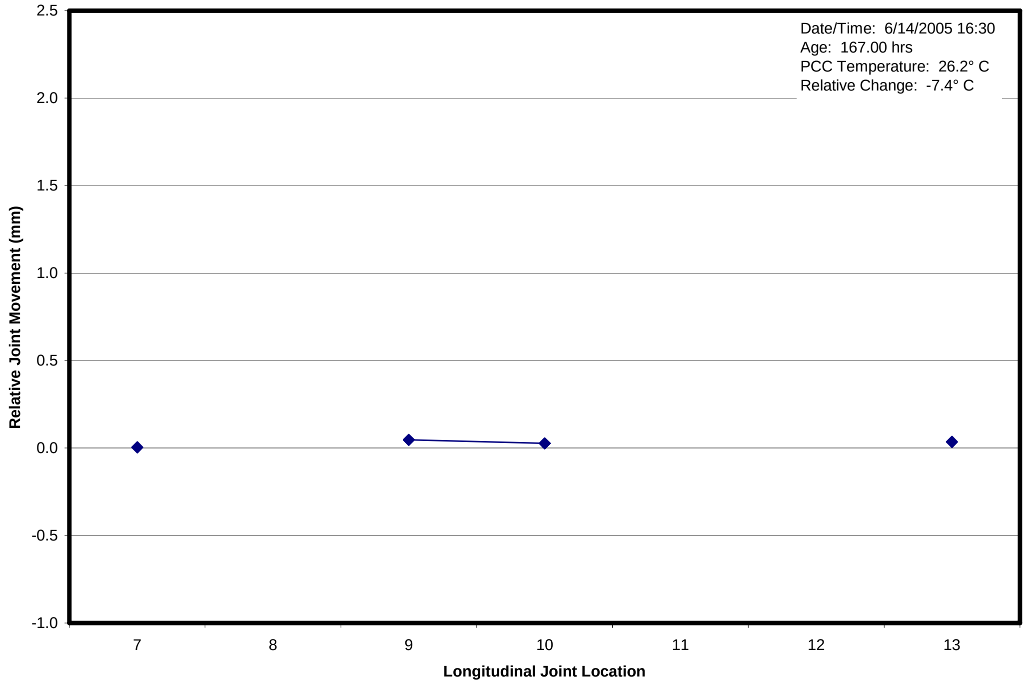


Figure F.27. Longitudinal joint relative opening

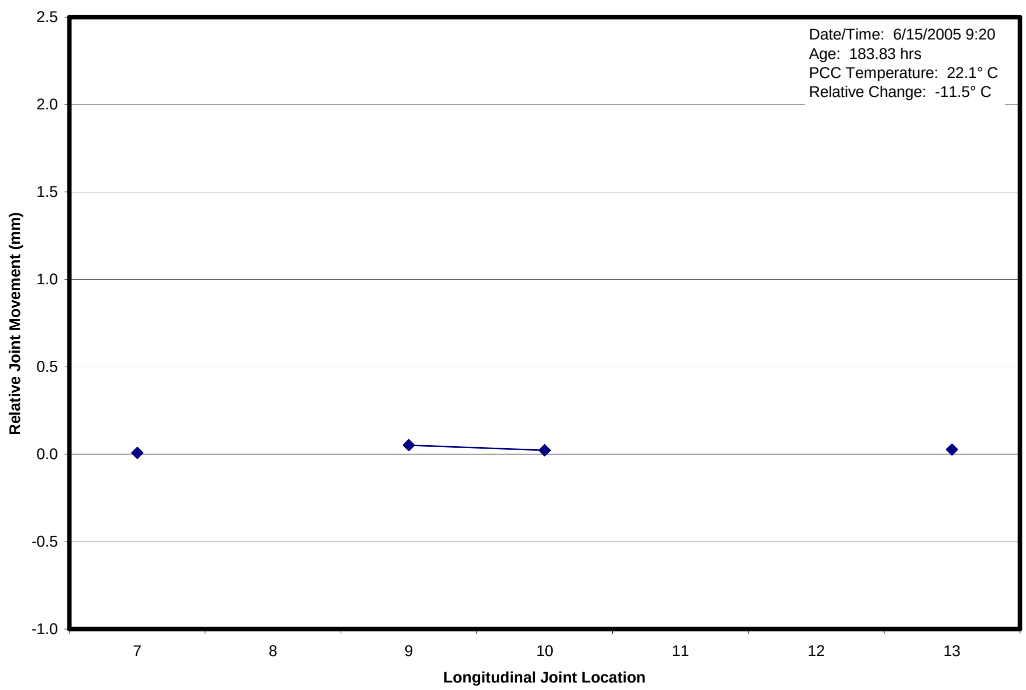


Figure F.28. Longitudinal joint relative opening

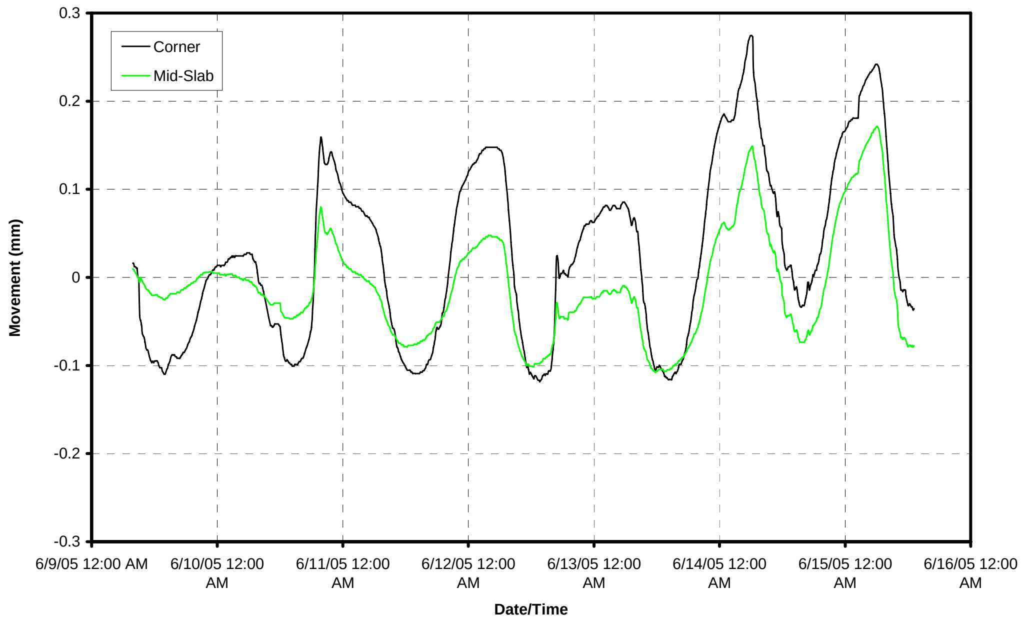


Figure F.29. LVDT record

Table F.1. Level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
08JN1814	6/8/2005 18:14	24.75	26.8	20.1	78.9	166.0	3.29
09JN0803	6/9/2005 8:03	38.58	23.7	20.6	75.8	161.9	3.32
09JN1446	6/9/2005 14:46	45.25	31.2	28.0	80.8	181.7	3.16
10JN0733	6/10/2005 7:33	62.08	26.7	22.4	79.8	170.4	3.25
10JN1429	6/10/2005 14:29	69.00	32.1	28.7	86.4	210.1	2.94
11JN0734	6/11/2005 7:34	86.08	24.2	20.9	79.0	172.9	3.23
11JN1459	6/11/2005 14:59	93.50	32.1	28.9	74.4	173.0	3.23
12JN0702	6/12/2005 7:02	109.50	24.9	20.4	80.2	182.4	3.15
12JN1315	6/12/2005 13:15	115.75	31.9	28.2	75.4	177.5	3.19
13JN0716	6/13/2005 7:16	133.75	25.2	21.0	78.9	173.1	3.23
13JN1310	6/13/2005 13:10	139.67	29.1	26.2	77.9	181.9	3.16
14JN0754	6/14/2005 7:54	158.42	23.7	18.9	82.6	194.6	3.06
14JN1615	6/14/2005 16:15	166.75	26.4	23.3	92.3	211.0	2.93
15JN0855	6/15/2005 8:55	183.42	21.6	20.3	75.8	174.0	3.22

Table F.2. Level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
08JN1836	6/8/2005 18:36	25.08	26.7	20.1	79.0	153.5	3.39
09JN0814	6/9/2005 8:14	38.75	23.9	21.0	70.9	162.0	3.32
09JN1456	6/9/2005 14:56	45.42	31.2	28.1	58.8	144.8	3.47
10JN0744	6/10/2005 7:44	62.25	26.9	22.9	67.1	159.5	3.34
10JN1436	6/10/2005 14:36	69.08	32.2	28.7	68.1	162.4	3.32
11JN0742	6/11/2005 7:42	86.17	24.2	21.3	64.8	161.9	3.32
11JN1508	6/11/2005 15:08	93.67	32.3	29.4	67.2	153.4	3.39
12JN0653	6/12/2005 6:53	109.42	25.0	20.4	66.3	174.8	3.22
12JN1323	6/12/2005 13:23	115.92	32.1	28.1	67.0	166.6	3.28
13JN0724	6/13/2005 7:24	133.92	25.1	20.8	64.1	134.6	3.56
13JN1318	6/13/2005 13:18	139.83	29.3	26.2	63.3	158.8	3.35
14JN0801	6/14/2005 8:01	158.50	23.7	18.9	67.6	169.6	3.26
14JN1622	6/14/2005 16:22	166.83	26.4	23.3	73.8	165.0	3.30
15JN0902	6/15/2005 9:02	183.50	21.6	20.3	62.3	161.4	3.33

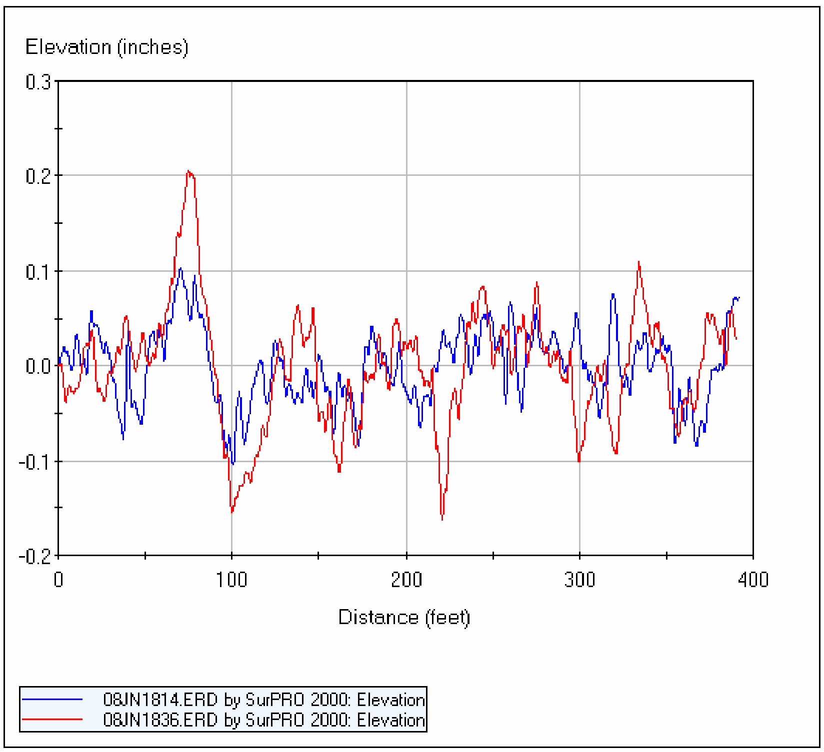


Figure F.30. Level A profile – June 8, 2005 afternoon

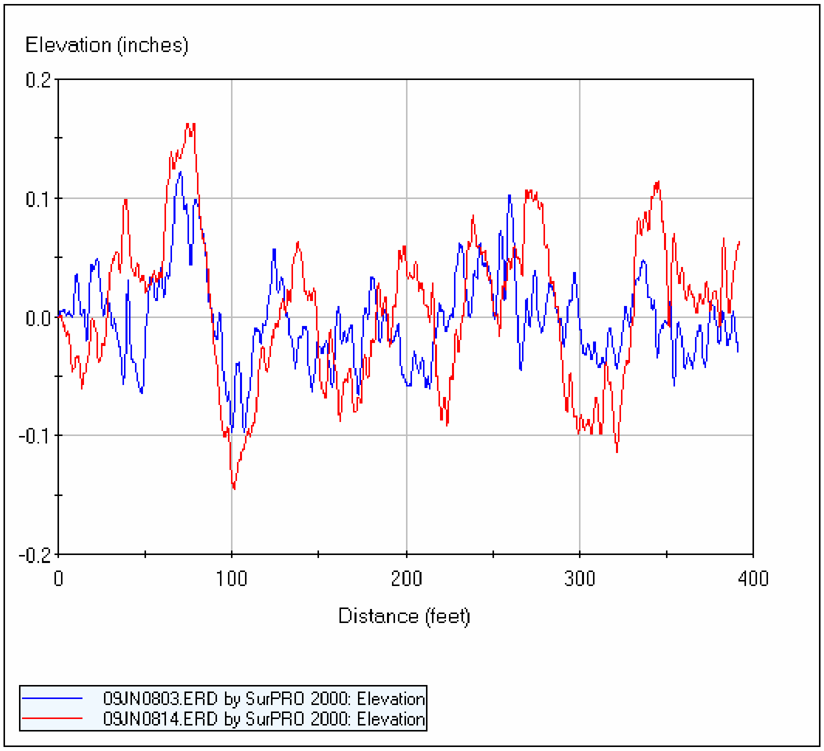


Figure F.31. Level A profile – June 9, 2005 morning

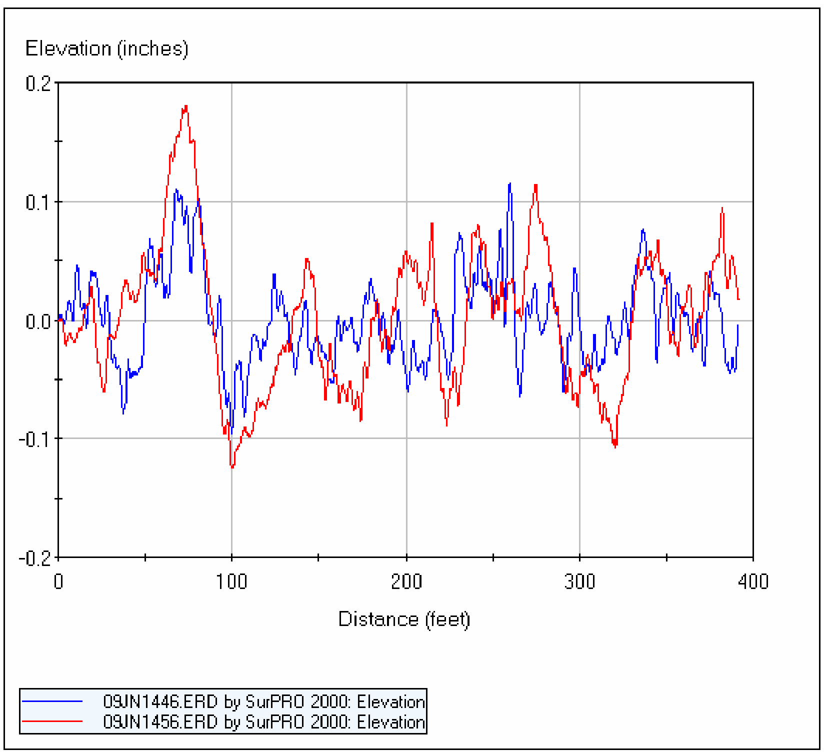


Figure F.32. Level A profile – June 9, 2005 afternoon

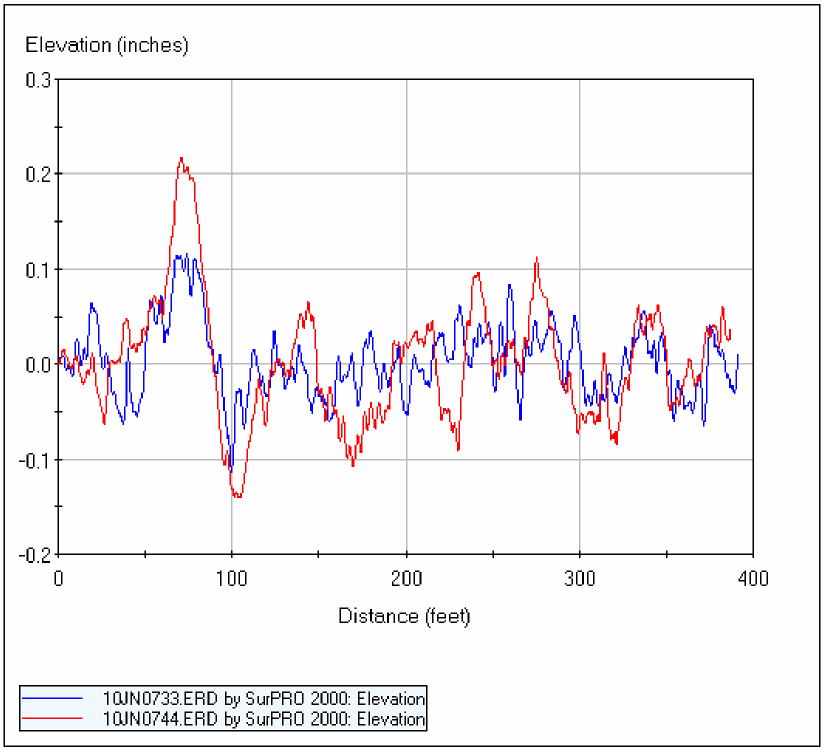


Figure F.33. Level A profile – June 10, 2005 morning

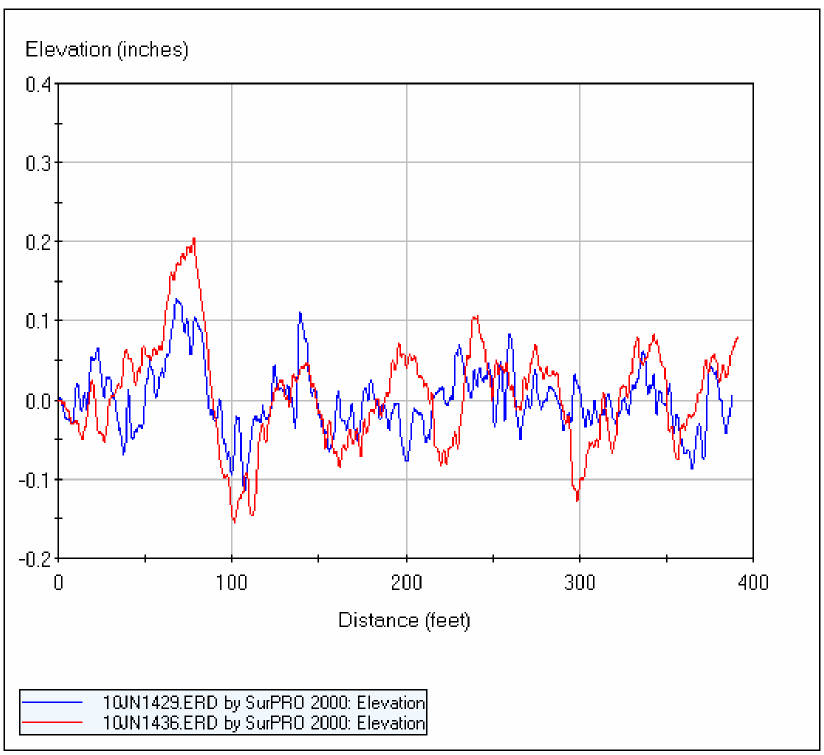


Figure F.34. Level A profile – June 10, 2005 afternoon

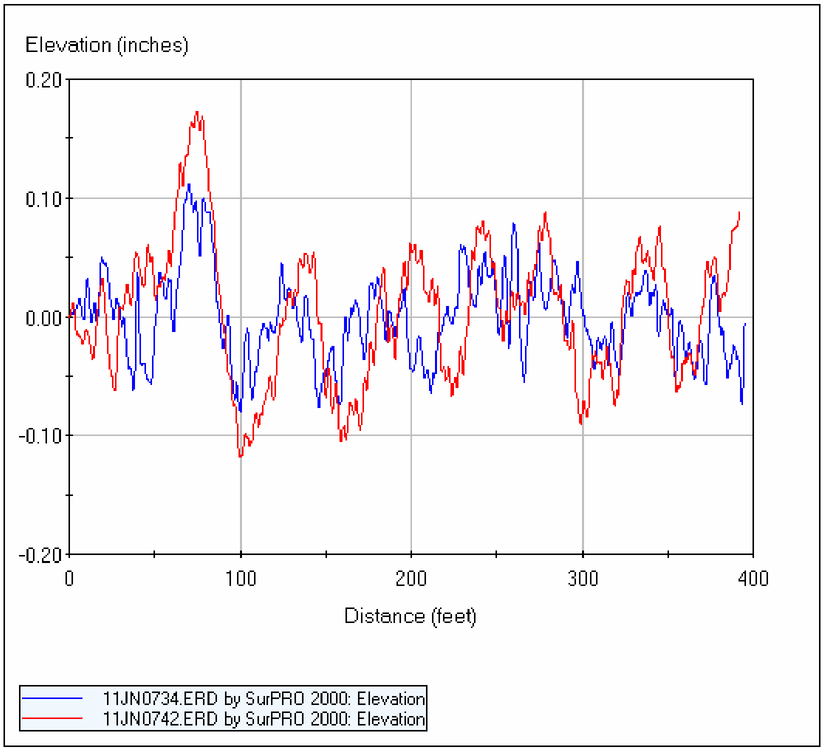


Figure F.35. Level A profile – June 11, 2005 morning

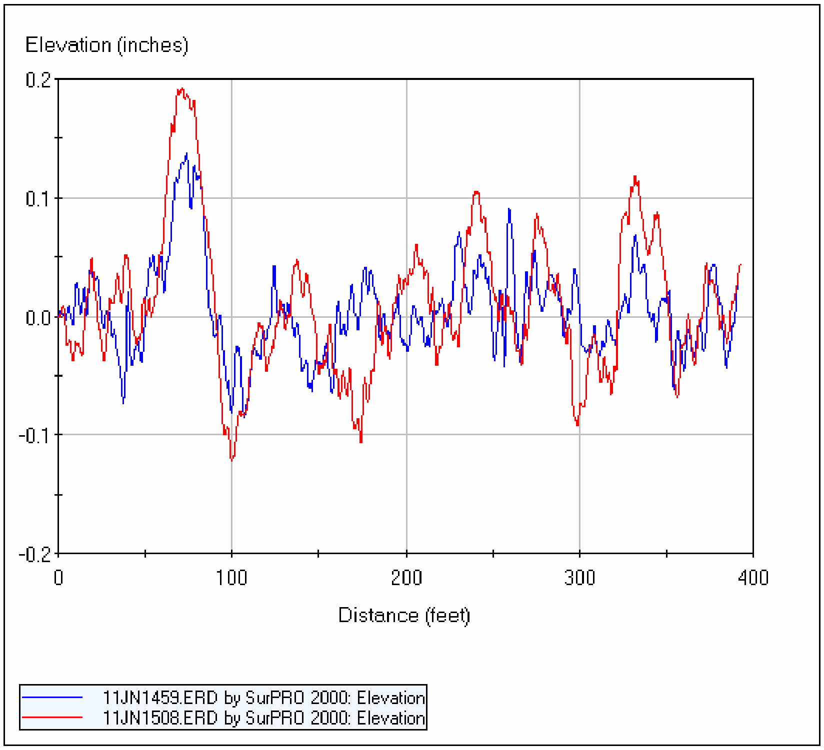


Figure F.36. Level A profile – June 11, 2005 afternoon

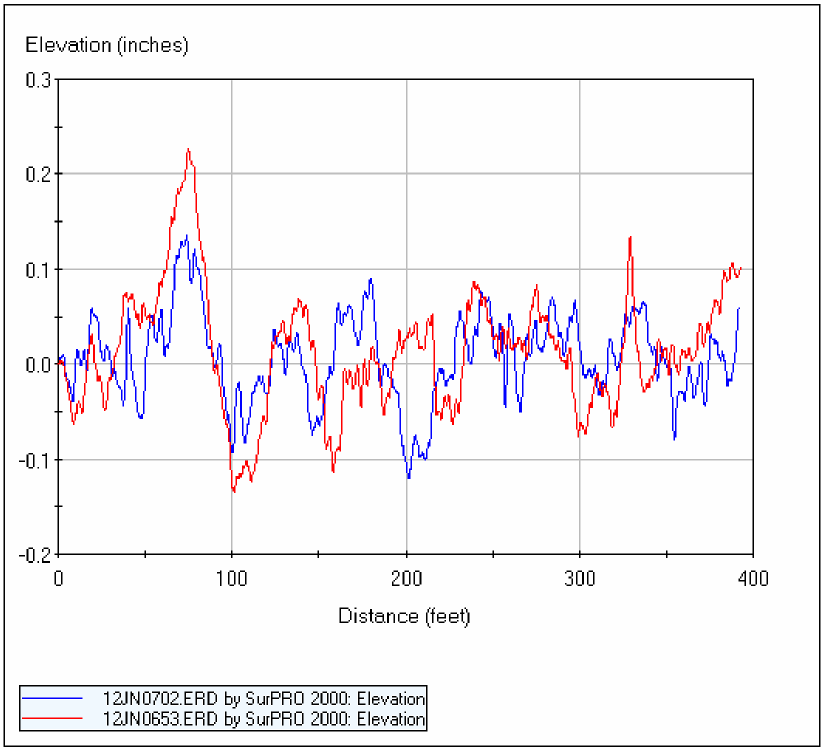


Figure F.37. Level A profile – June 12, 2005 morning

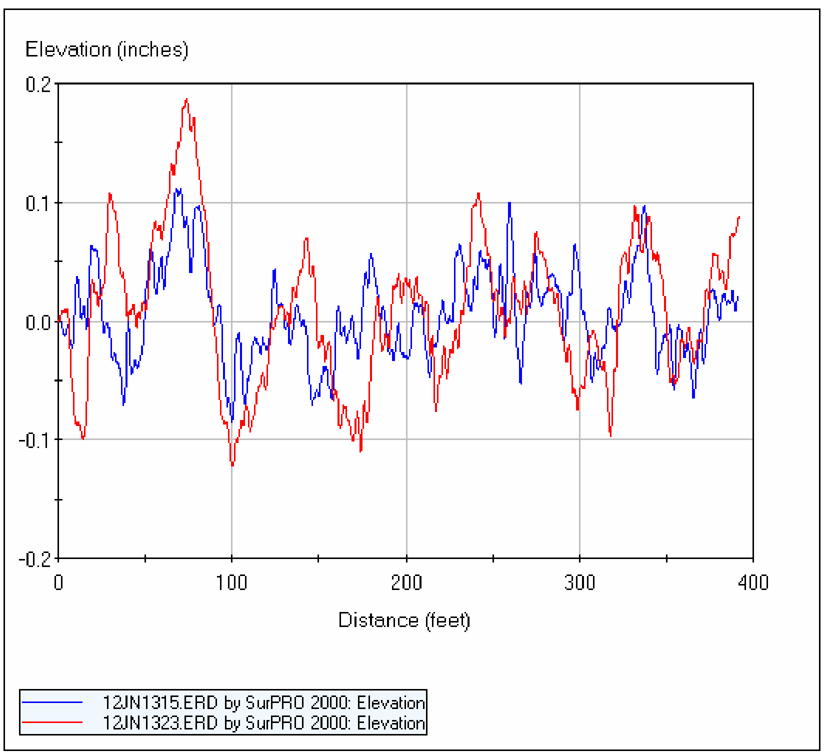


Figure F.38. Level A profile – June 12, 2005 afternoon

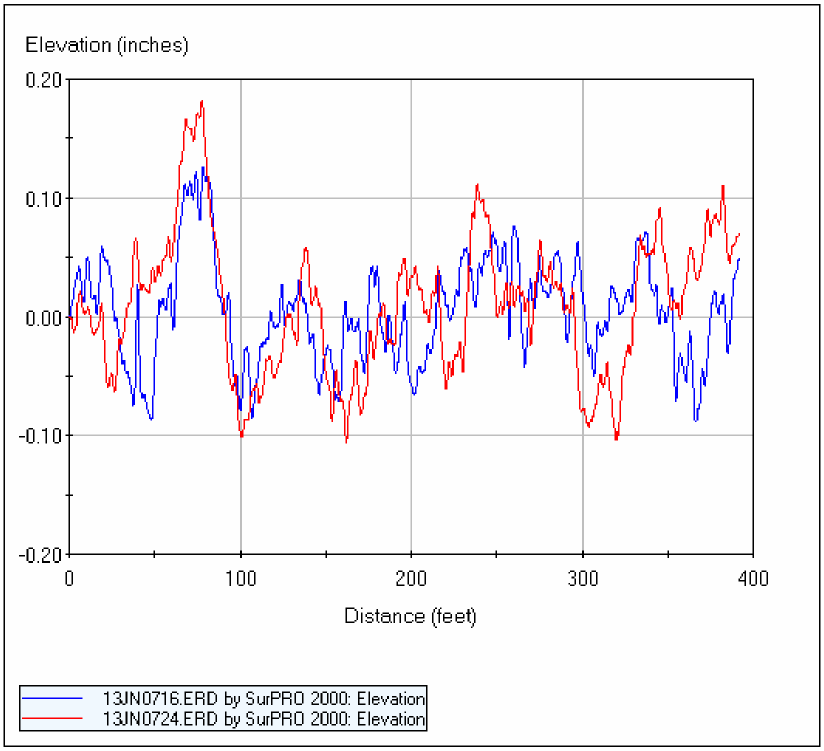


Figure F.39. Level A profile – June 13, 2005 morning

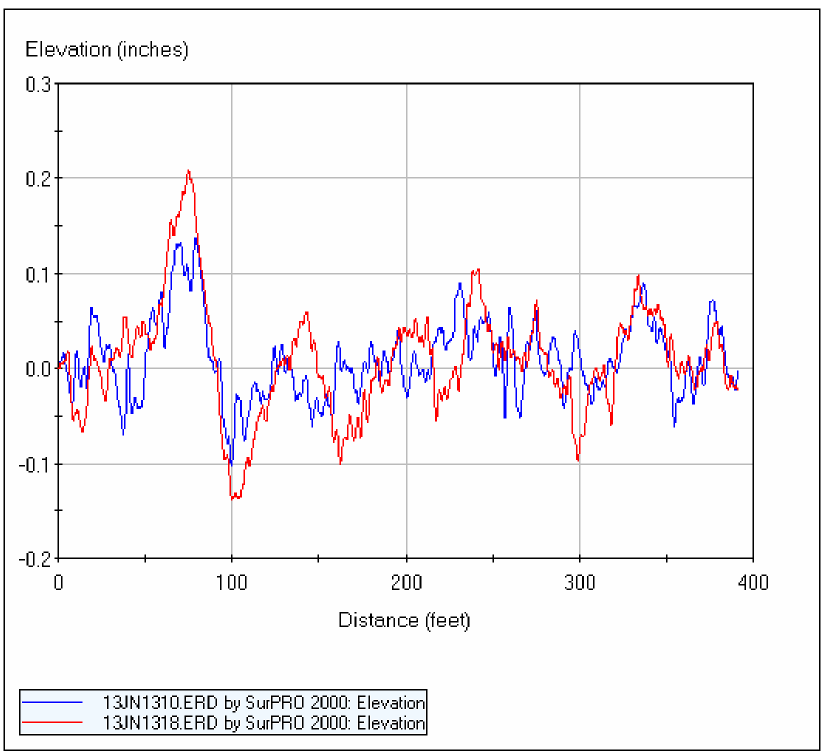


Figure F.40. Level A profile – June 13, 2005 afternoon

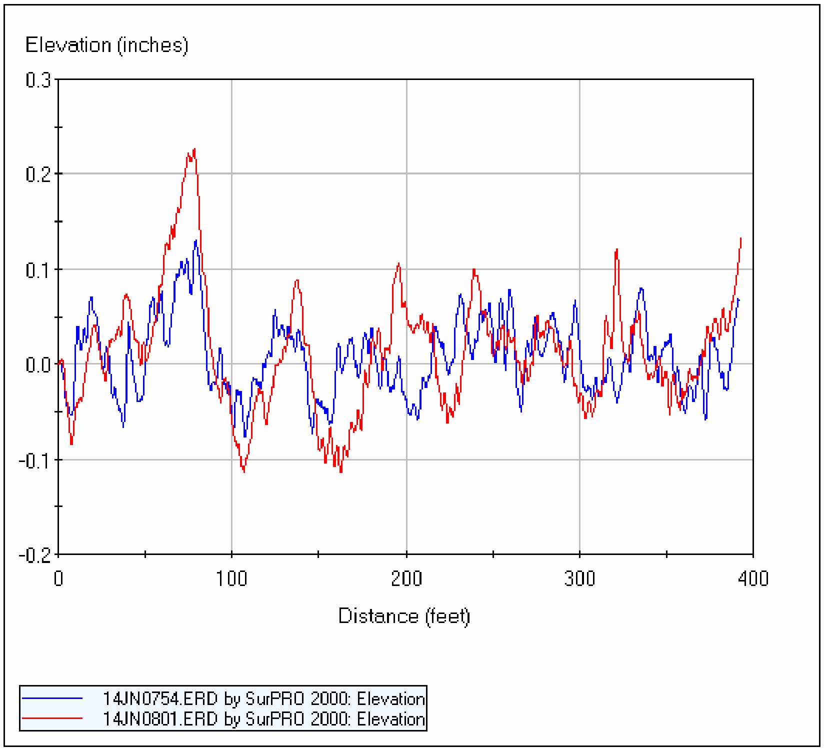


Figure F.41. Level A profile – June 14, 2005 morning

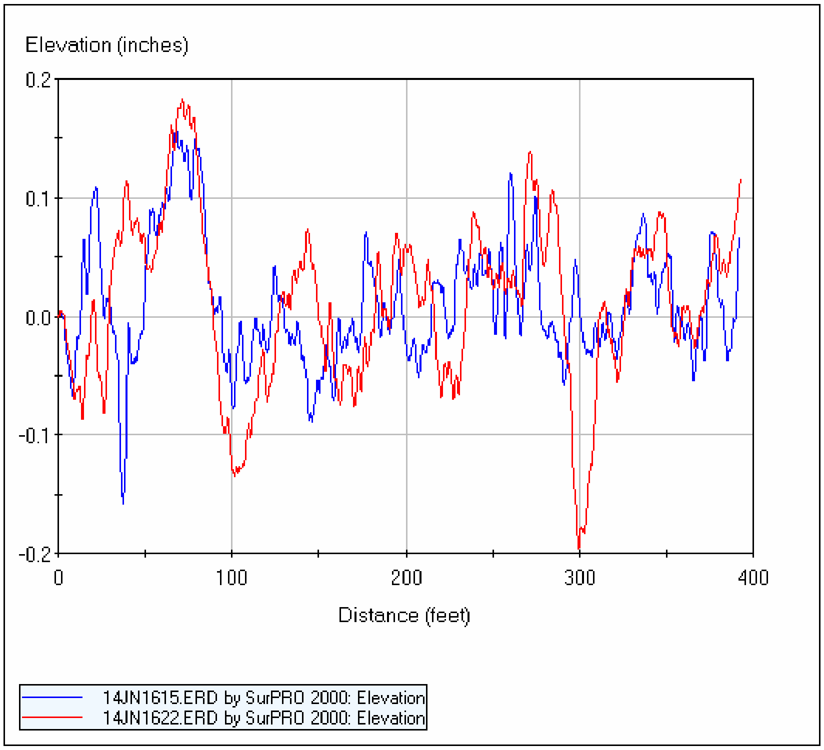


Figure F.42. Level A profile – June 14, 2005 afternoon

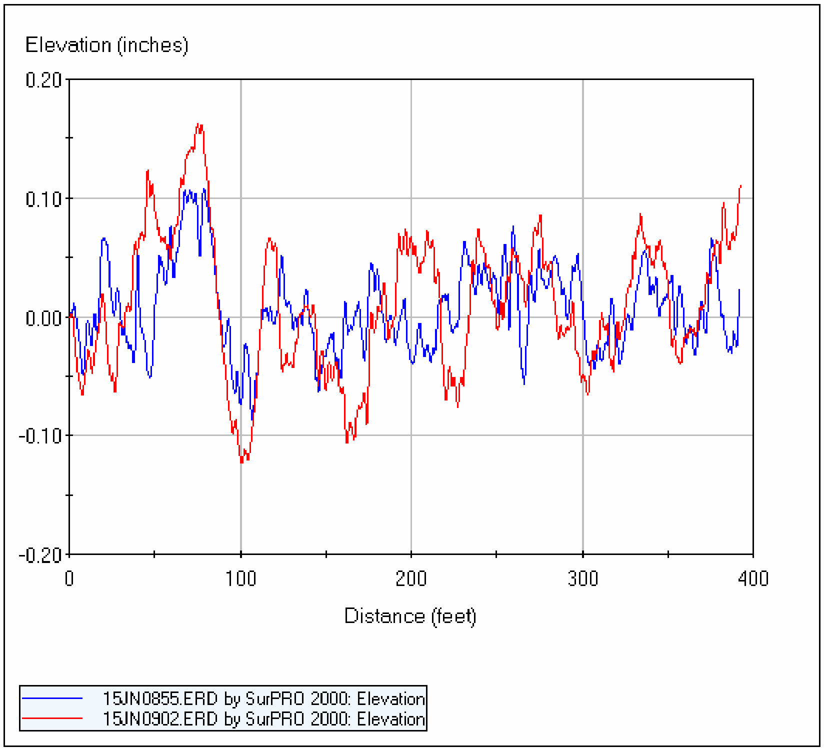


Figure F.43. Level A profile – June 15, morning

Table F.3. Level B profile summary (2 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
09JN0843	6/9/2005 8:43	39.25	24.2	22.1	94.2	195.4	3.05
09JN1509	6/9/2005 15:09	45.67	31.2	28.2	95.9	198.4	3.03
10JN0754	6/10/2005 7:54	62.42	27.0	23.2	96.2	220.0	2.87
10JN1443	6/10/2005 14:43	69.25	32.4	28.9	107.7	226.7	2.82
11JN1516	6/11/2005 15:16	93.75	32.3	29.4	104.1	231.1	2.79
12JN1333	6/12/2005 13:33	116.08	32.3	28.1	107.6	237.6	2.74
13JN0733	6/13/2005 7:33	134.08	25.1	20.8	98.5	174.9	3.21
13JN1326	6/13/2005 13:26	140.00	29.6	26.4	107.3	219.1	2.88
14JN0807	6/14/2005 8:07	158.67	23.8	18.9	102.0	231.4	2.79
14JN1629	6/14/2005 16:29	167.00	26.2	23.3	99.4	211.8	2.93
15JN0909	6/15/2005 9:09	183.67	21.9	21.3	96.1	203.0	2.99

Table F.4. Level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
09JN0849	6/9/2005 8:49	39.33	24.2	22.1	86.4	219.4	2.87
09JN1519	6/9/2005 15:19	45.83	31.2	28.2	77.7	183.8	3.14
10JN0811	6/10/2005 8:11	62.67	26.9	23.1	75.2	190.2	3.09
10JN1450	6/10/2005 14:50	69.33	32.6	28.9	74.1	173.9	3.22
11JN1525	6/11/2005 15:25	93.92	32.4	29.4	81.2	197.6	3.04
12JN1339	6/12/2005 13:39	116.17	32.4	28.3	72.4	179.6	3.18
13JN0742	6/13/2005 7:42	134.17	25.1	20.9	69.7	154.3	3.39
13JN1333	6/13/2005 13:33	140.08	29.6	26.4	78.8	186.4	3.12
14JN0814	6/14/2005 8:14	158.75	23.8	18.8	80	197.3	3.04
14JN1641	6/14/2005 16:41	167.17	26.3	23.2	76.6	188.7	3.10
15JN0917	6/15/2005 9:17	183.83	22.1	21.3	67.5	160.2	3.34

Table F.5. Level B profile summary (3 ft. from longitudinal joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
09JN0915	6/9/2005 9:15	39.75	24.7	22.9	76.6	168	3.27
09JN1531	6/9/2005 15:31	46.00	31.2	28.3	73.8	154.6	3.38
10JN0825	6/10/2005 8:25	62.92	26.9	23.3	68.8	152.0	3.41
10JN1458	6/10/2005 14:58	69.50	32.6	28.9	64.1	124.6	3.65
11JN1533	6/11/2005 15:33	94.08	32.6	29.4	66.0	139.2	3.52
12JN1349	6/12/2005 13:49	116.33	32.6	28.3	57.5	129.8	3.60
13JN0750	6/13/2005 7:50	134.33	25.0	20.9	59.9	113.6	3.75
13JN1341	6/13/2005 13:41	140.17	29.9	26.6	77.2	146.9	3.45
14JN0821	6/14/2005 8:21	158.83	23.8	18.8	65.0	150.1	3.42
14JN1650	6/14/2005 16:50	167.33	26.1	23.2	62.7	138.8	3.52
15JN0925	6/15/2005 9:25	183.92	22.1	21.2	58.4	124	3.66

Table F.6. Level B Profile Summary (1 ft. from Longitudinal Joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
09JN0920	6/9/2005 9:20	39.83	24.7	22.9	71.6	192.2	3.08
09JN1543	6/9/2005 15:43	46.25	31.4	28.8	68.6	181.8	3.16
10JN0834	6/10/2005 8:34	63.08	26.9	23.3	57.3	174.9	3.21
10JN1507	6/10/2005 15:07	69.67	32.8	28.9	56.7	160.0	3.34
11JN1546	6/11/2005 15:46	94.25	32.7	29.1	61.9	154.0	3.39
12JN1355	6/12/2005 13:55	116.42	32.6	28.9	62.4	163.8	3.31
13JN0758	6/13/2005 7:58	134.50	25.0	21.0	60.2	161.3	3.33
13JN1348	6/13/2005 13:48	140.33	30.0	26.6	68.8	178.2	3.19
14JN0826	6/14/2005 8:26	158.92	23.8	18.8	74.8	186.2	3.12
14JN1656	6/14/2005 16:56	167.42	26.1	23.7	69.1	159.7	3.34
15JN0932	6/15/2005 9:32	184.00	22.1	21.2	59.0	145.8	3.46

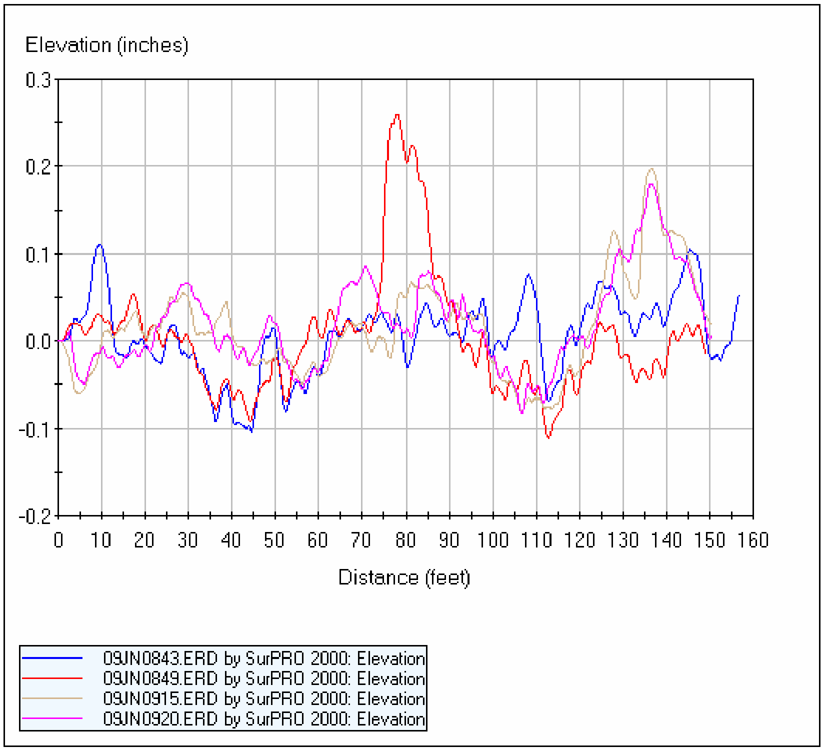


Figure F.44. Level B profile – June 9, 2005 morning

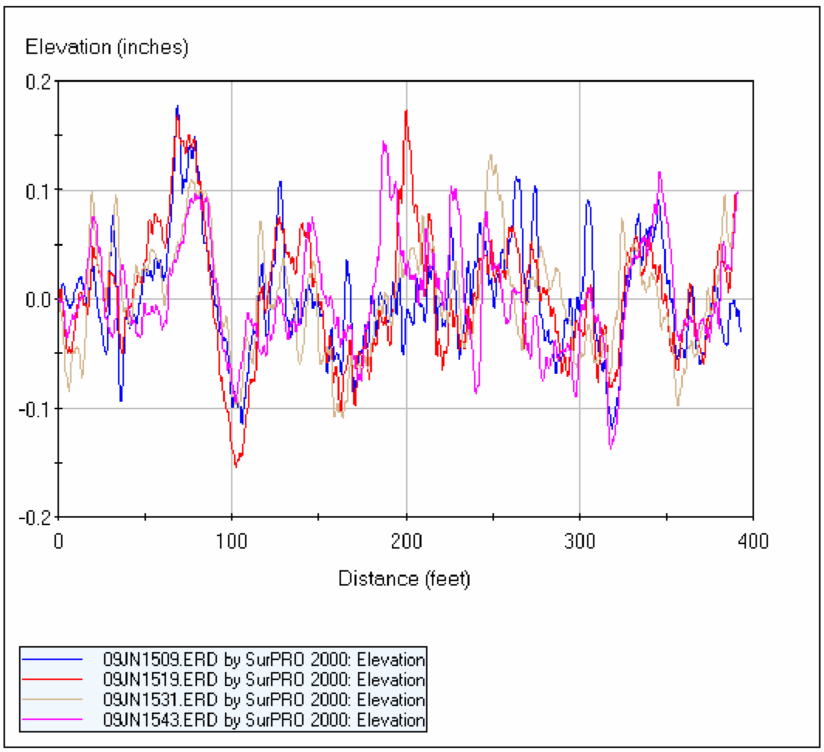


Figure F.45. Level B profile – June 9, 2005 afternoon

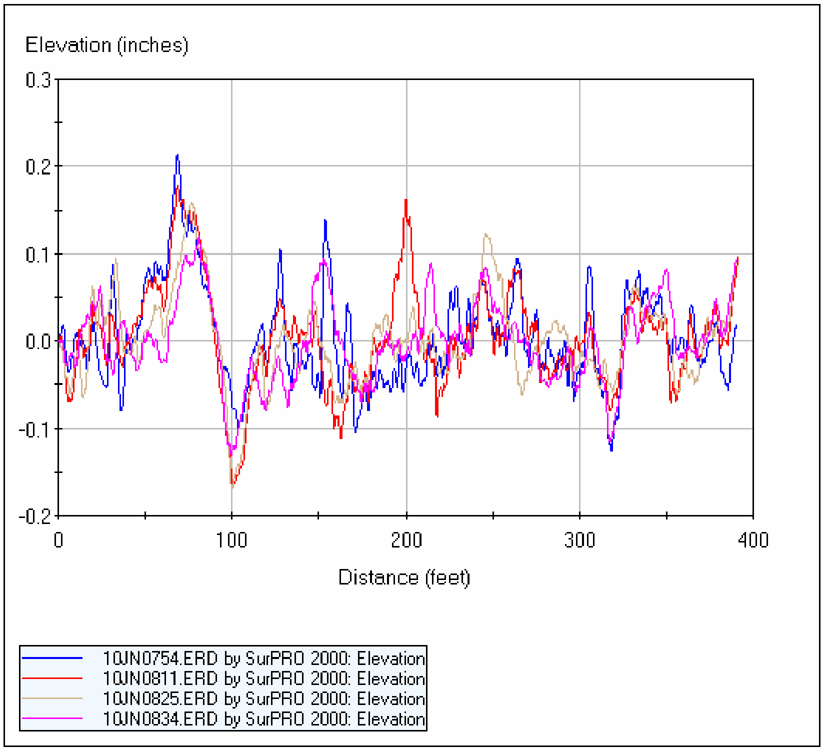


Figure F.46. Level B profile – June 10, 2005 morning

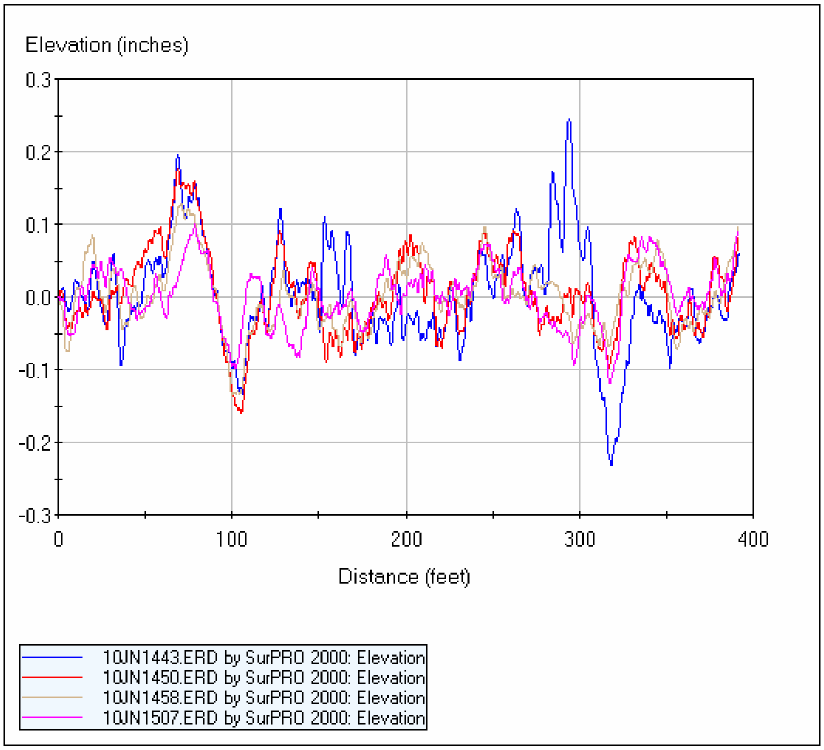


Figure F.47. Level B profile – June 10, 2005 afternoon

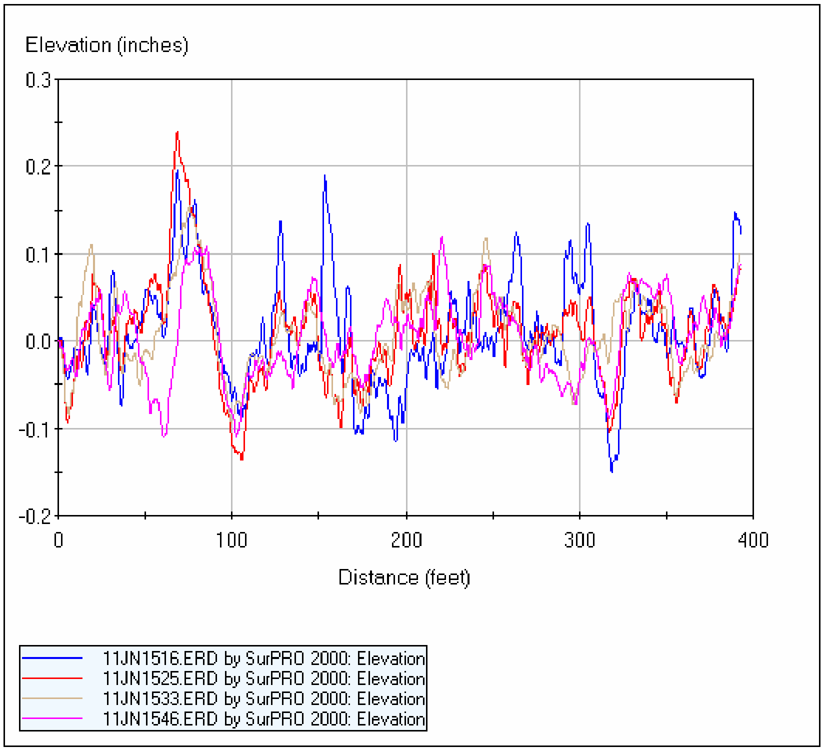


Figure F.48. Level B profile – June 11, 2005 afternoon

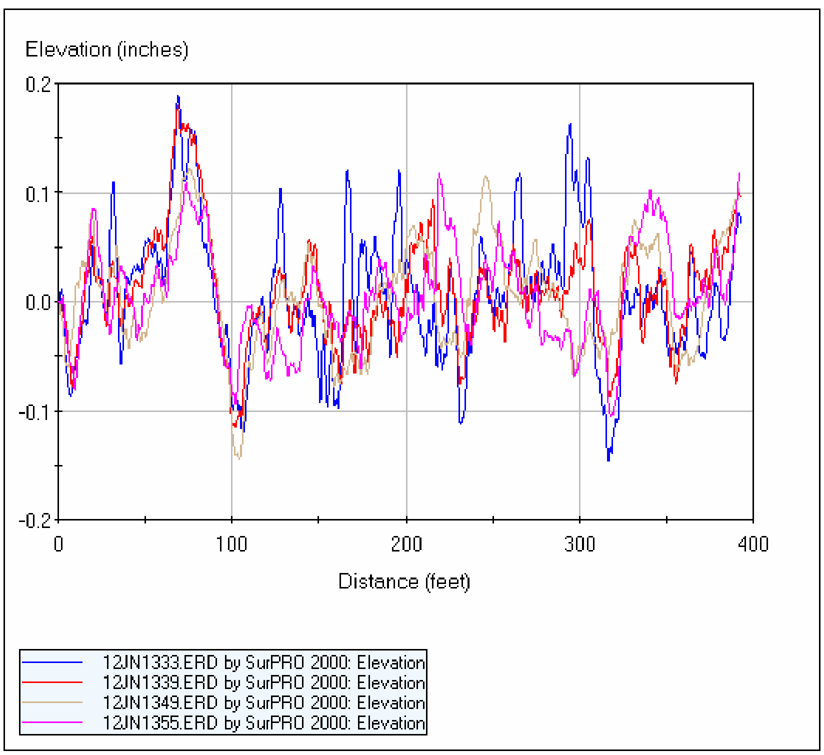


Figure F.49. Level B profile – June 12, 2005 afternoon

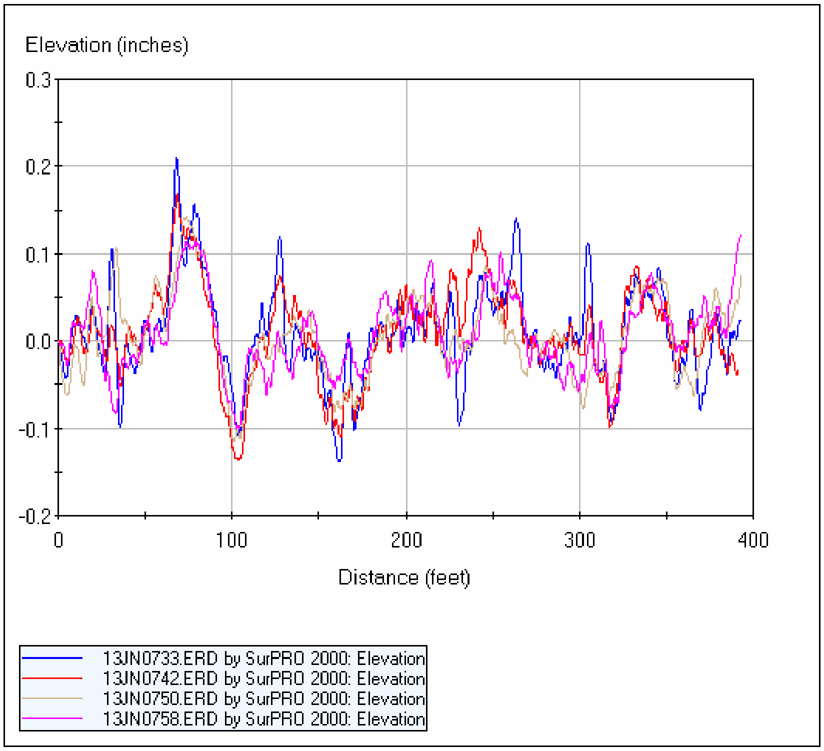


Figure F.50. Level B profile – June 13, 2005 morning

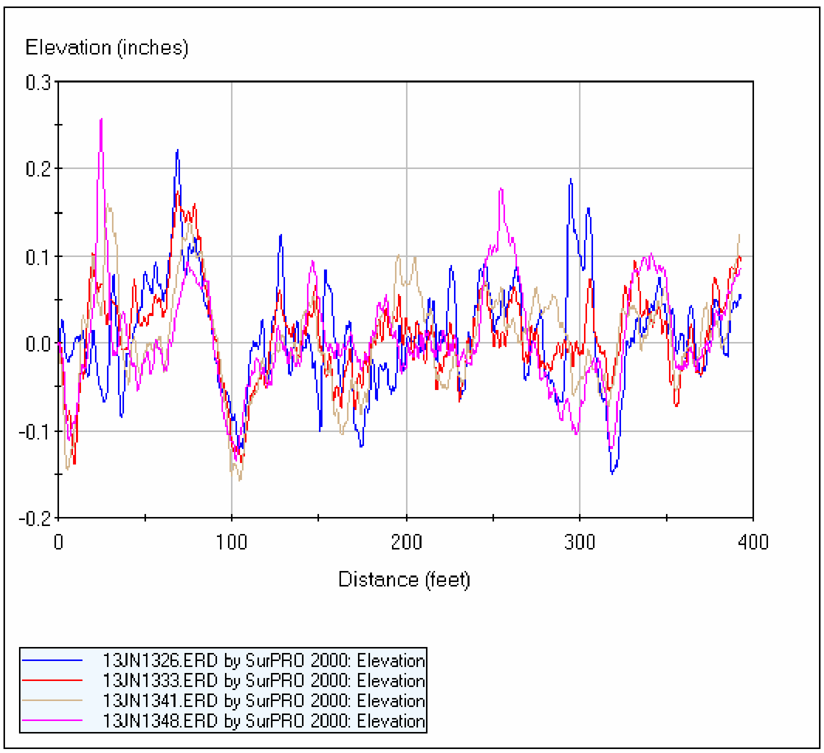


Figure F.51. Level B profile – June 13, 2005 afternoon

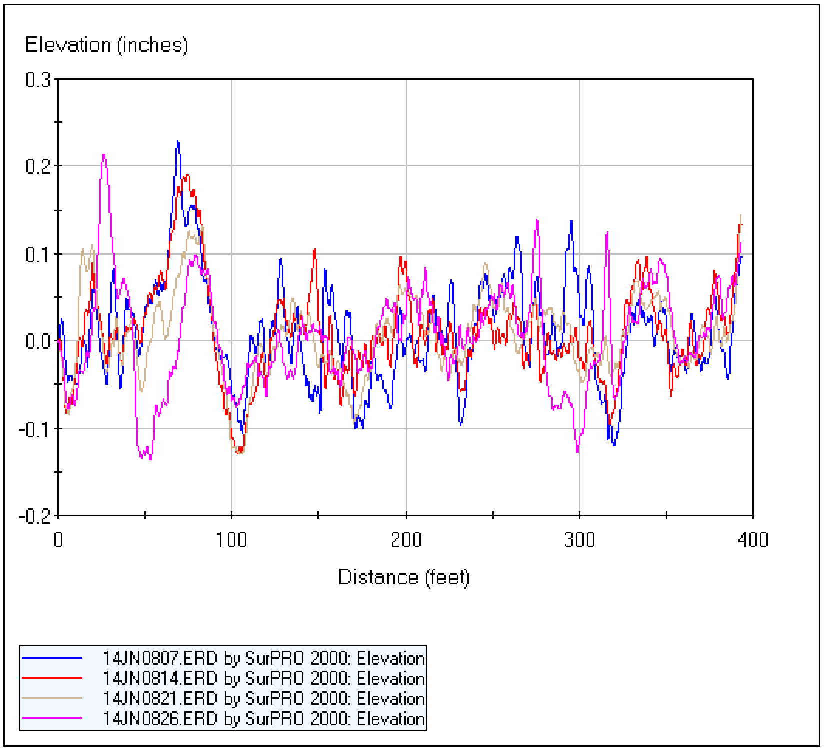


Figure F.52. Level B profile – June 14, 2005 morning

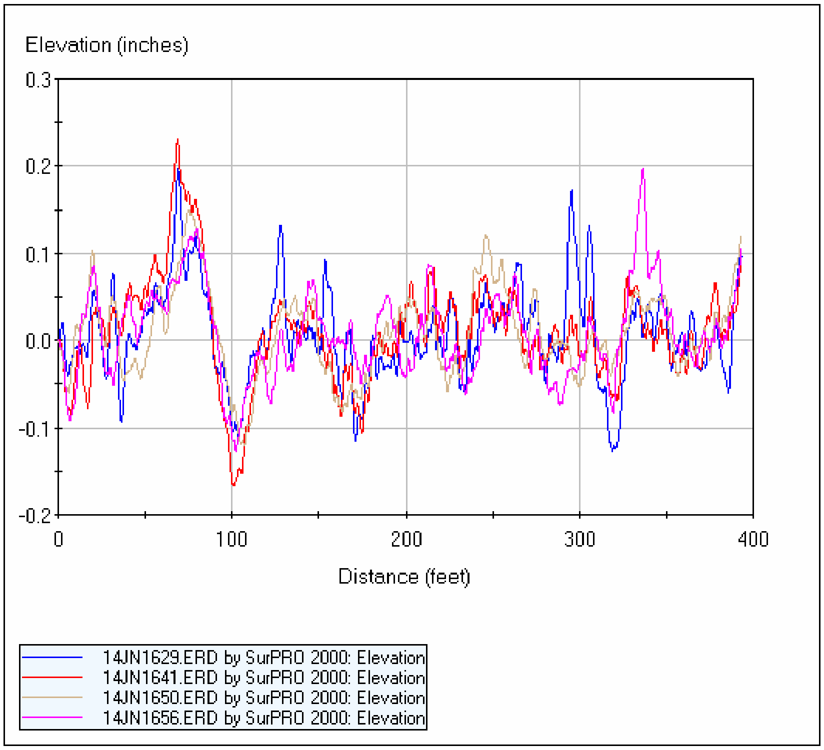


Figure F.53. Level B profile – June 14, 2005 afternoon

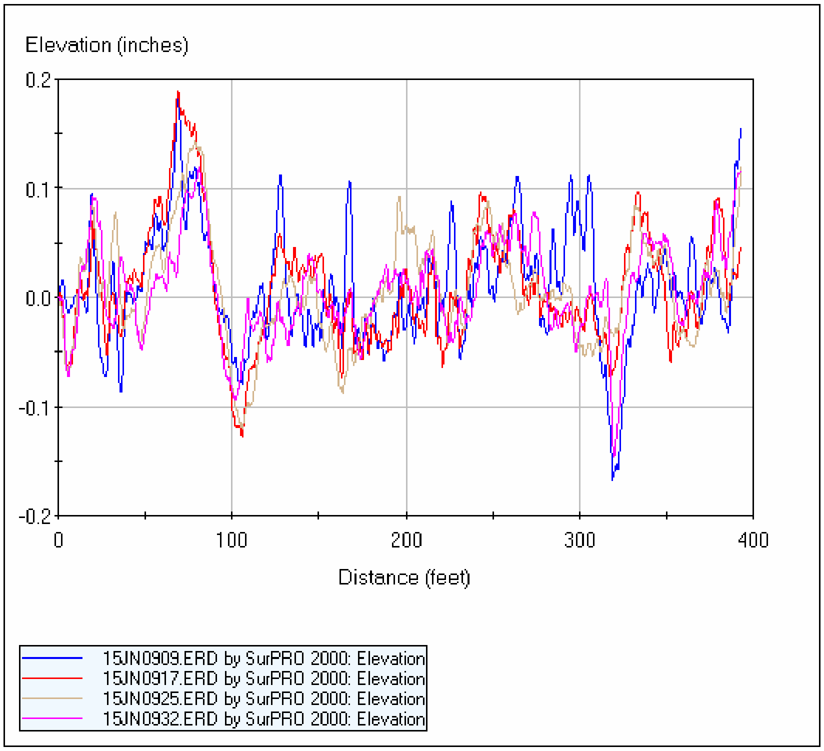


Figure F.54. Level B profile – June 15, 2005 morning

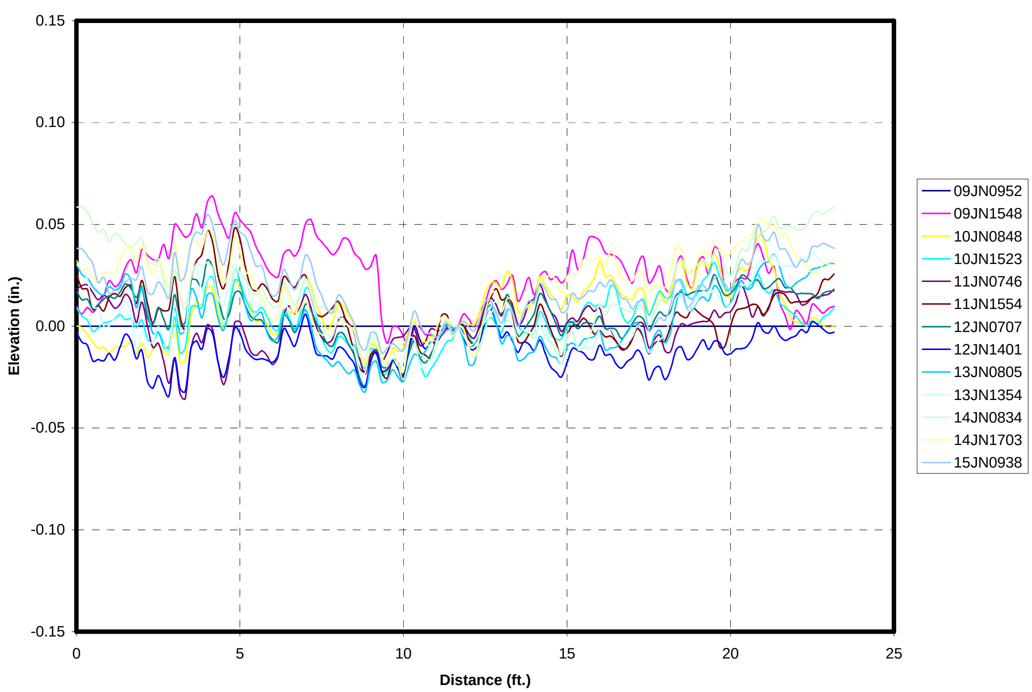


Figure F.55. Level C profiles path 1 – slab 9

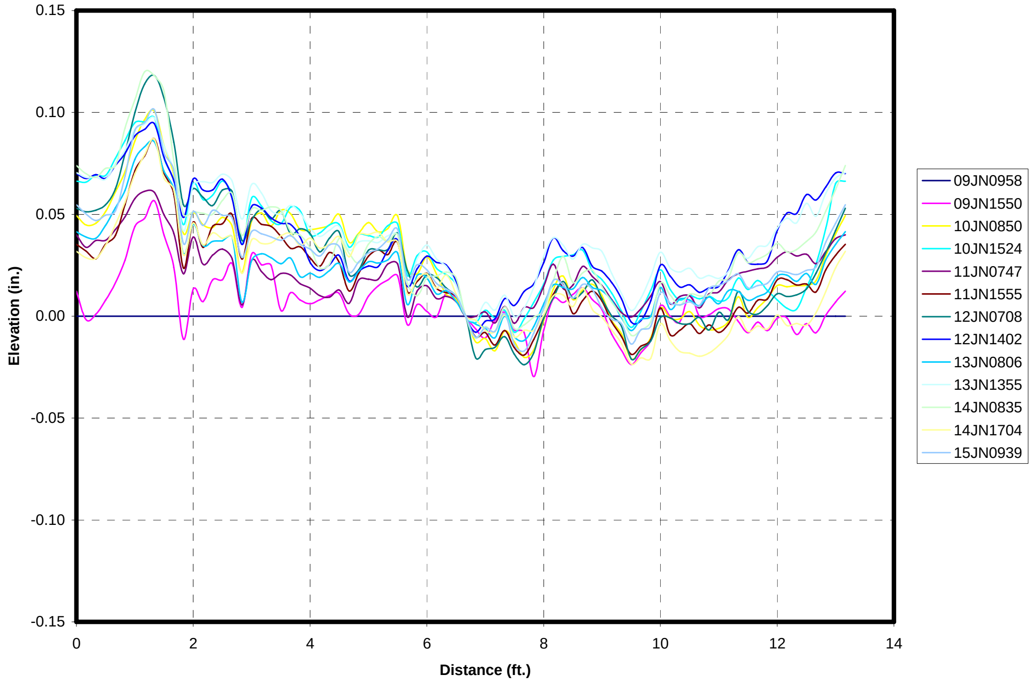


Figure F.56. Level C profiles path 2 – slab 9

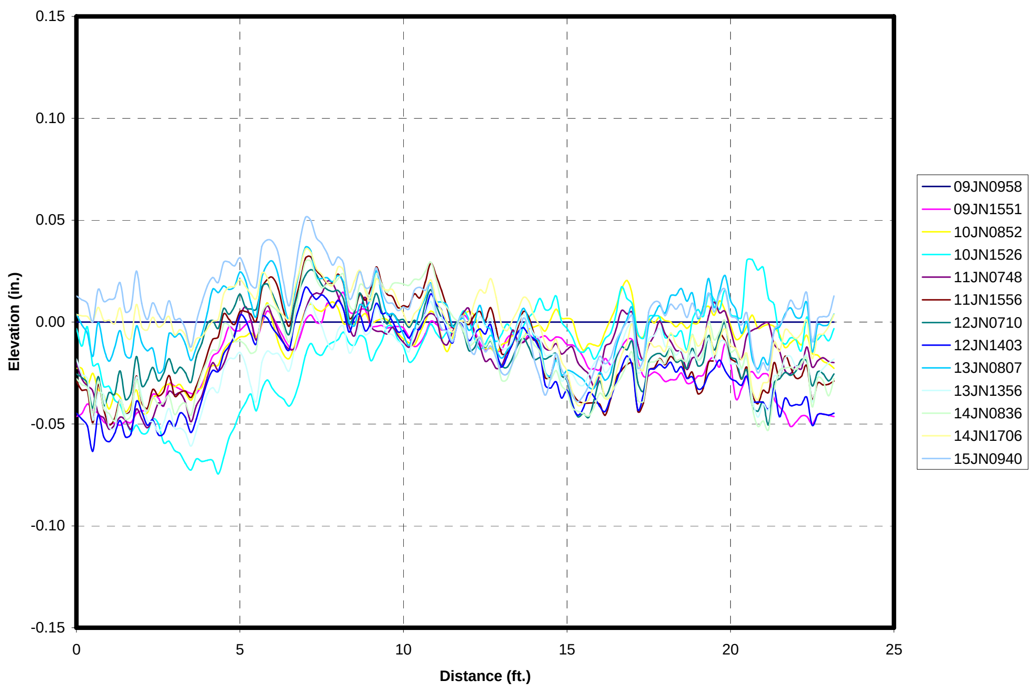


Figure F.57. Level C profiles path 3 – slab 9

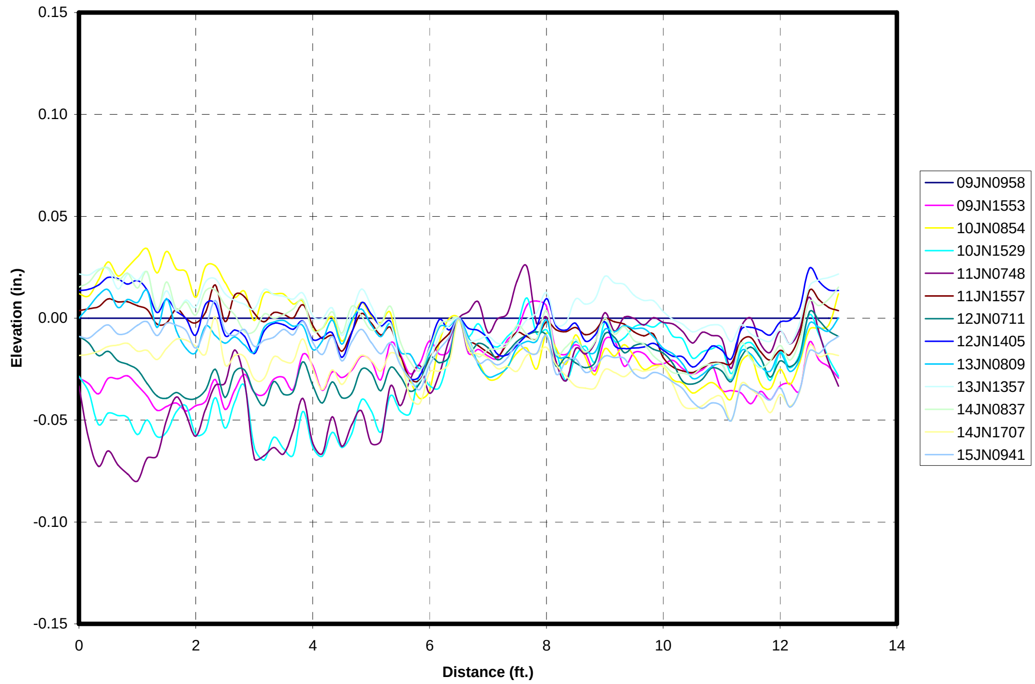


Figure F.58. Level C profiles path 4 – slab 9

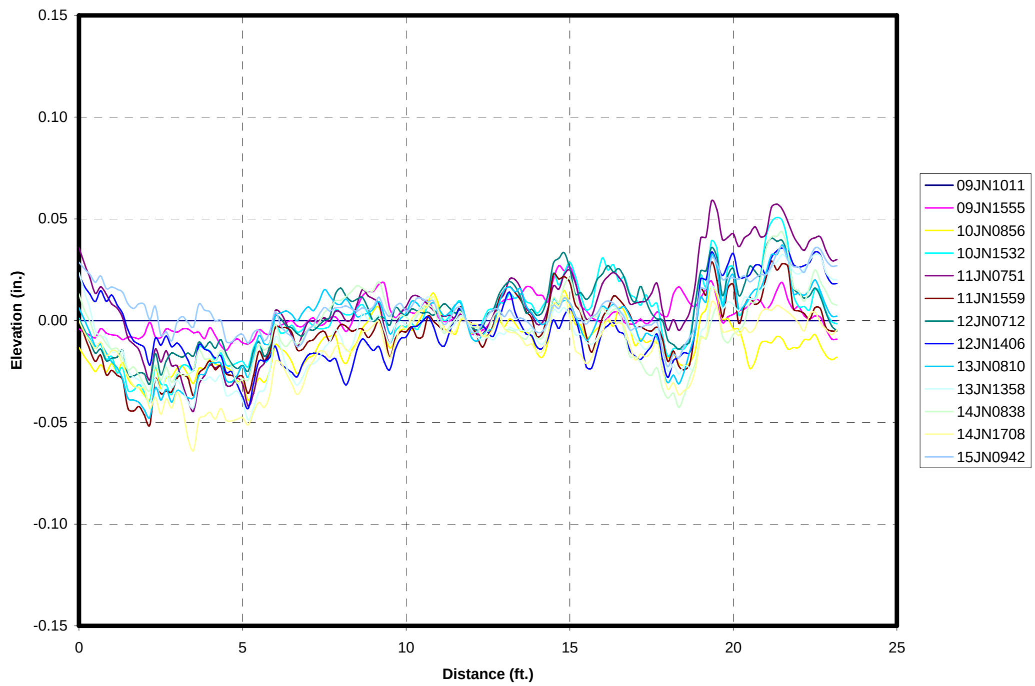


Figure F.59. Level C profiles path 1 – slab 10

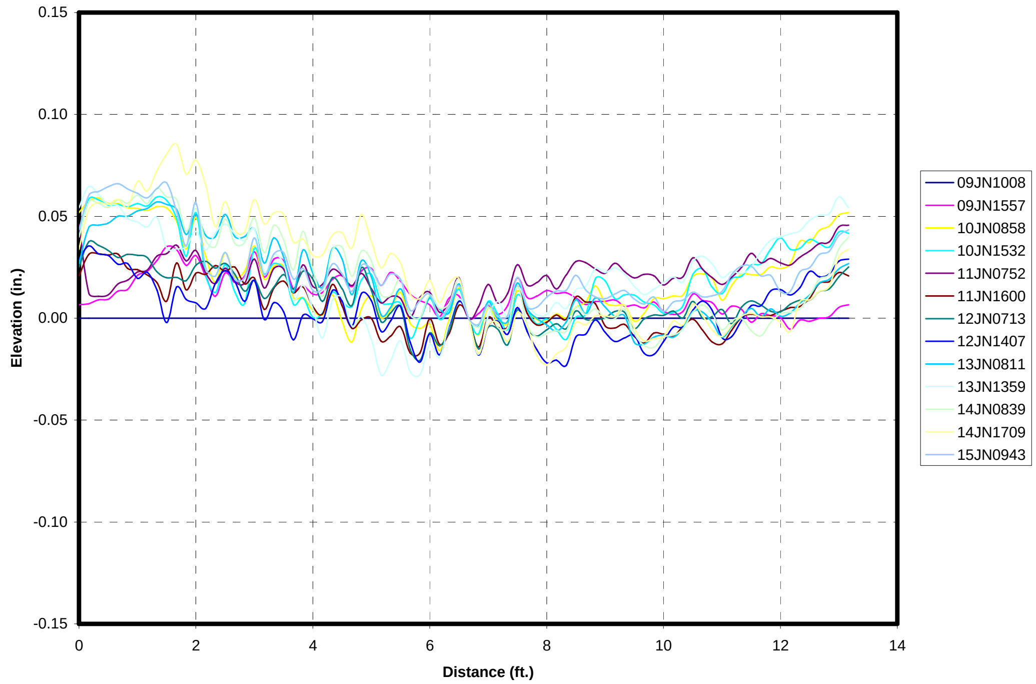


Figure F.60. Level C profiles path 2 – slab 10

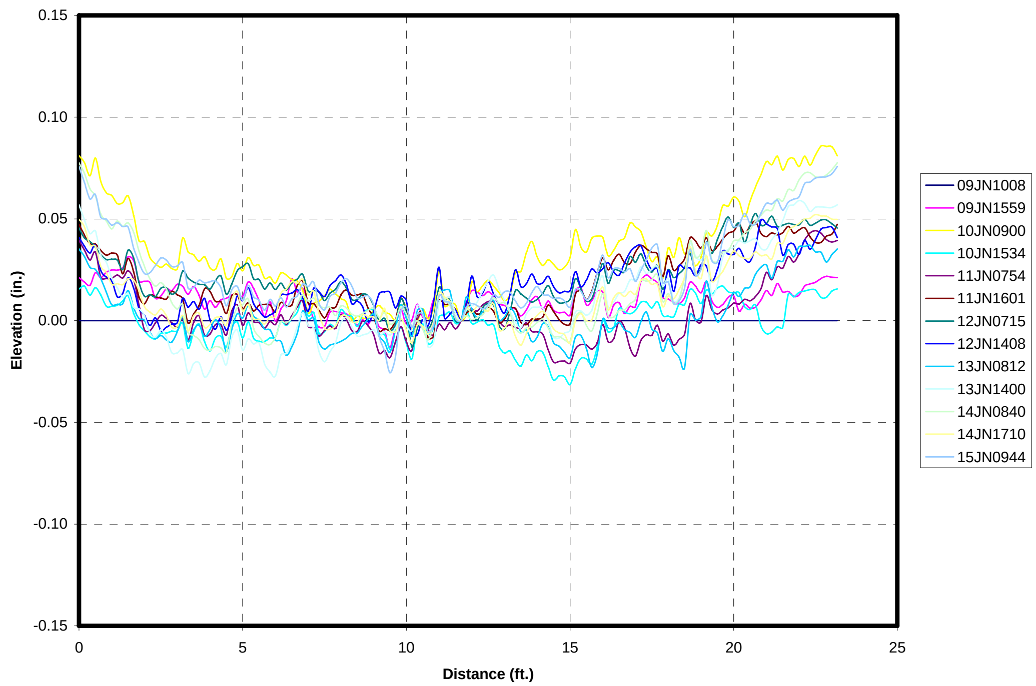


Figure F.61. Level C profiles path 3 – slab 10

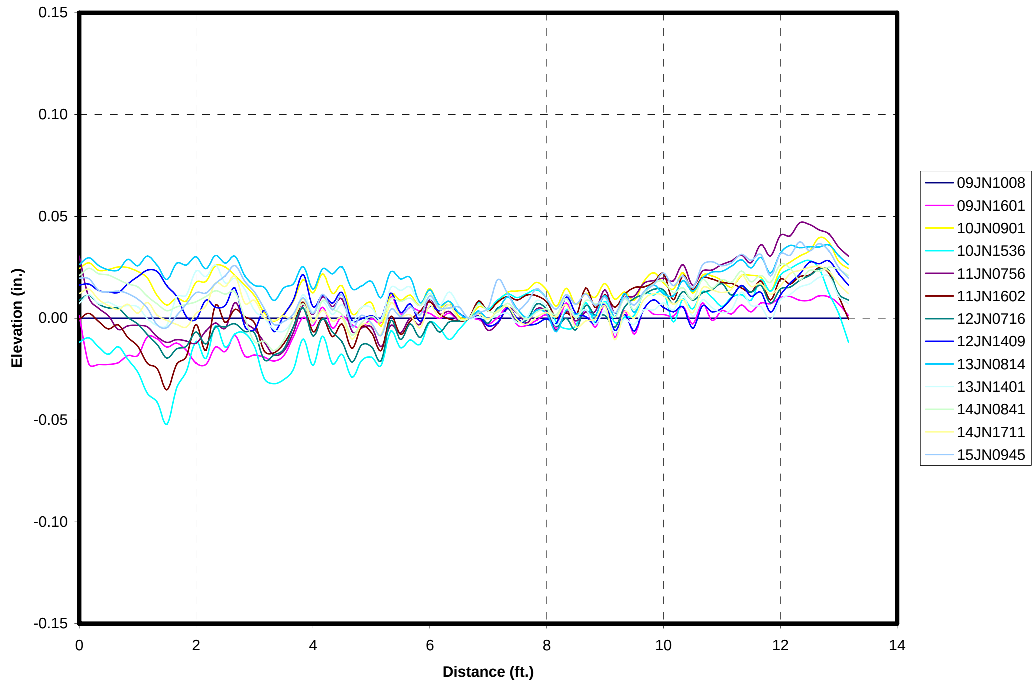


Figure F.62. Level C profiles path 4 – slab 10

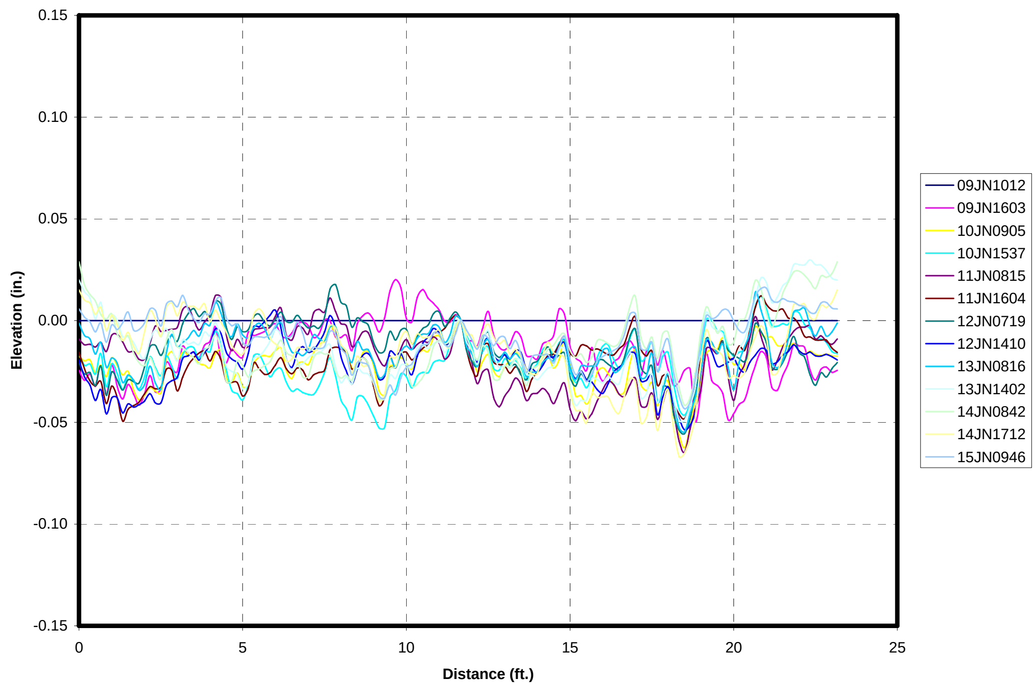


Figure F.63. Level C profiles path 1 – slab 11

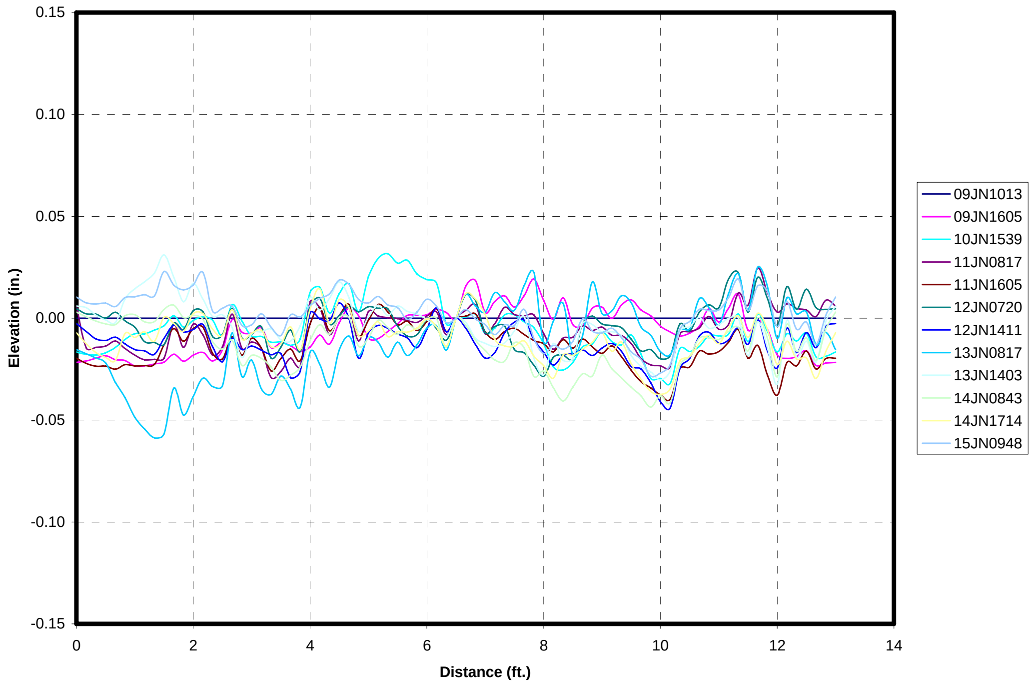


Figure F.64. Level C profiles path 2 – slab 11

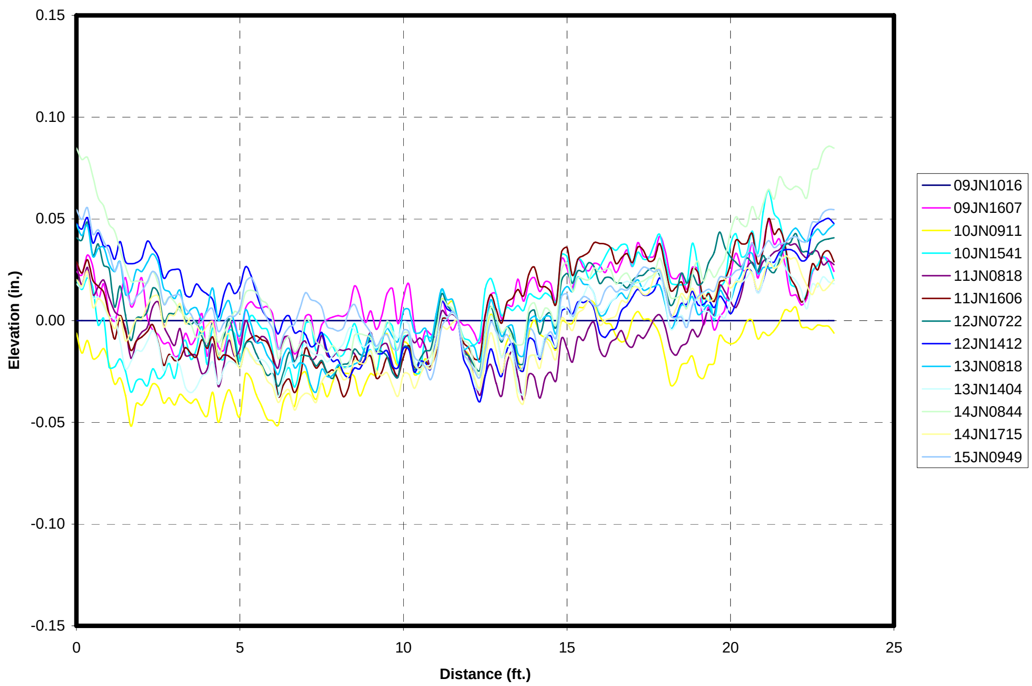


Figure F.65. Level C profiles path 3 – slab 11

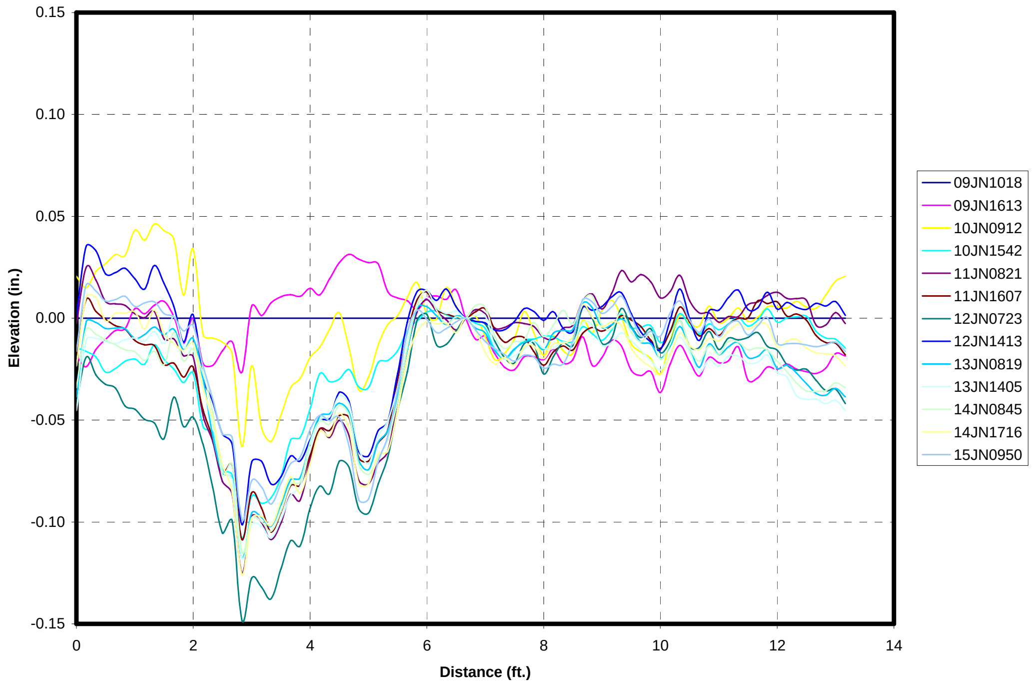


Figure F.66. Level C profiles path 4 – slab 11

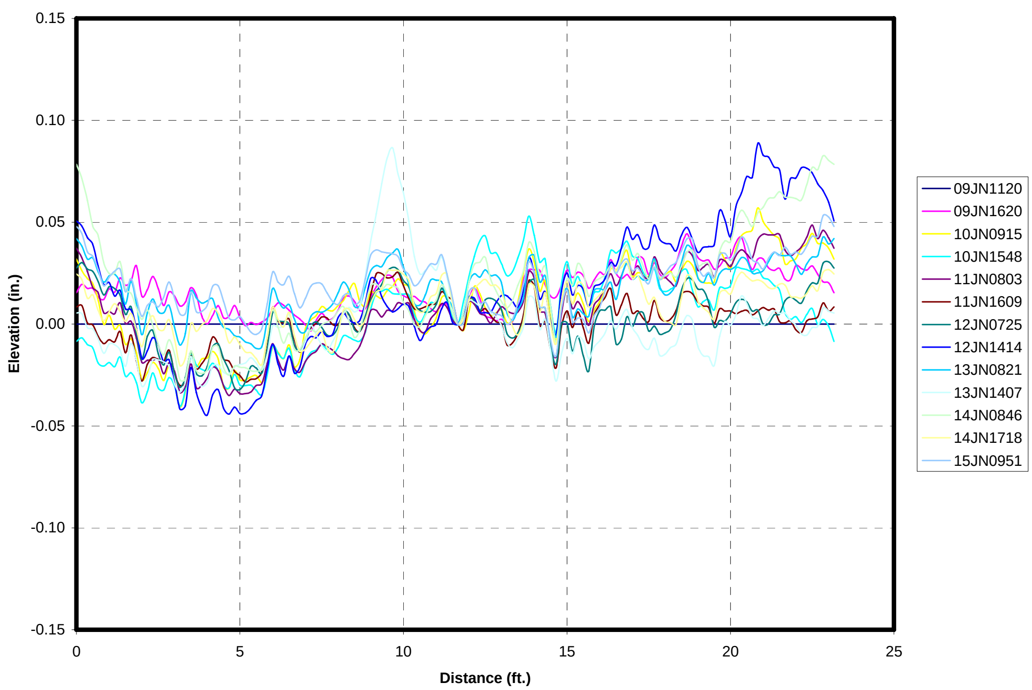


Figure F.67. Level C profiles path 1 – slab 12

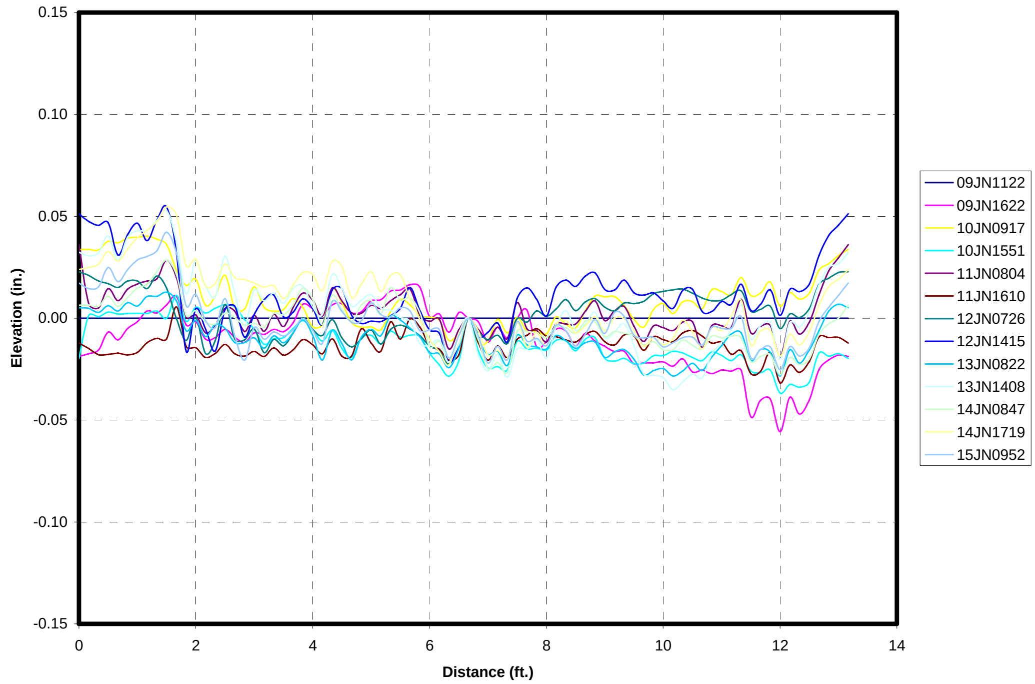


Figure F.68. Level C profiles path 2 – slab 12

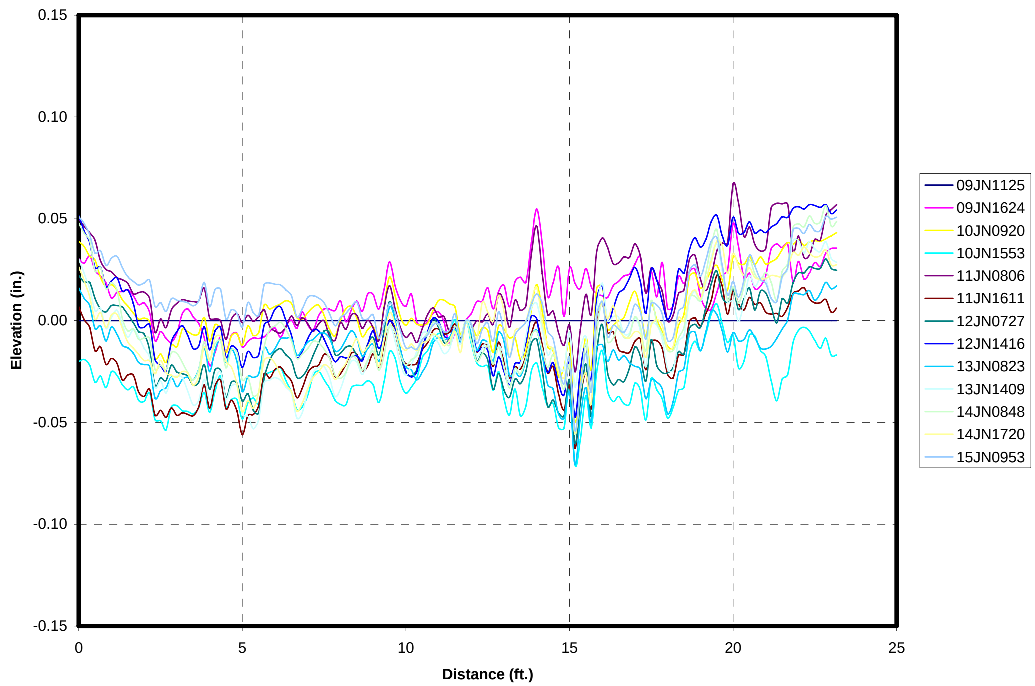


Figure F.69. Level C profiles path 3 – slab 12

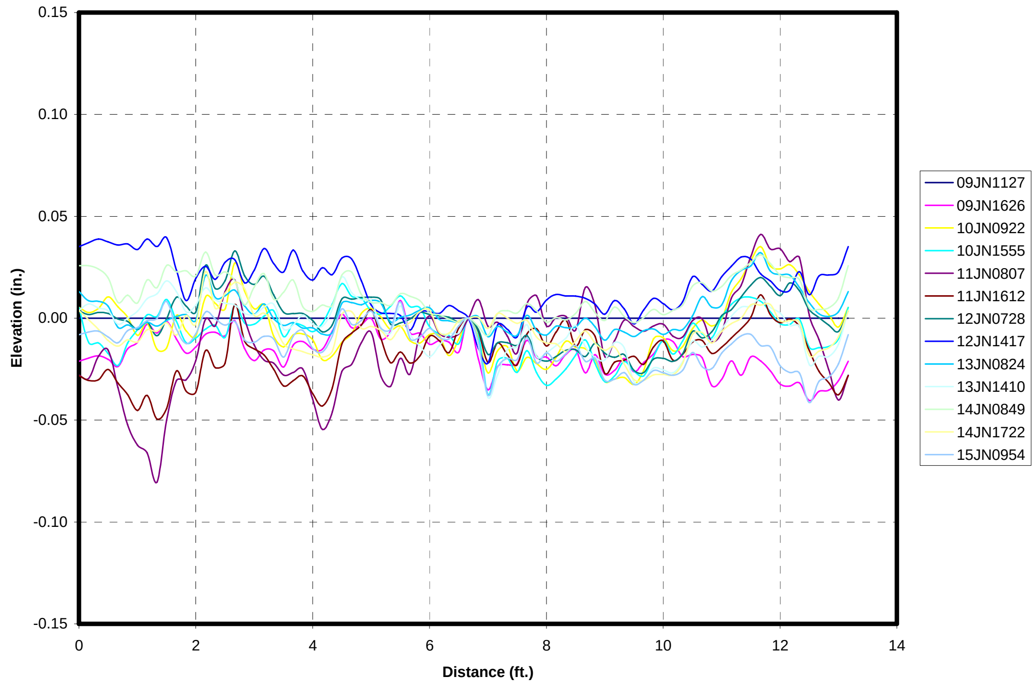


Figure F.70. Level C profiles path 4 – slab 12

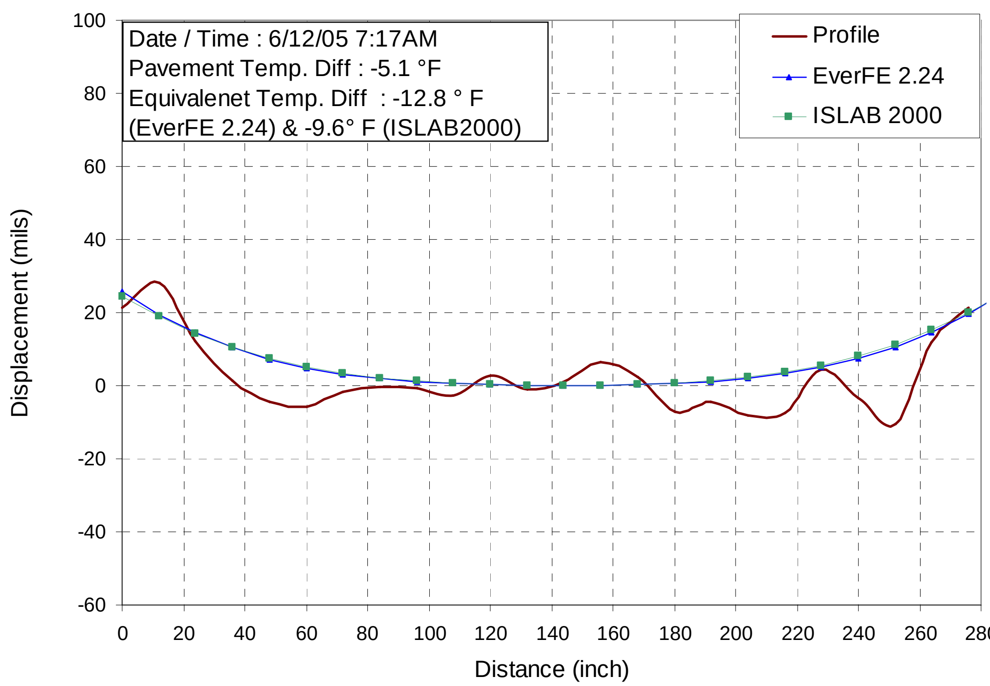


Figure F.71. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 12 morning

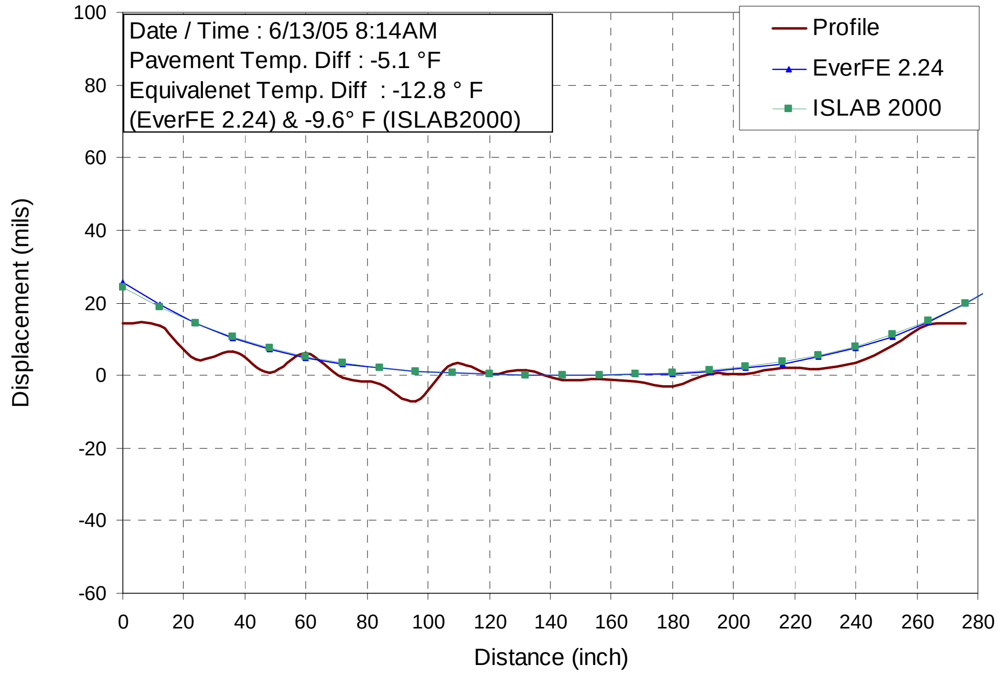


Figure F.72. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 13 morning

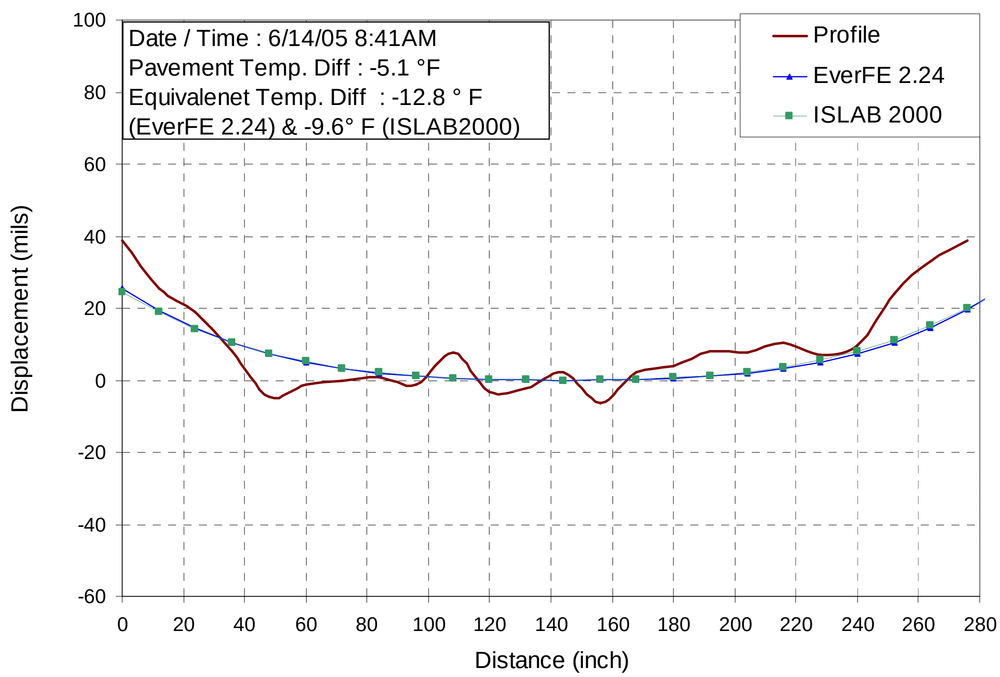


Figure F.73. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 14 morning

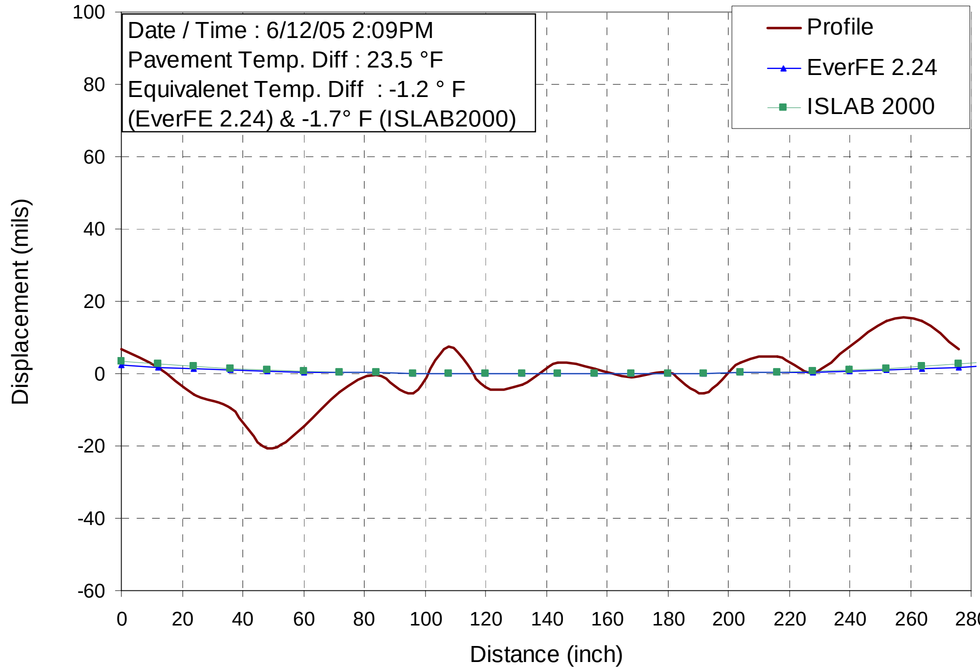


Figure F.74. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 12 afternoon

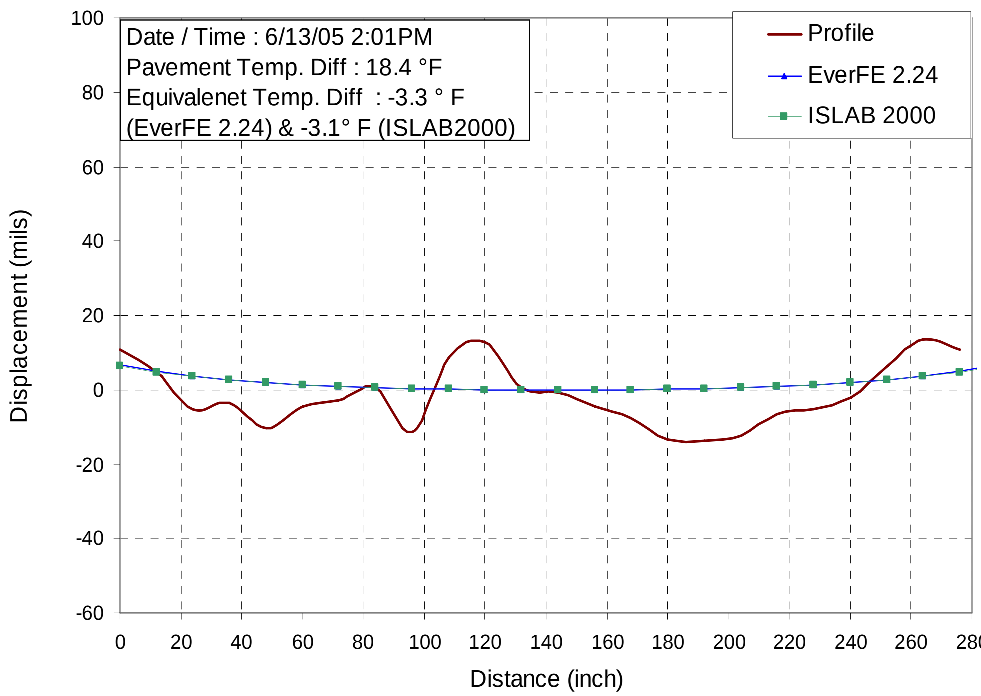


Figure F.75. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 13 afternoon

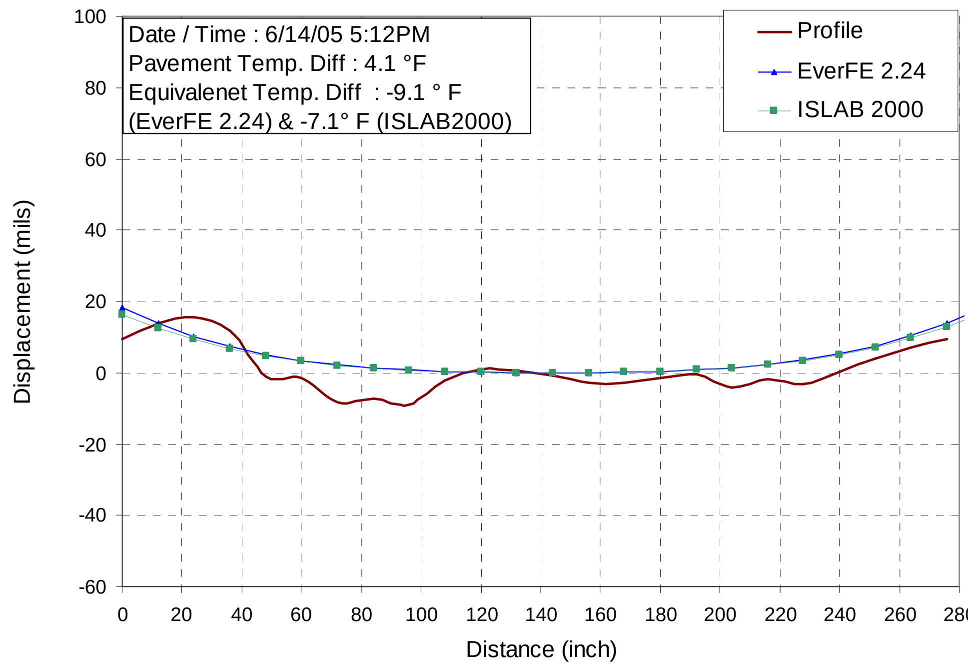


Figure F.76. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 14 afternoon

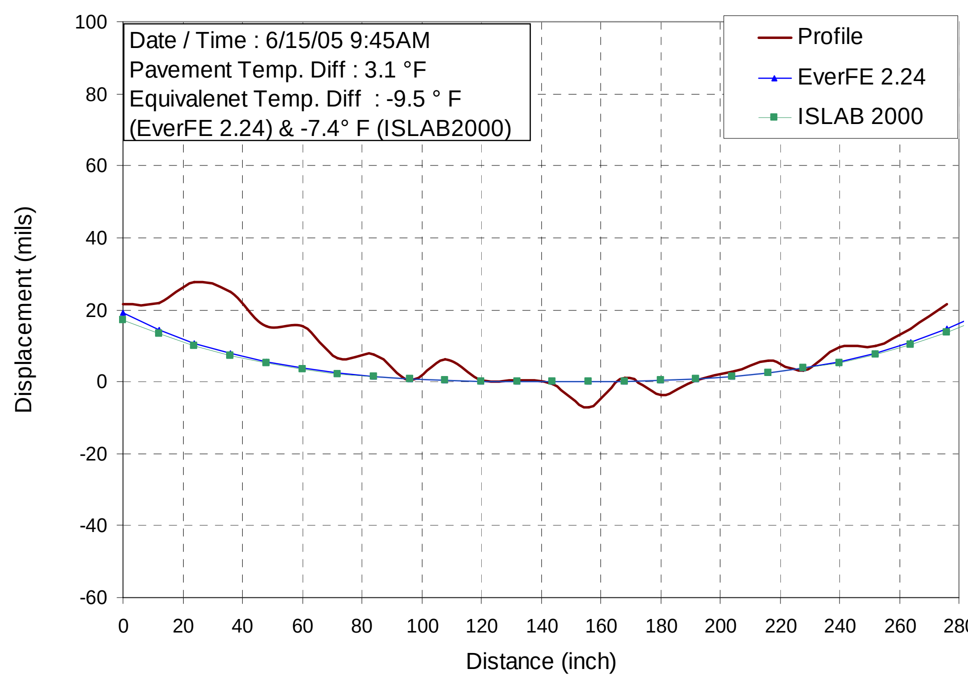


Figure F.77. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – June 15 morning

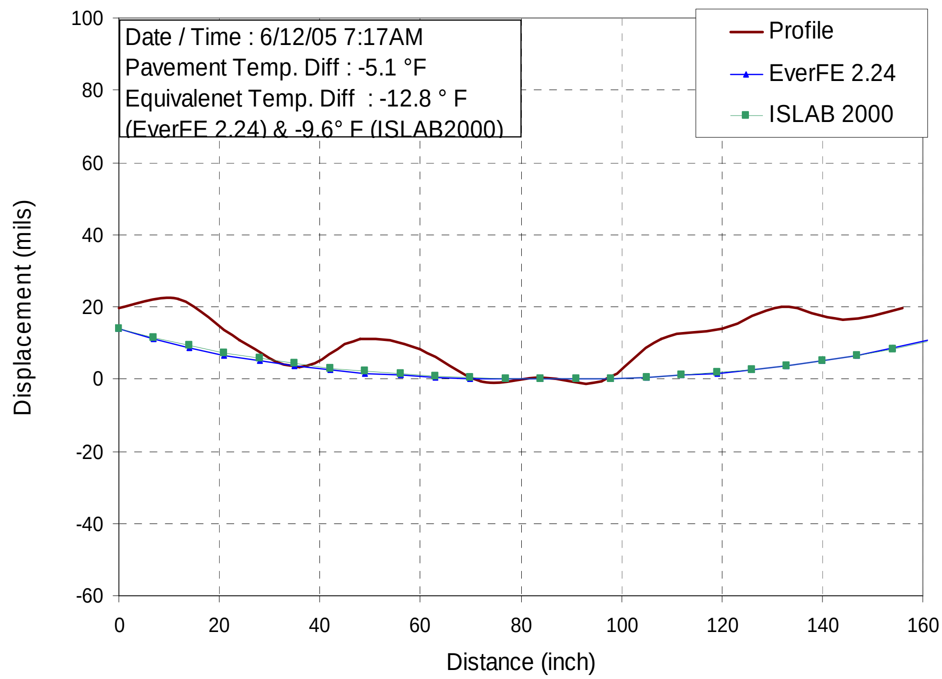


Figure F.78. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 12 morning

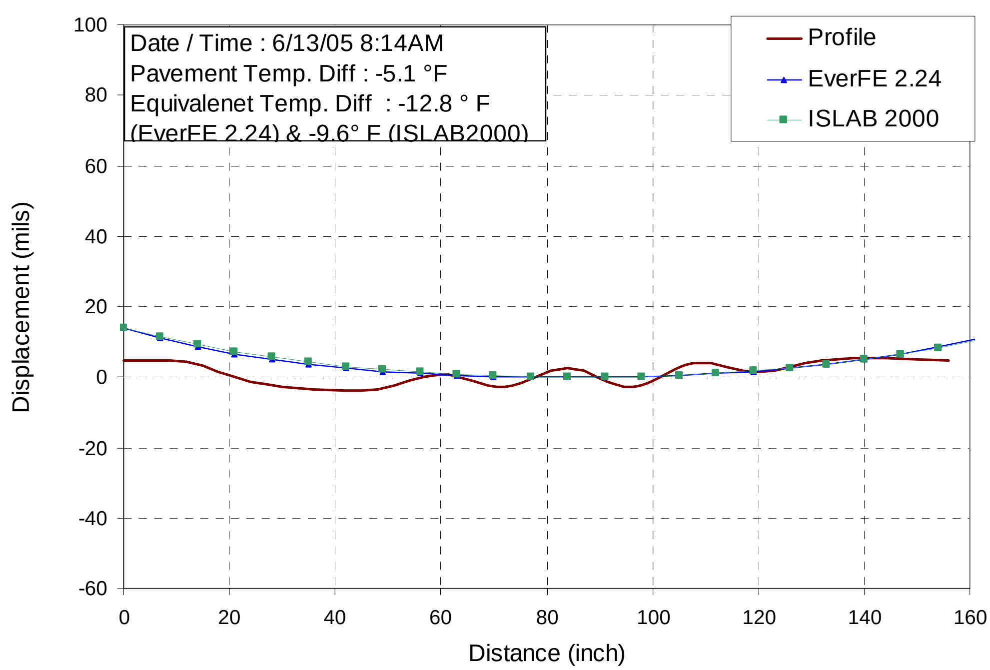


Figure F.79. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 13 morning

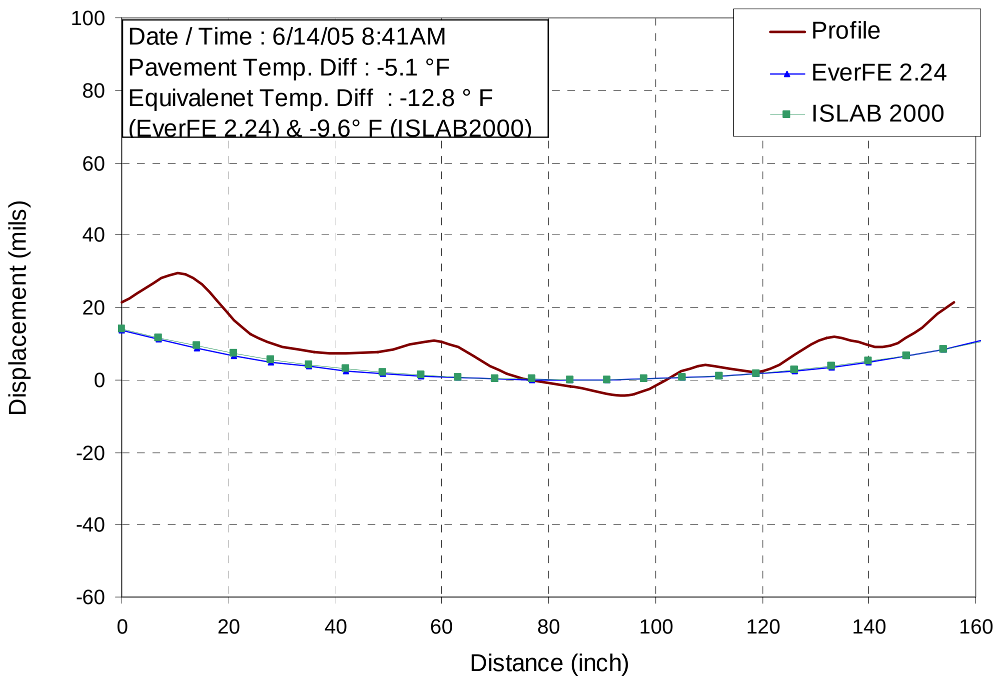


Figure F.80. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 14 morning

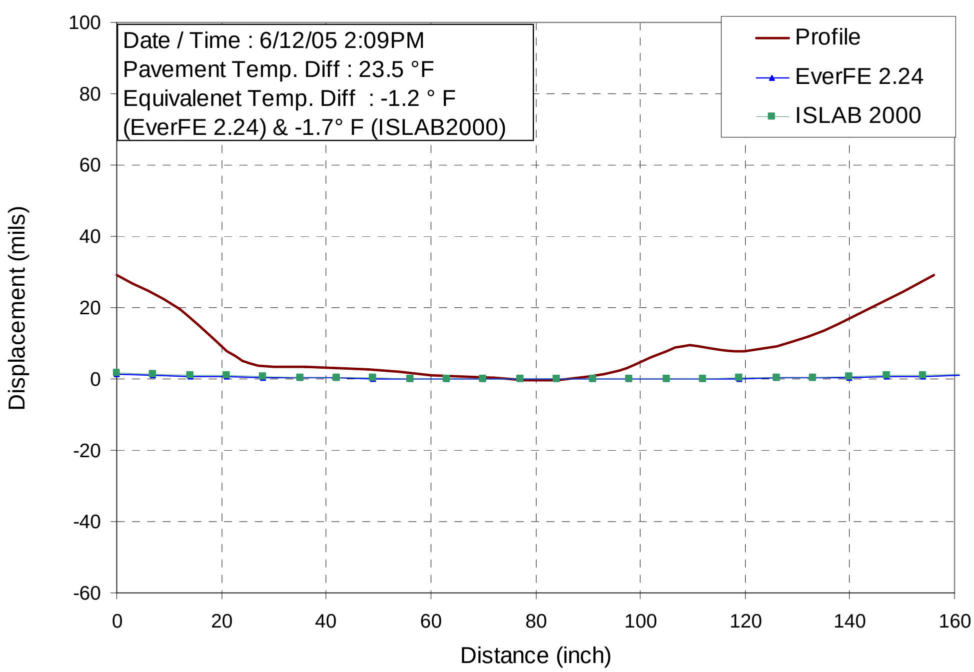


Figure F.81. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 12 afternoon

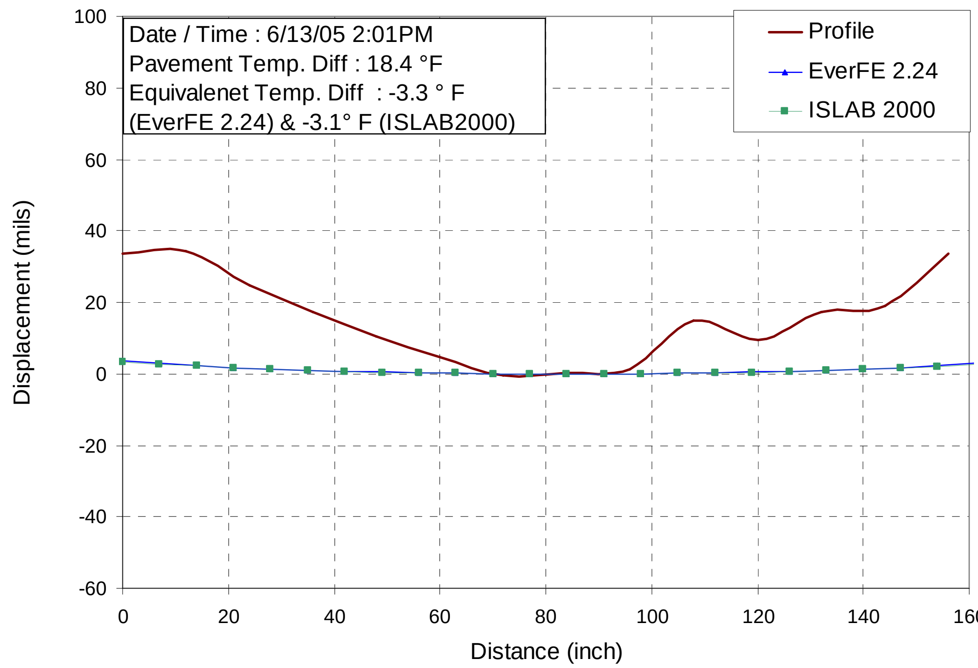


Figure F.82. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 13 afternoon

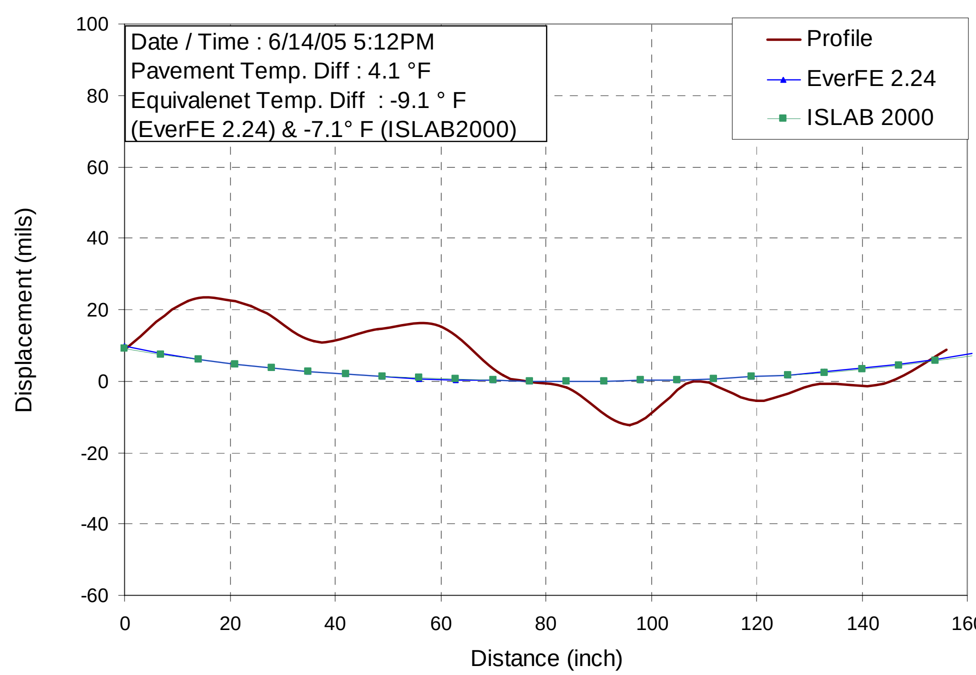


Figure F.83. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 14 afternoon

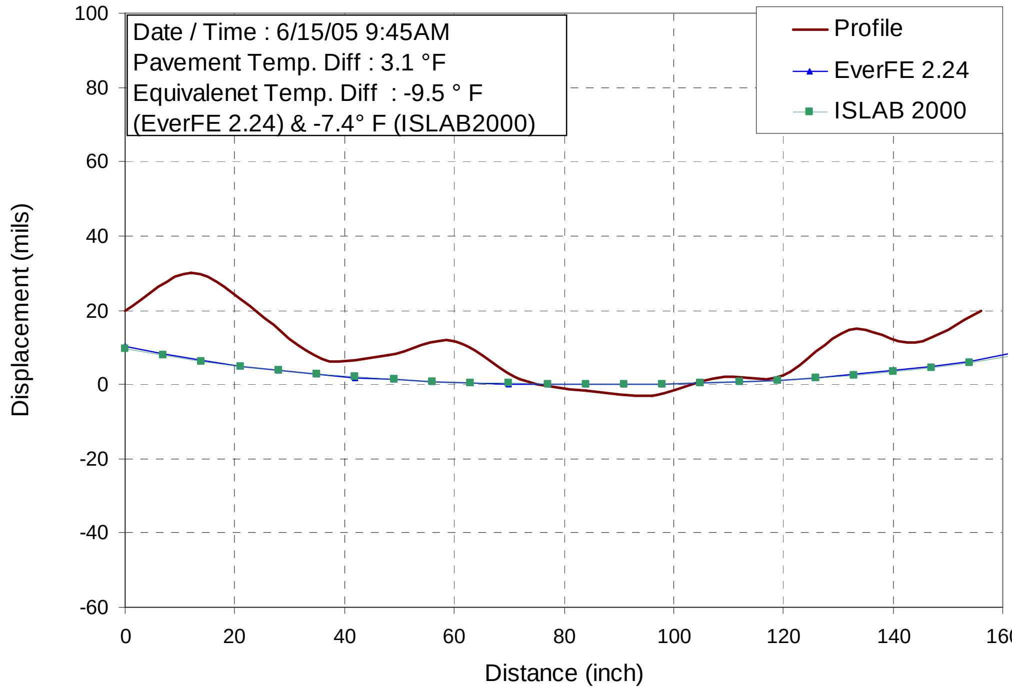


Figure F.84. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – June 15 morning

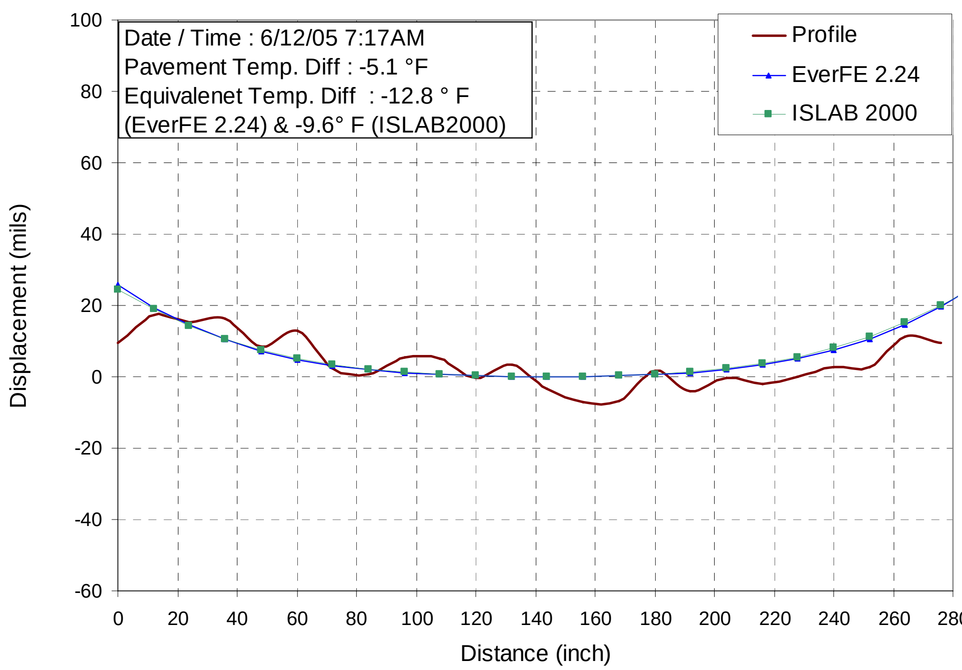


Figure F.85. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 12 morning

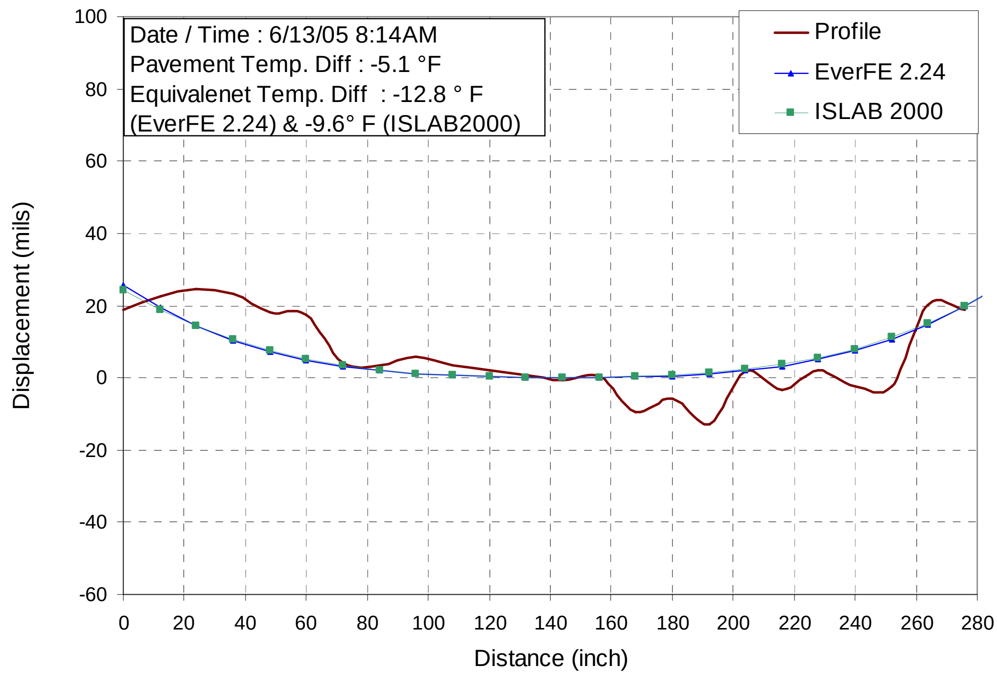


Figure F.86. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 13 morning

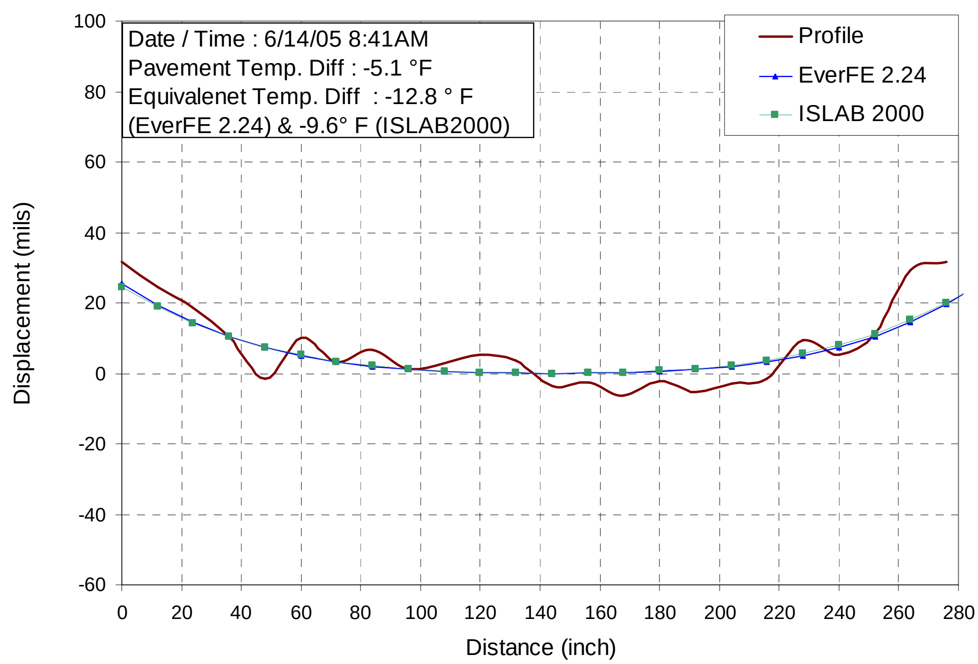


Figure F.87. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 14 morning

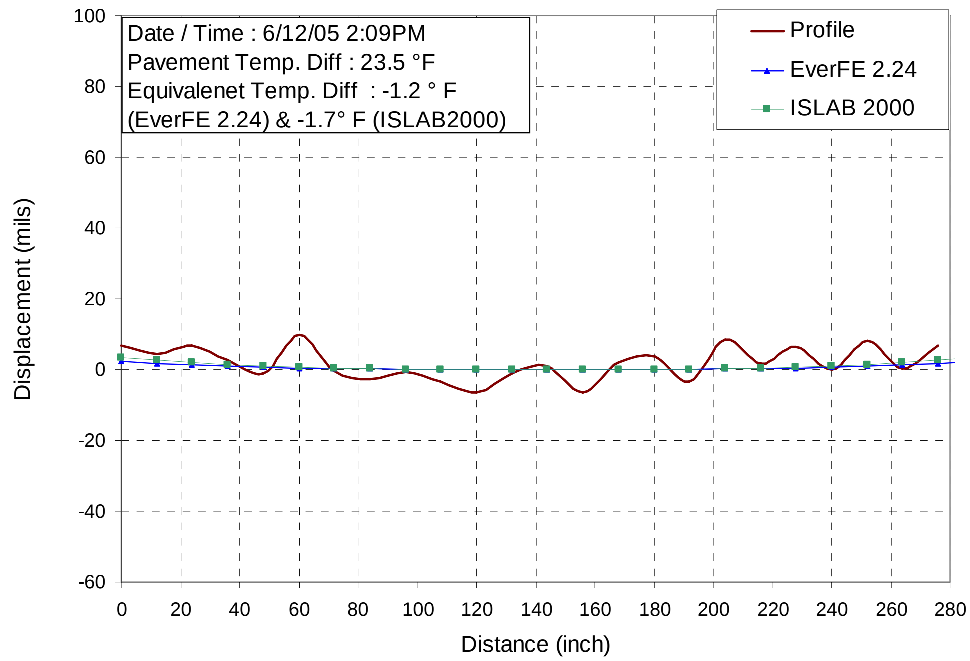


Figure F.88. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 12 afternoon

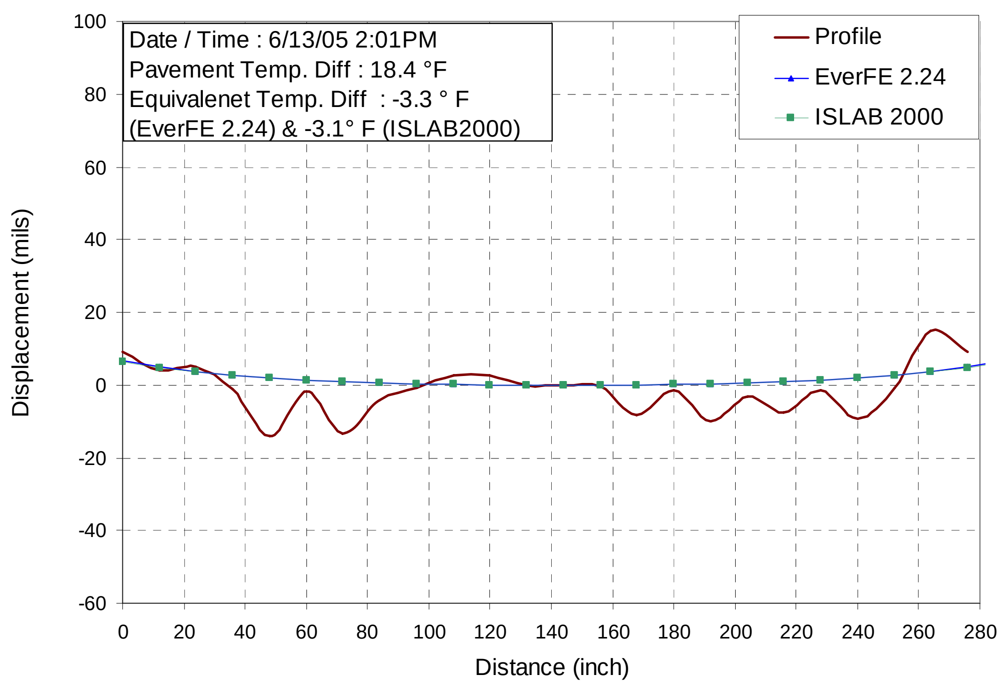


Figure F.89. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 13 afternoon

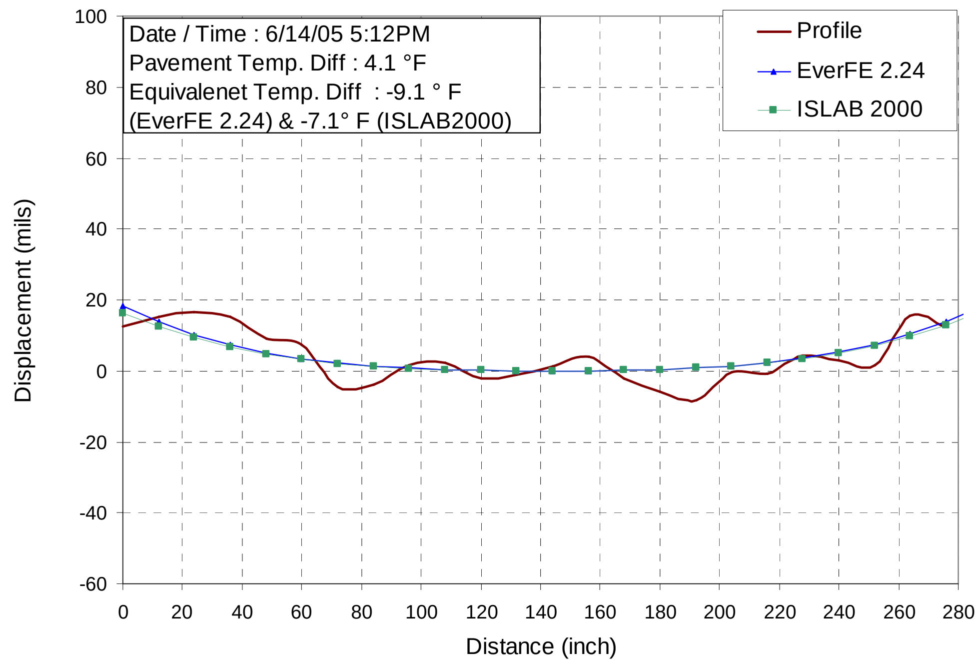


Figure F.90. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 14 afternoon

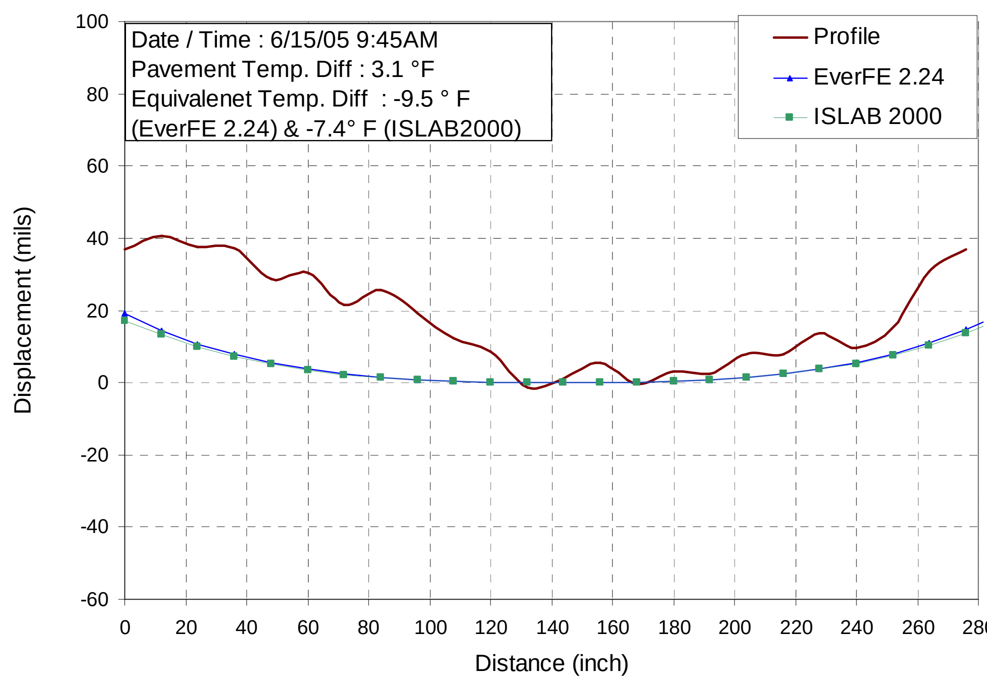


Figure F.91. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – June 15 morning

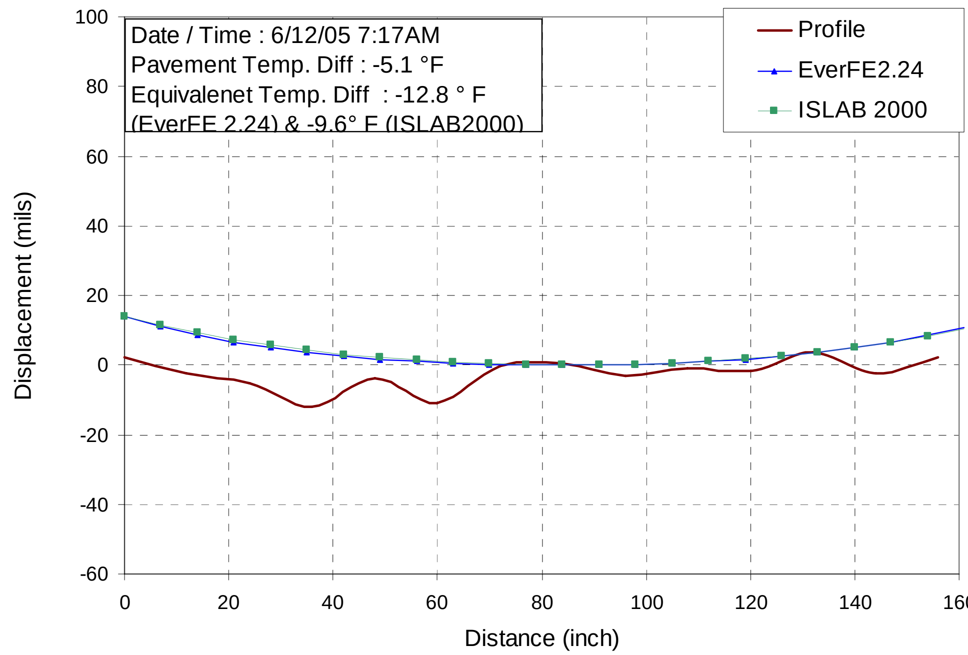


Figure F.92. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 12 morning

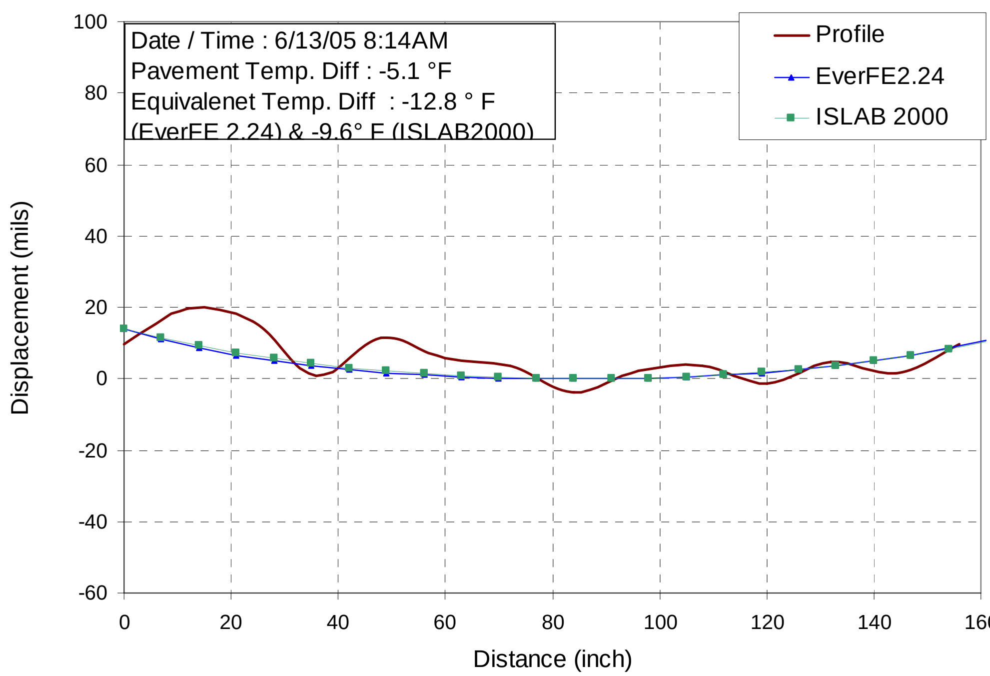


Figure F.93. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 13 morning

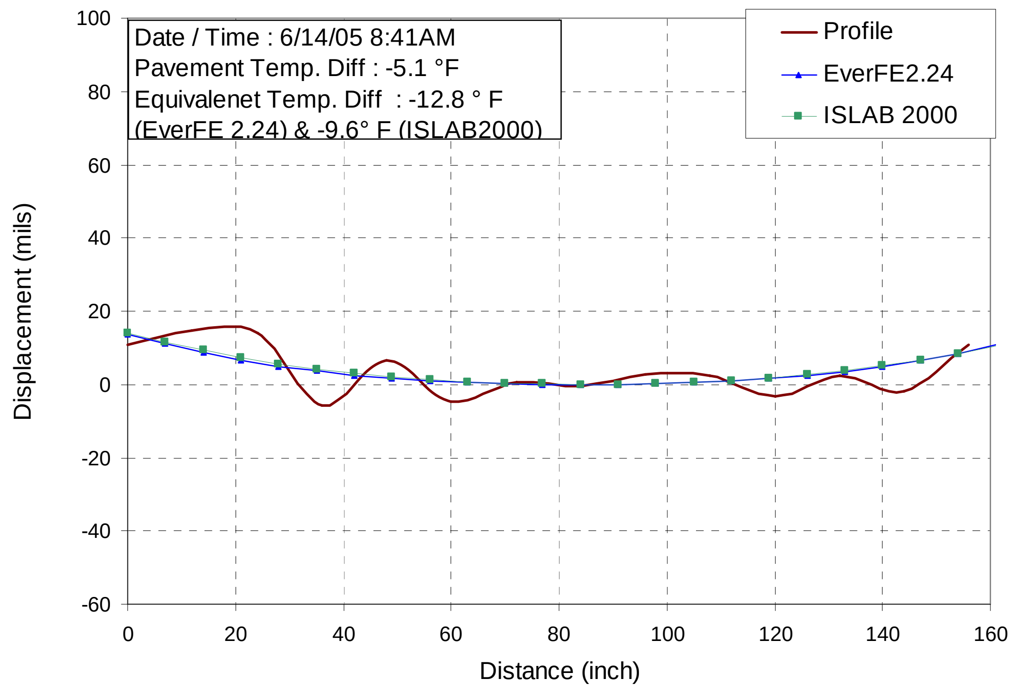


Figure F.94. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 14 morning

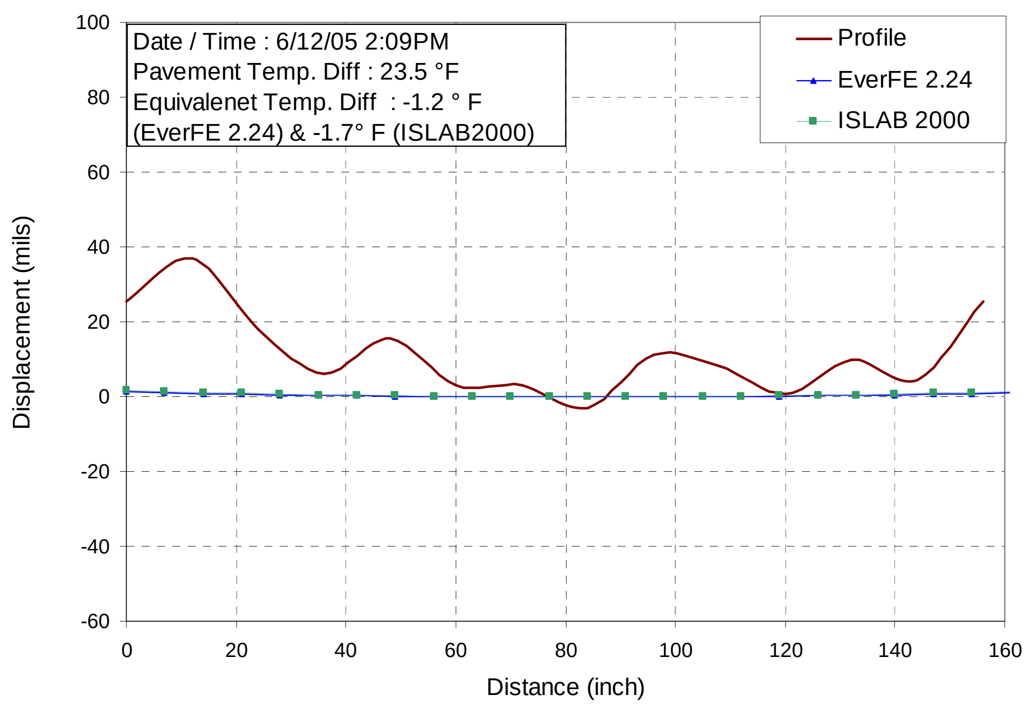


Figure F.95. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 12 afternoon

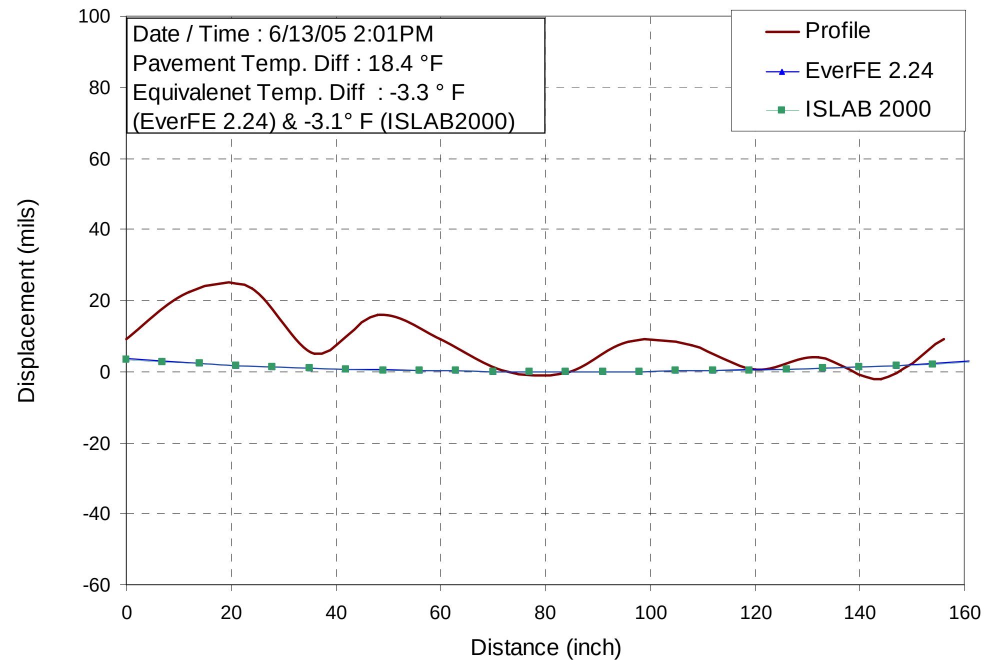


Figure F.96. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 13 afternoon

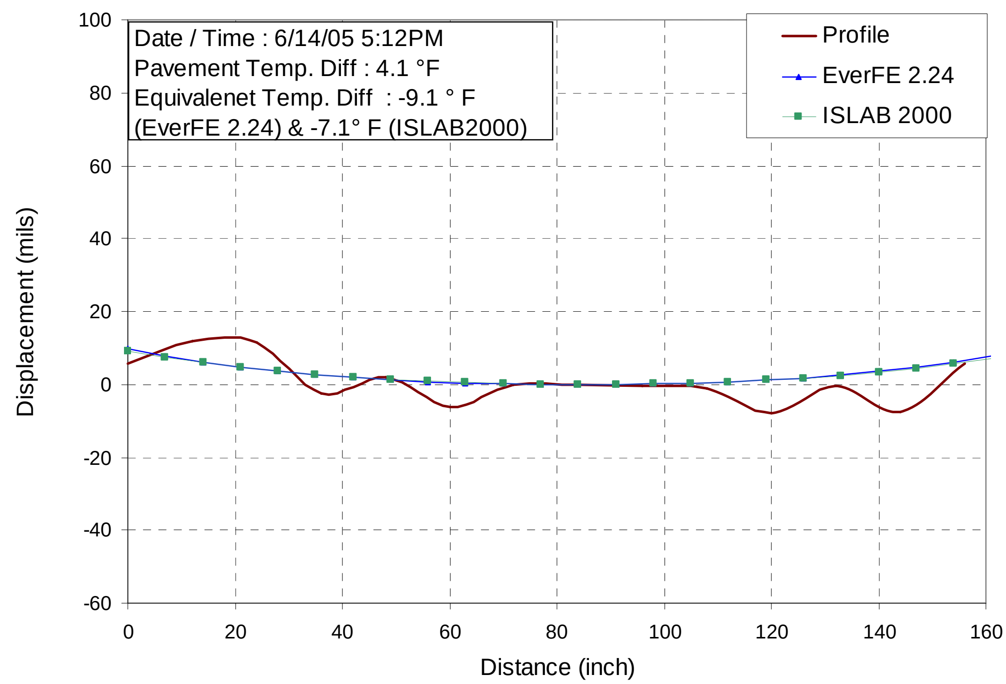


Figure F.97. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 14 afternoon

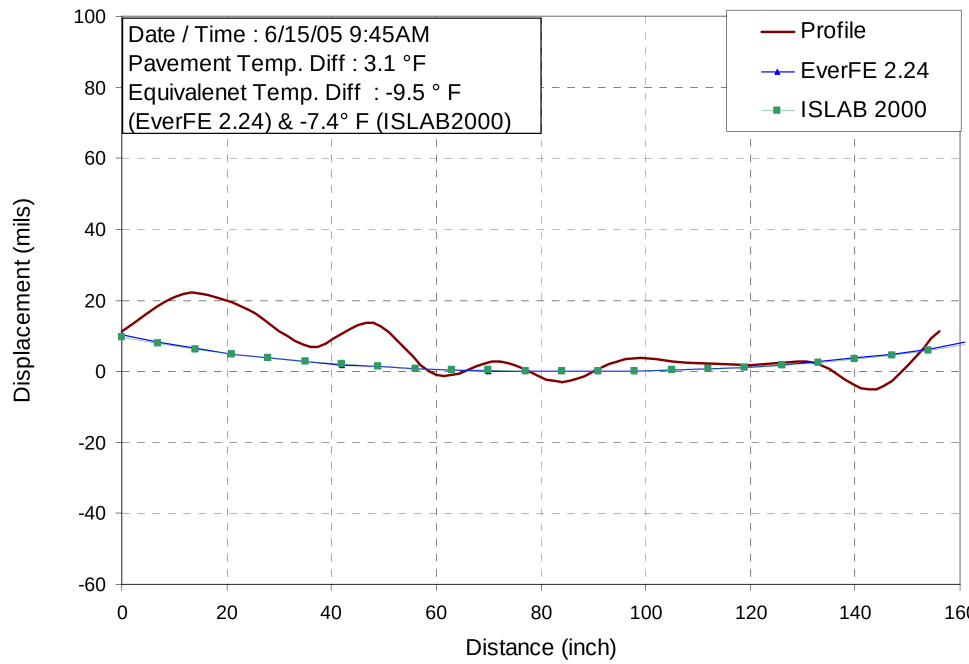


Figure F.98. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – June 15 morning

APPENDIX G: MARSHALLTOWN SITE PHOTO LOG

Figure G.1. Slipform paver

Figure G.2. Concrete delivery operations

Figure G.3. Tie bar insertion operations

Figure G.4. Finishing operations

Figure G.5. Texturing and curing operations

Figure G.6. Temperature instrumentation

Figure G.7. Temperature instrumentation

Figure G.8. Temperature instrumentation

Figure G.9. Hygrochron relative humidity instrumentation casing

Figure G.10. Hygrochron instrumentation casing insertion

Figure G.11. Hygrochron relative humidity instrumentation

Figure G.12. Ultrasonic pulse velocity measurements

Figure G.13. DEMEC location

Figure G.14. Rolling inclinometer profiler

APPENDIX H: MARSHALLTOWN SITE MORNING PAVING TEST SECTION

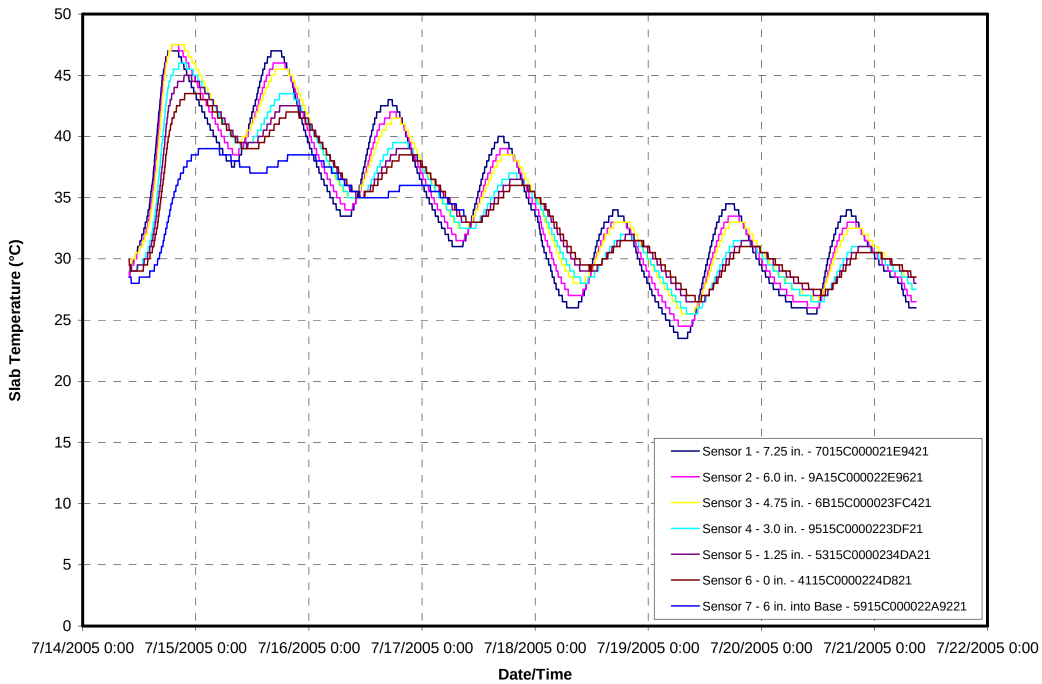


Figure H.1. Slab temperature data

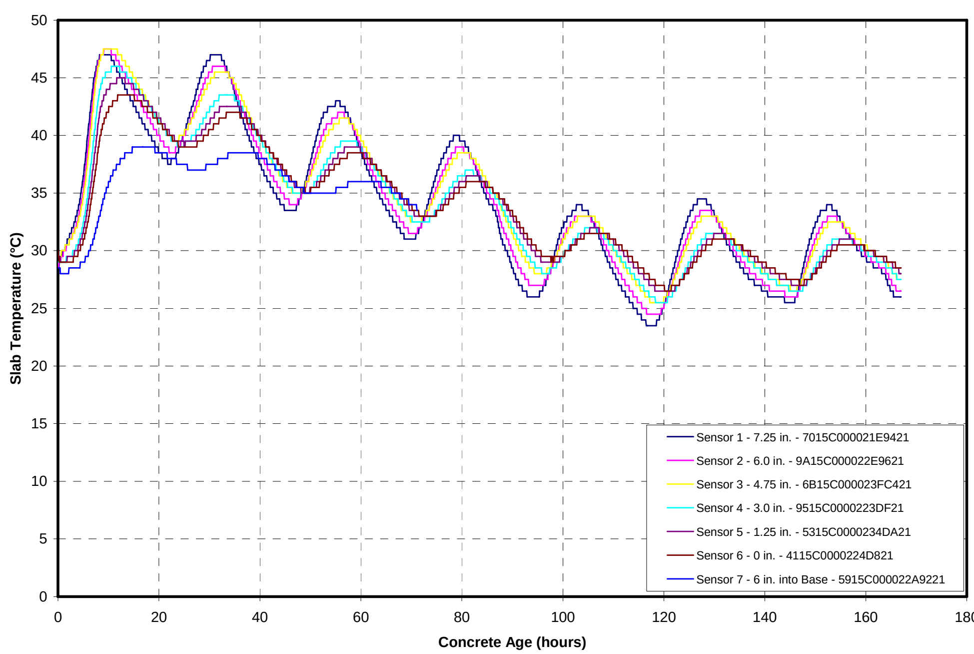


Figure H.2. Slab temperature data

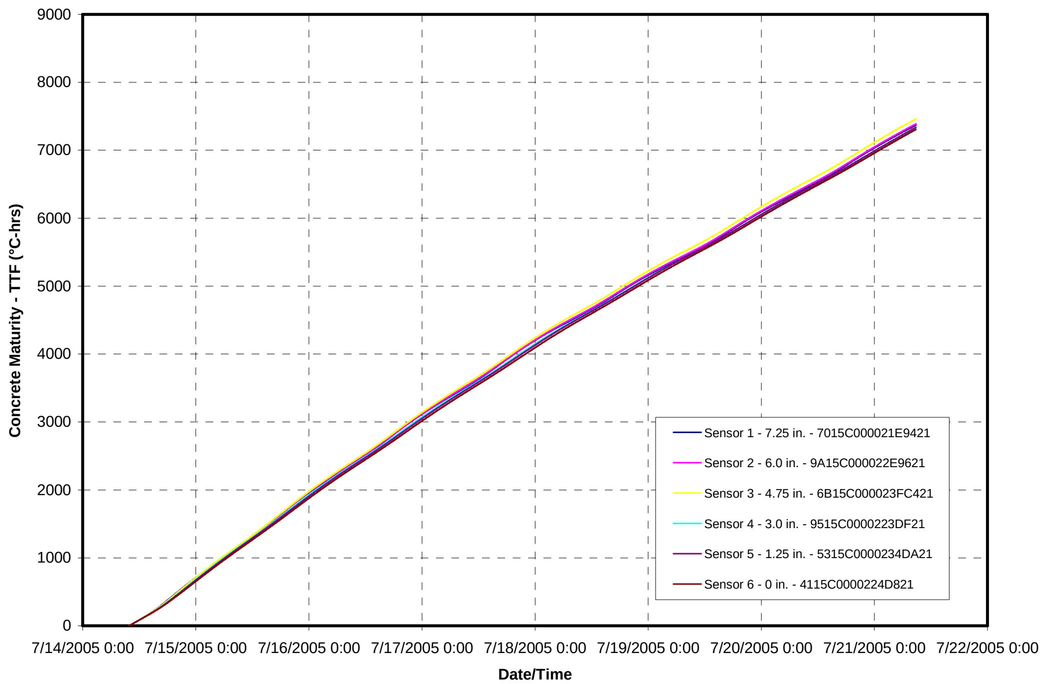


Figure H.3. Slab maturity data

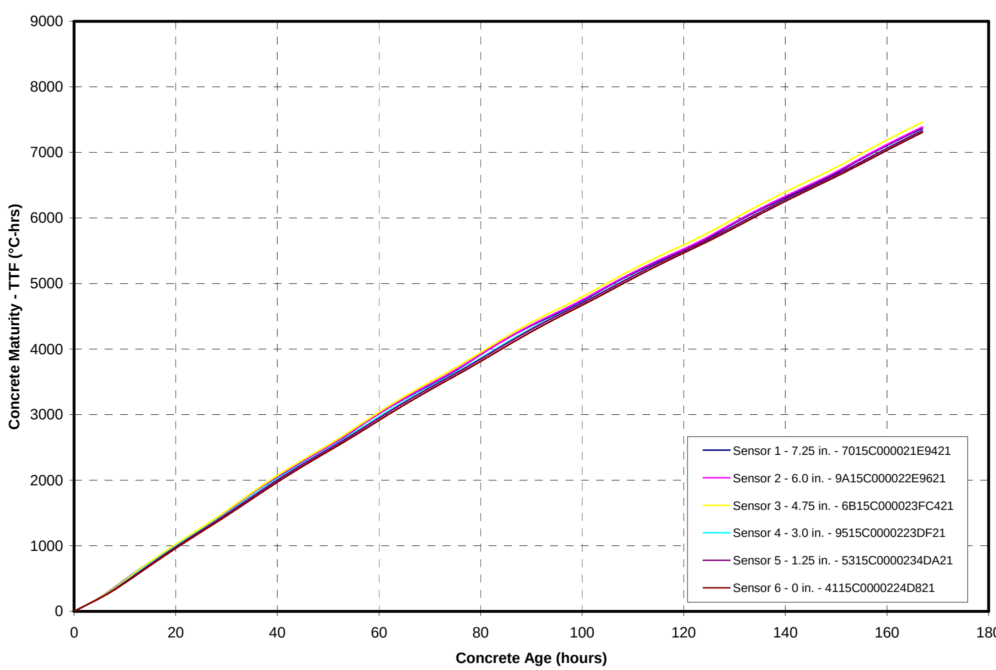


Figure H.4. Slab maturity data

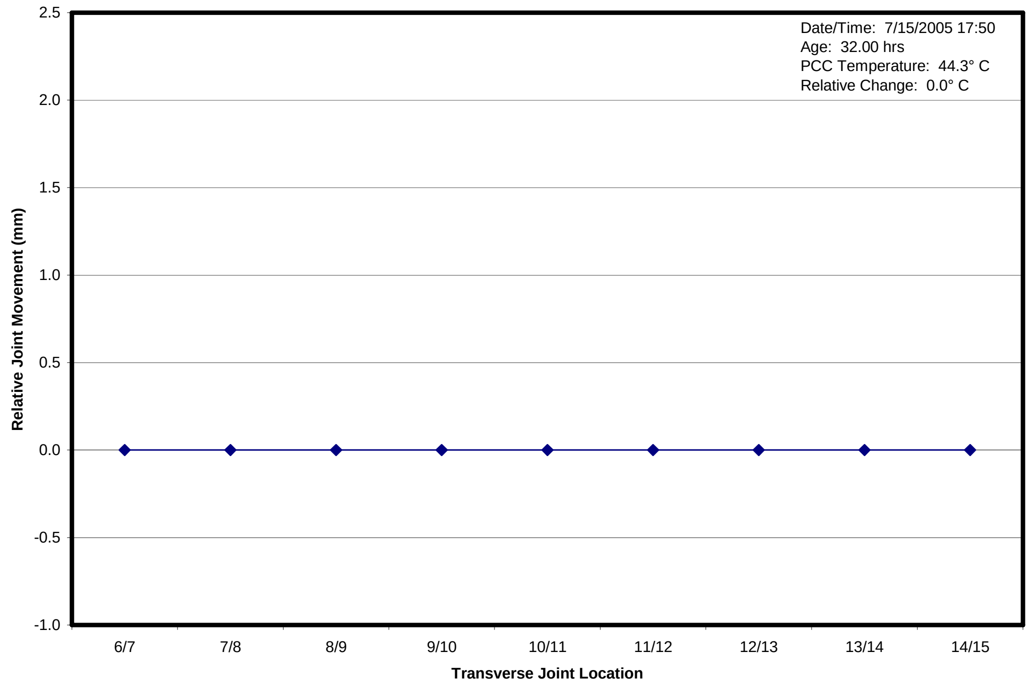


Figure H.5. Transverse joint relative opening

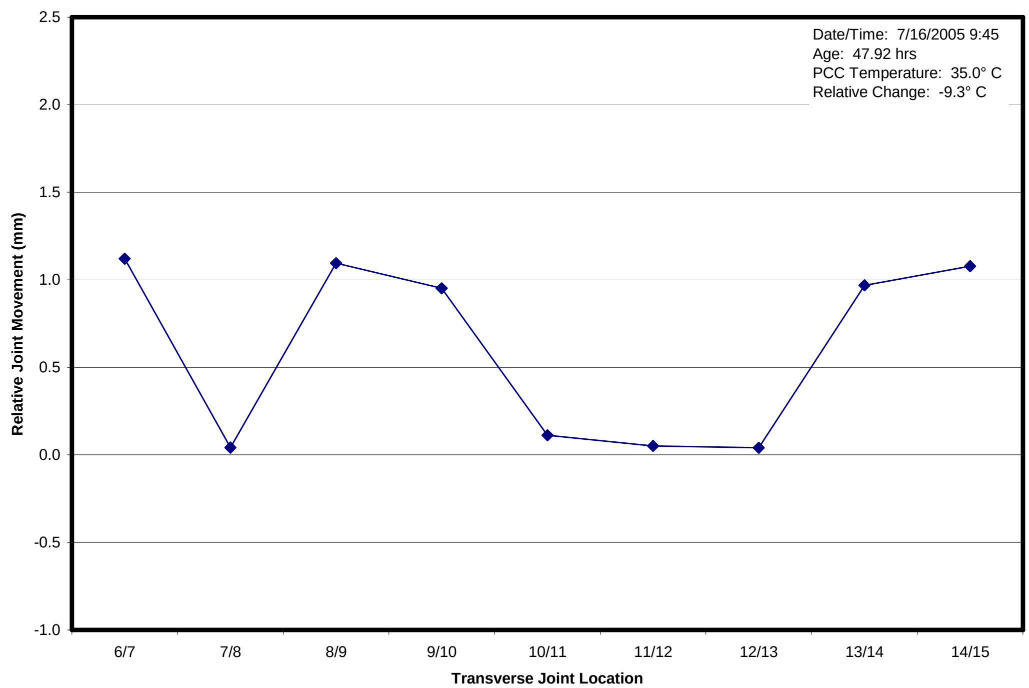


Figure H.6. Transverse joint relative opening

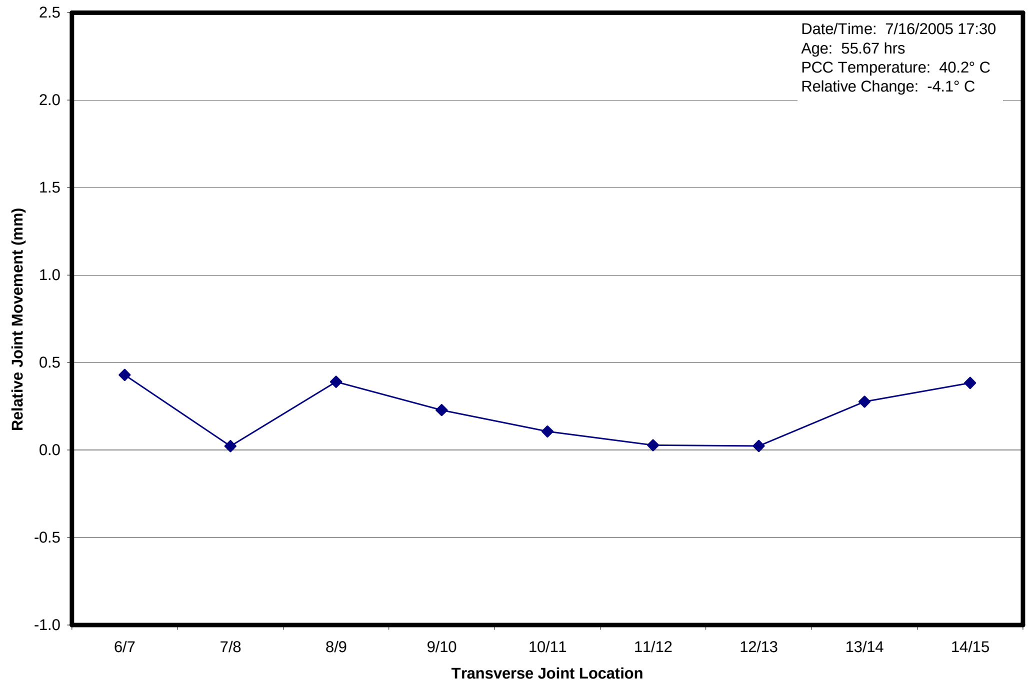


Figure H.7. Transverse joint relative opening

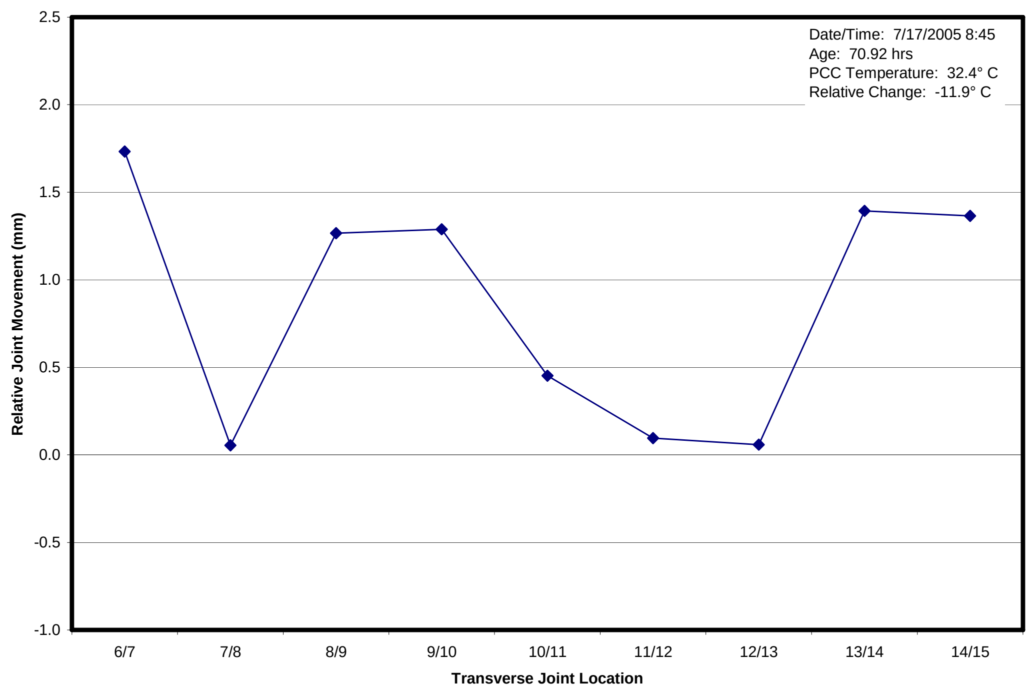


Figure H.8. Transverse joint relative opening

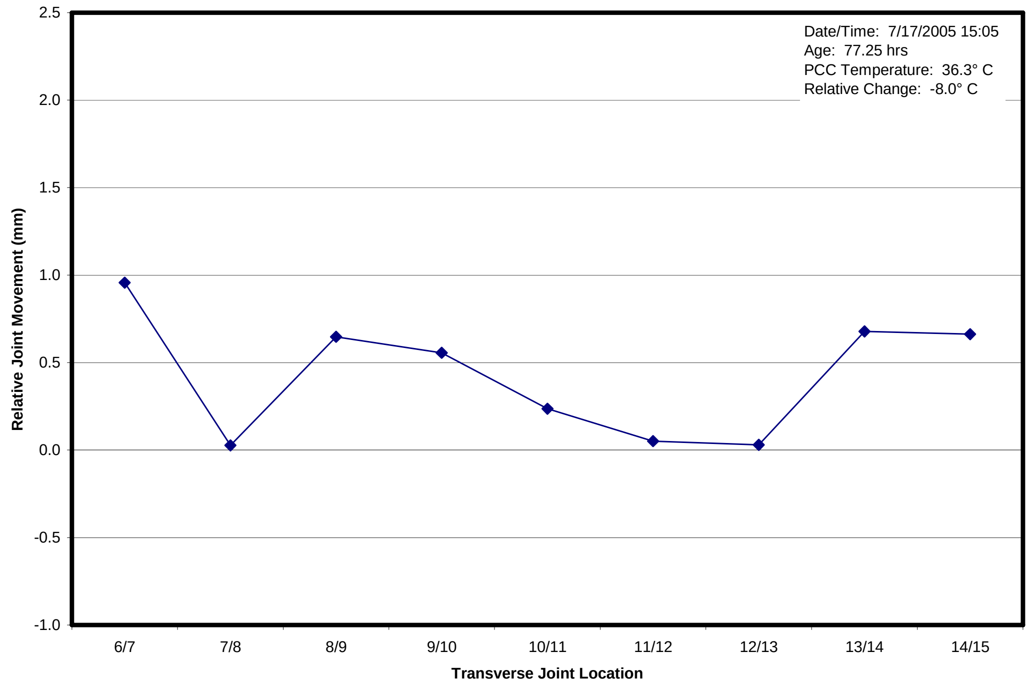


Figure H.9. Transverse joint relative opening

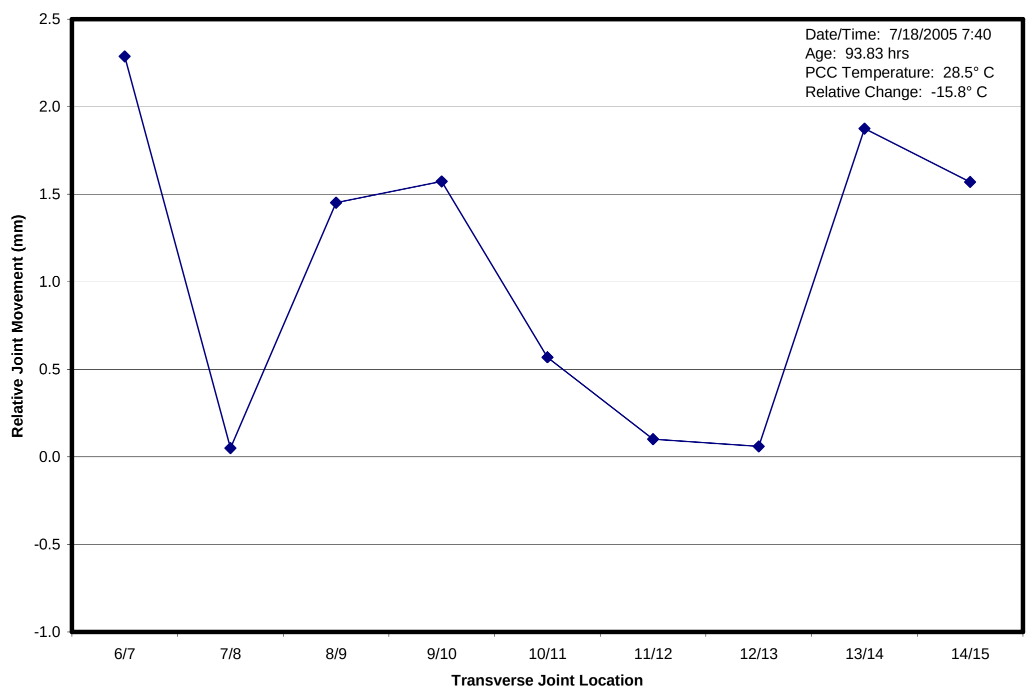


Figure H.10. Transverse joint relative opening

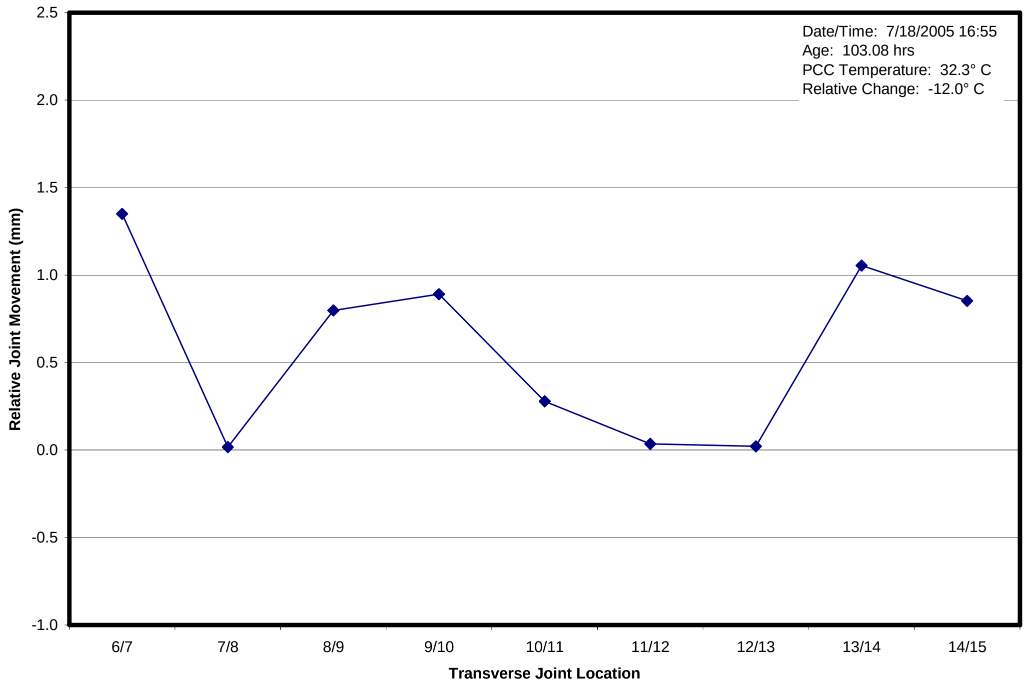


Figure H.11. Transverse joint relative opening

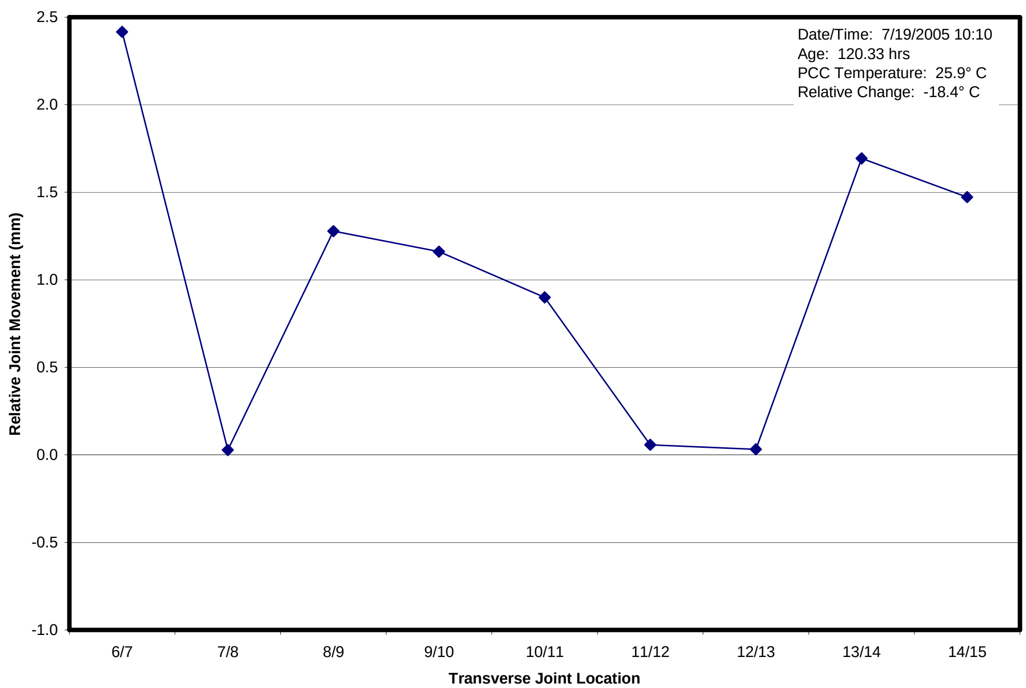


Figure H.12. Transverse joint relative opening

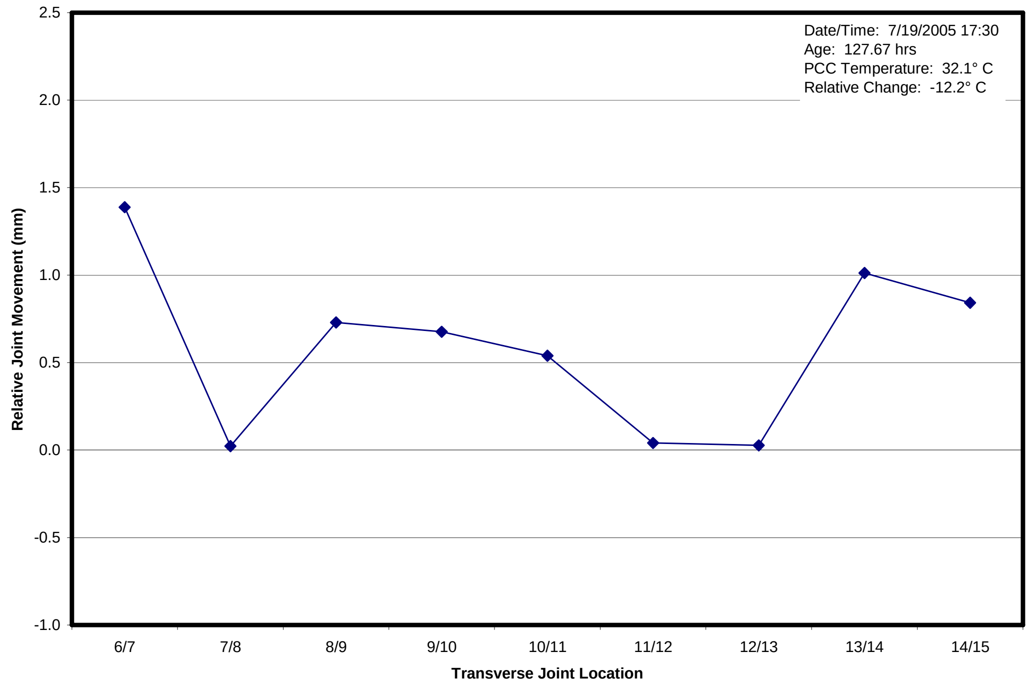


Figure H.13. Transverse joint relative opening

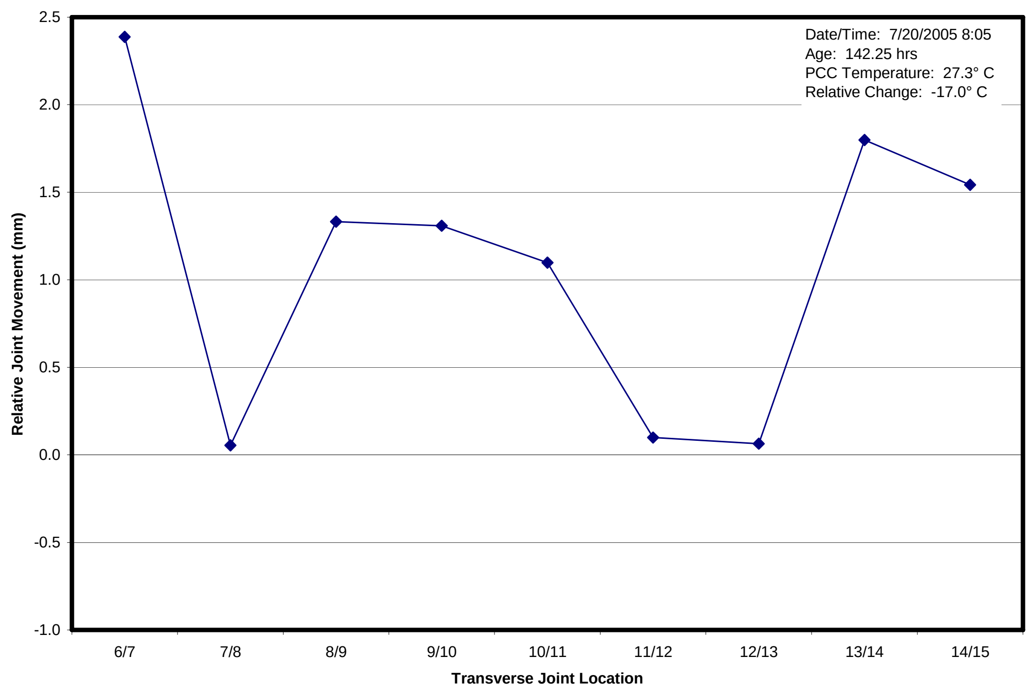


Figure H.14. Transverse joint relative opening

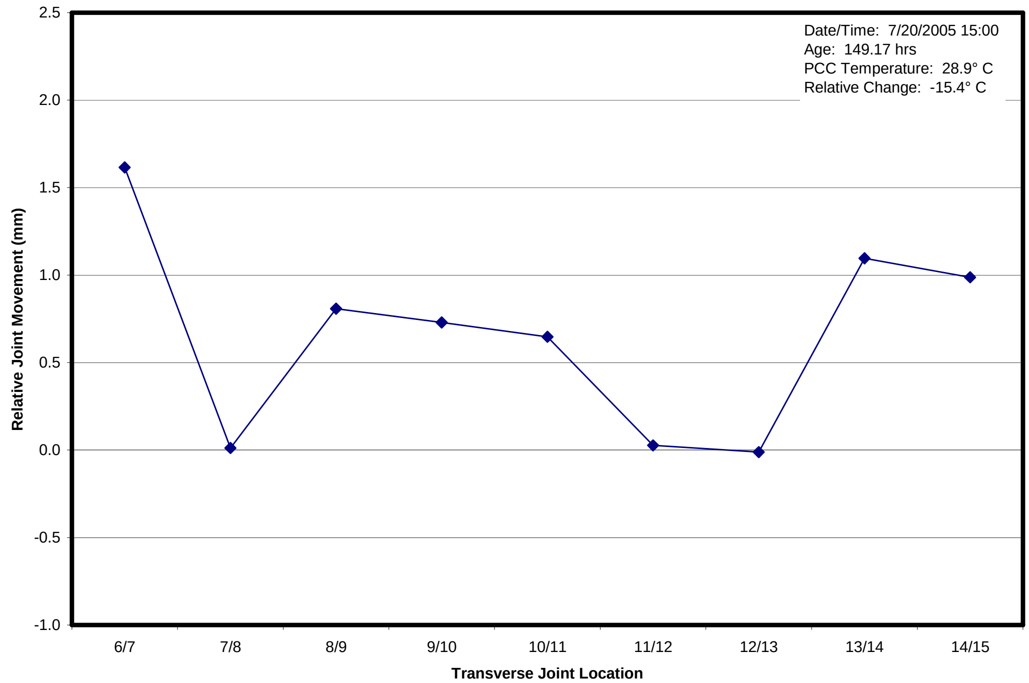


Figure H.15. Transverse joint relative opening

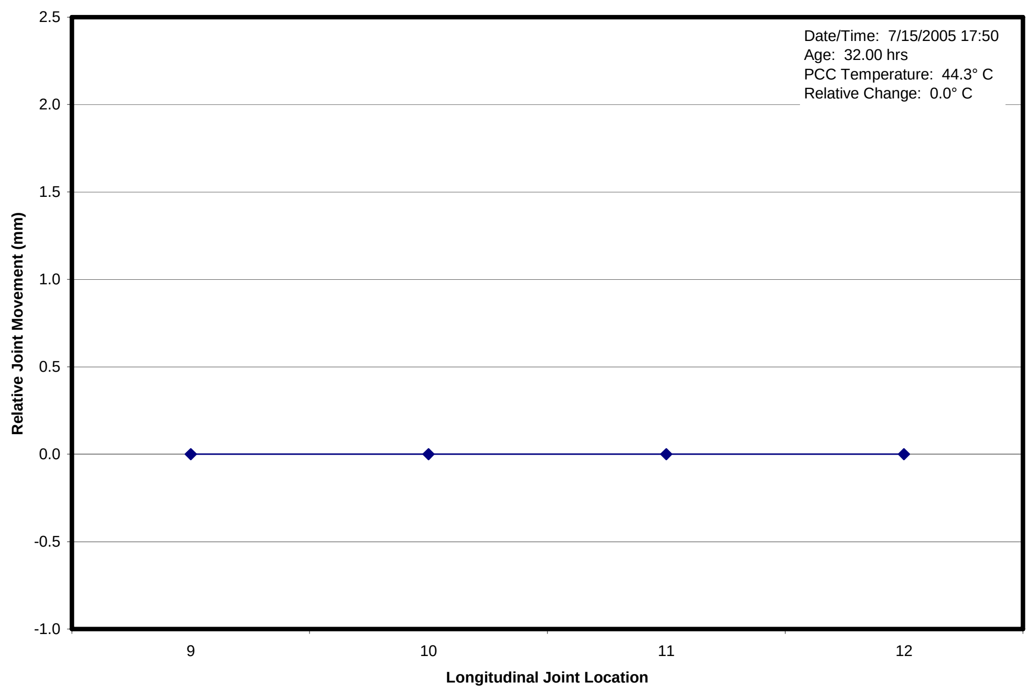


Figure H.16. Longitudinal joint relative opening

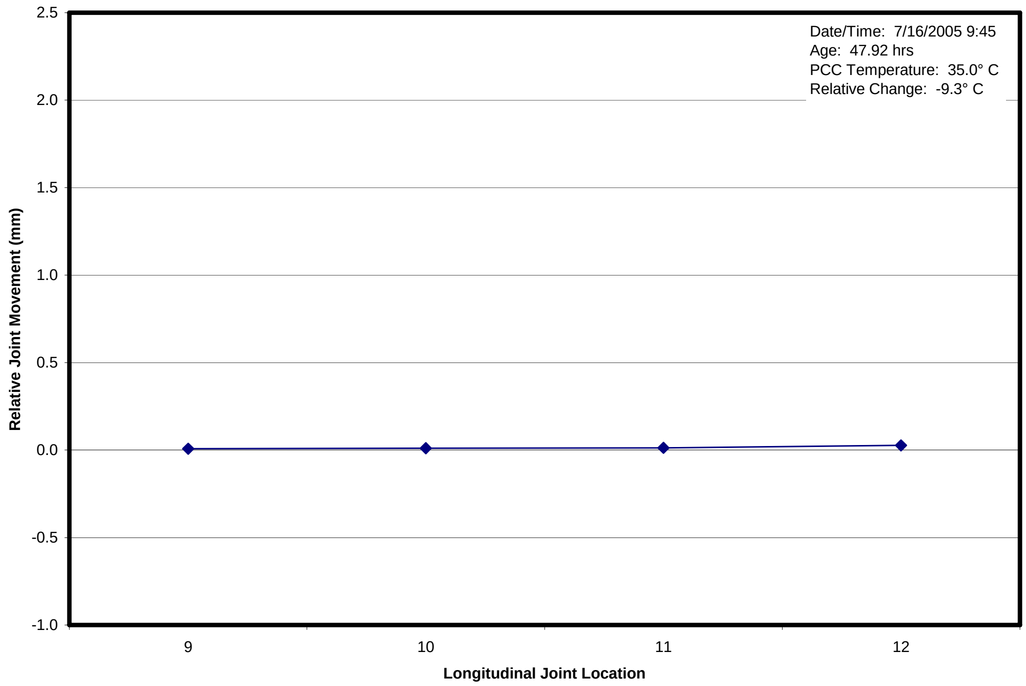


Figure H.17. Longitudinal joint relative opening

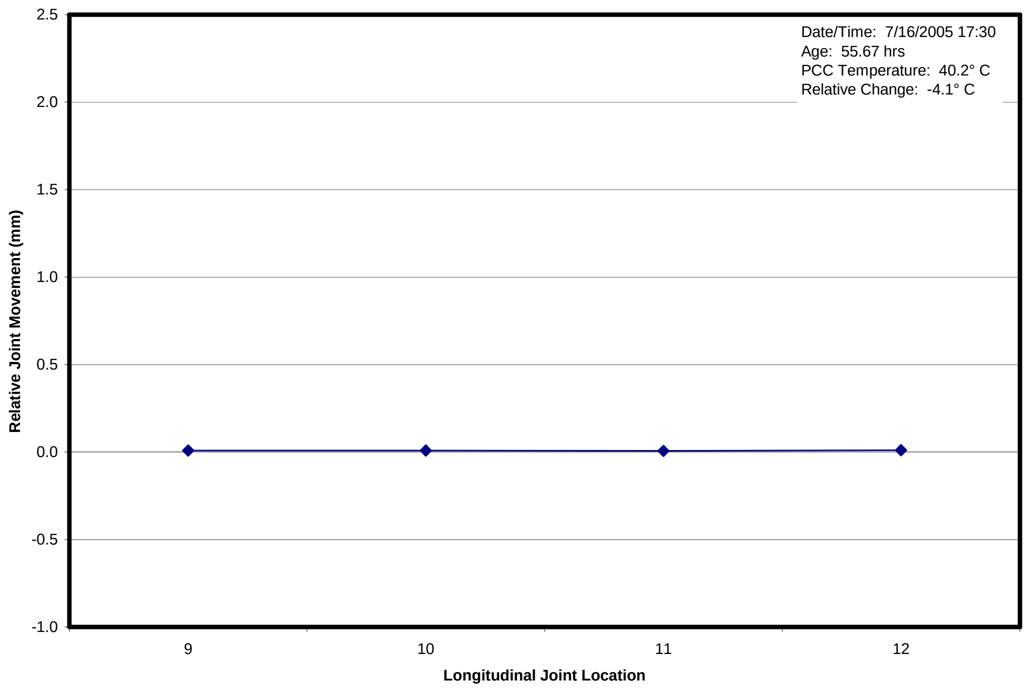


Figure H.18. Longitudinal joint relative opening

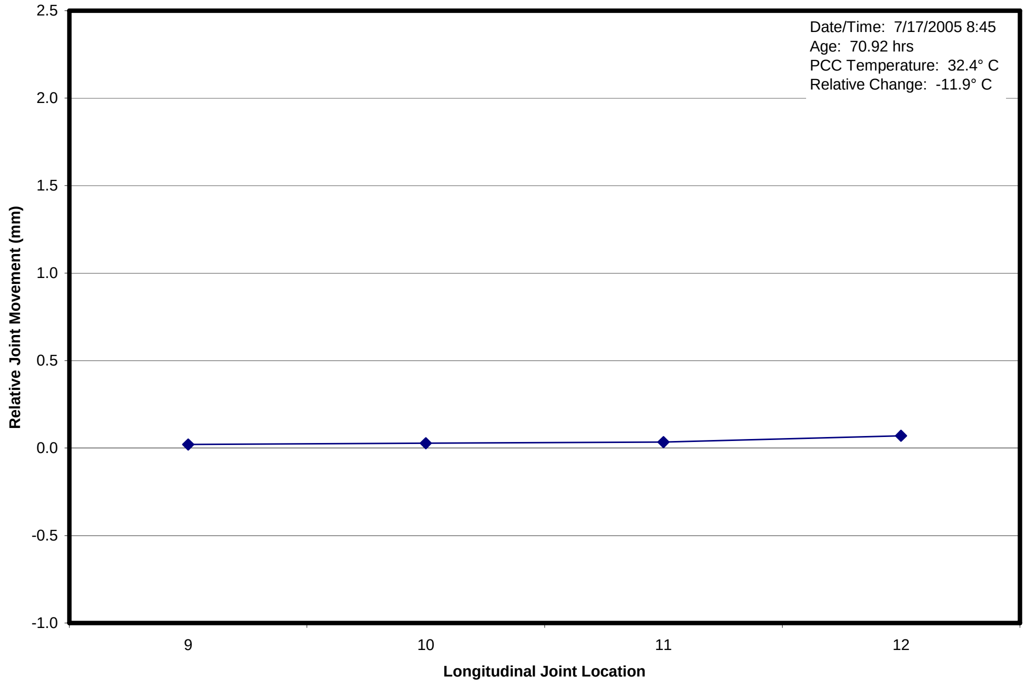


Figure H.19. Longitudinal joint relative opening

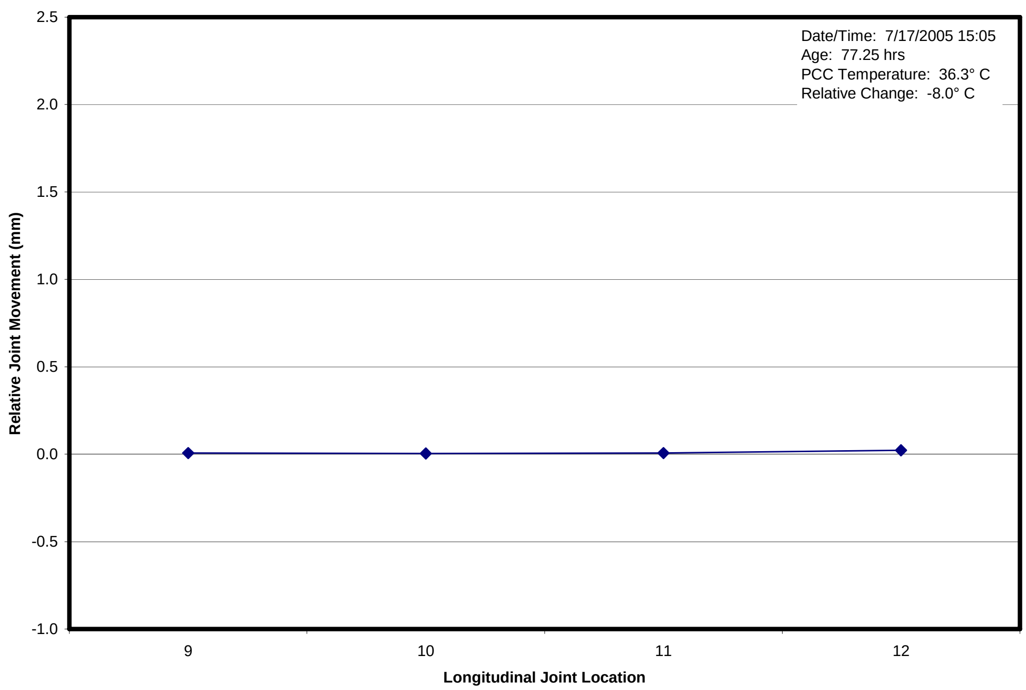


Figure H.20. Longitudinal joint relative opening

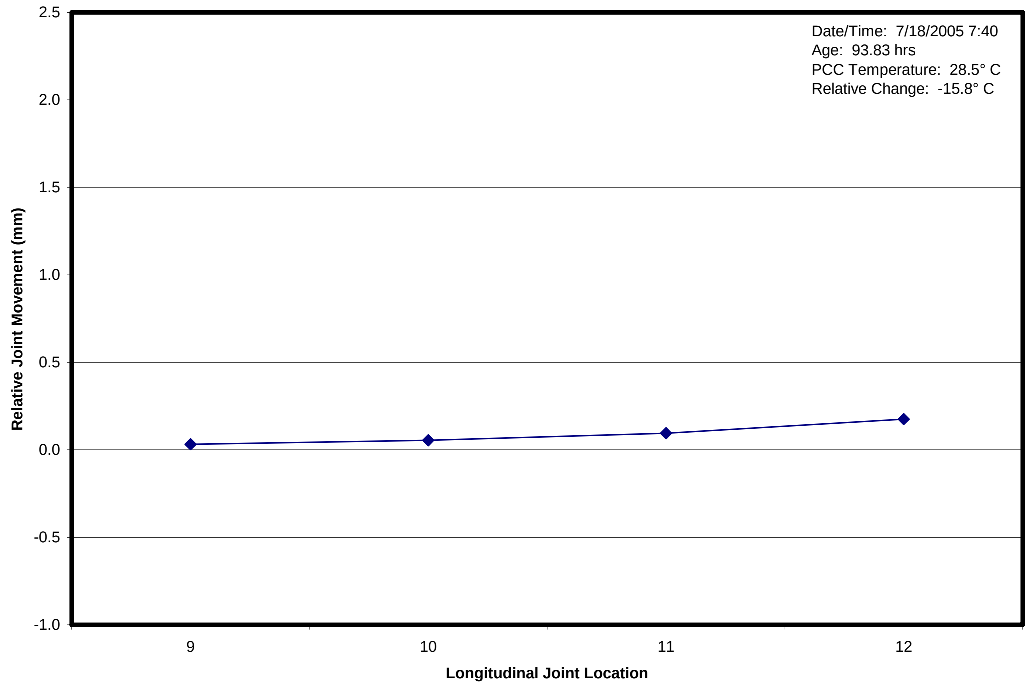


Figure H.21. Longitudinal joint relative opening

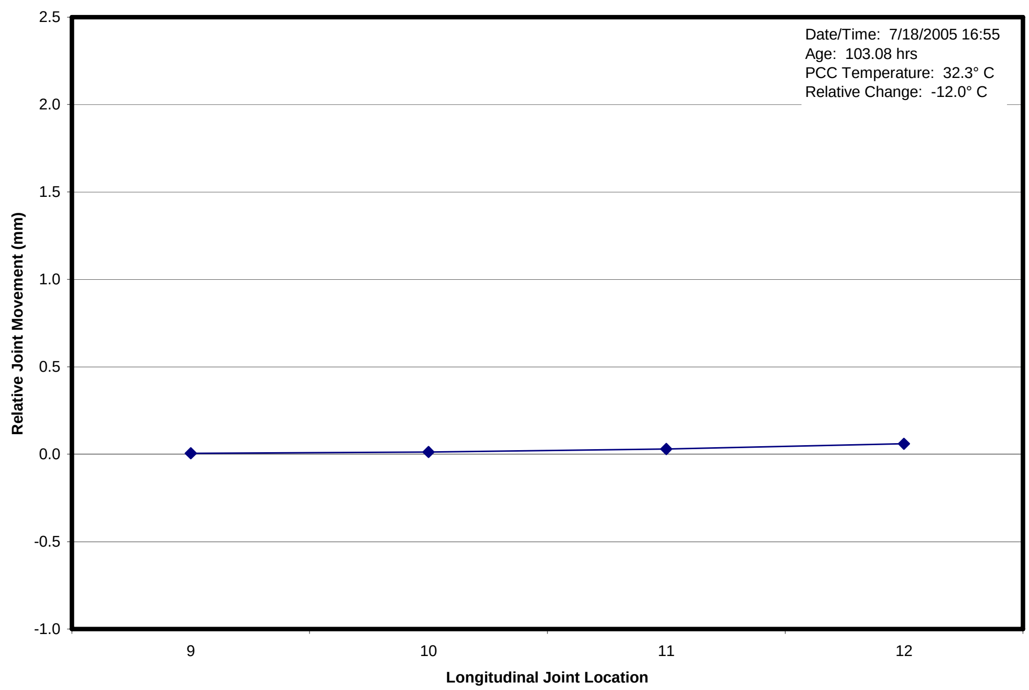


Figure H.22. Longitudinal joint relative opening

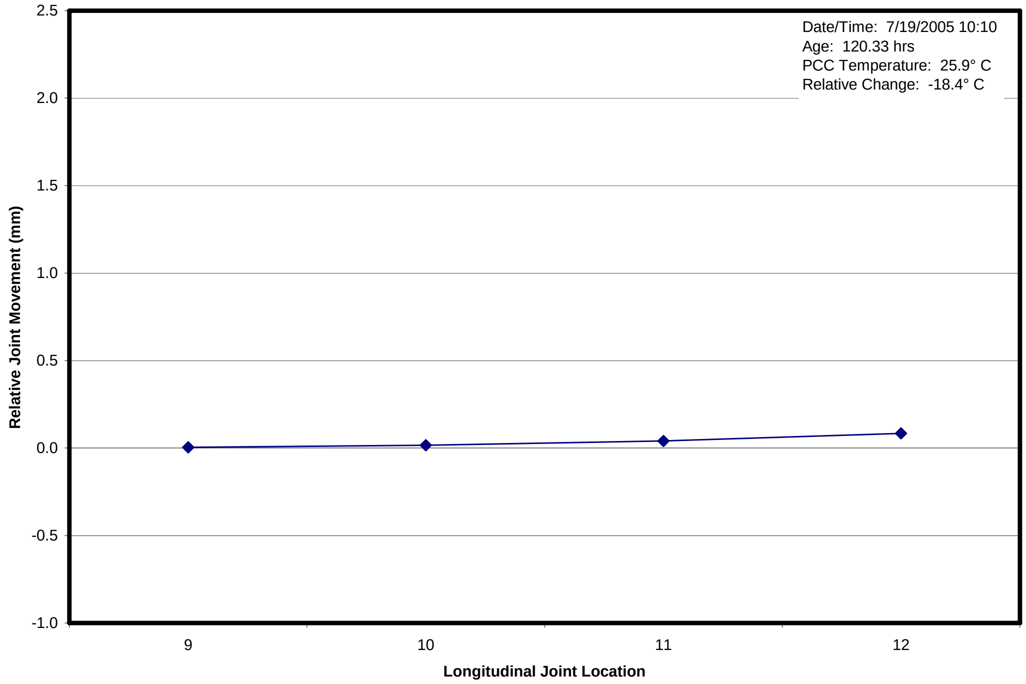


Figure H.23. Longitudinal joint relative opening

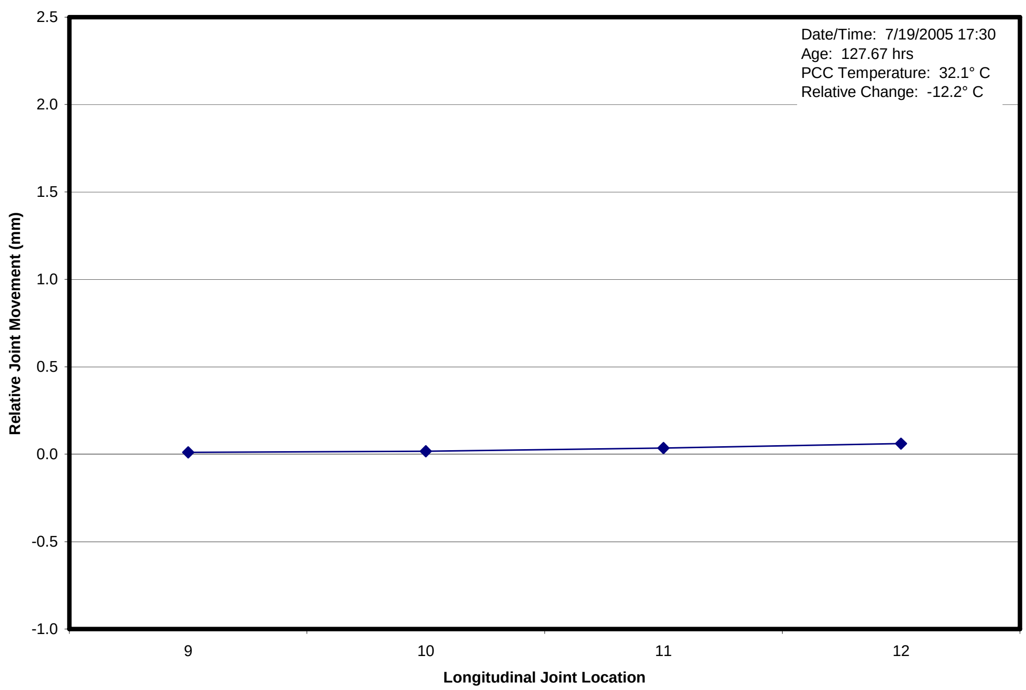


Figure H.24. Longitudinal joint relative opening

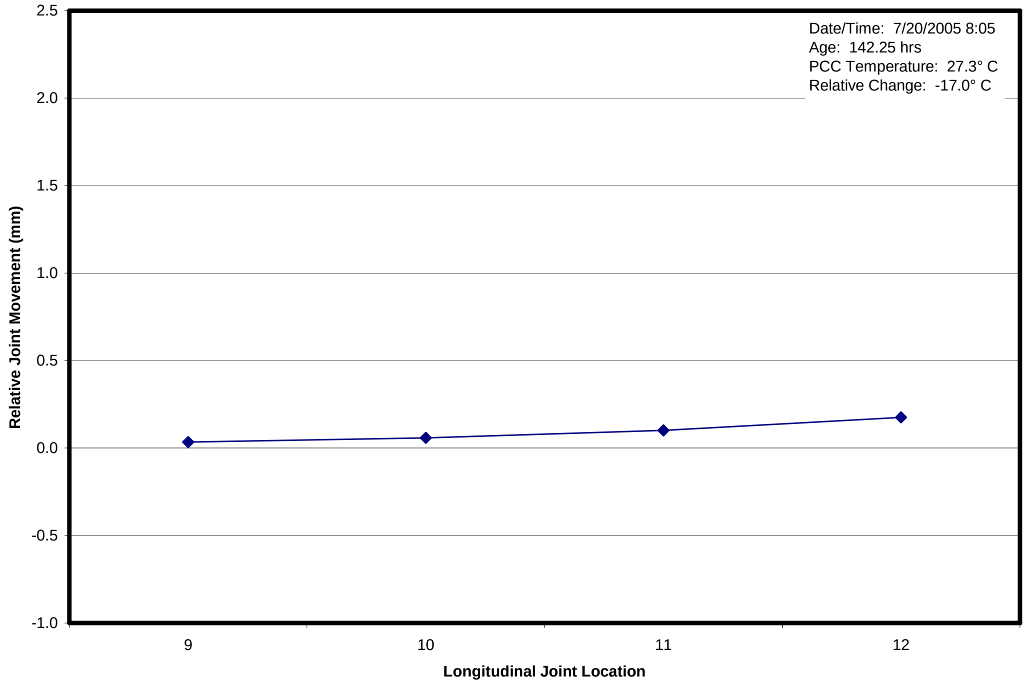


Figure H.25. Longitudinal joint relative opening

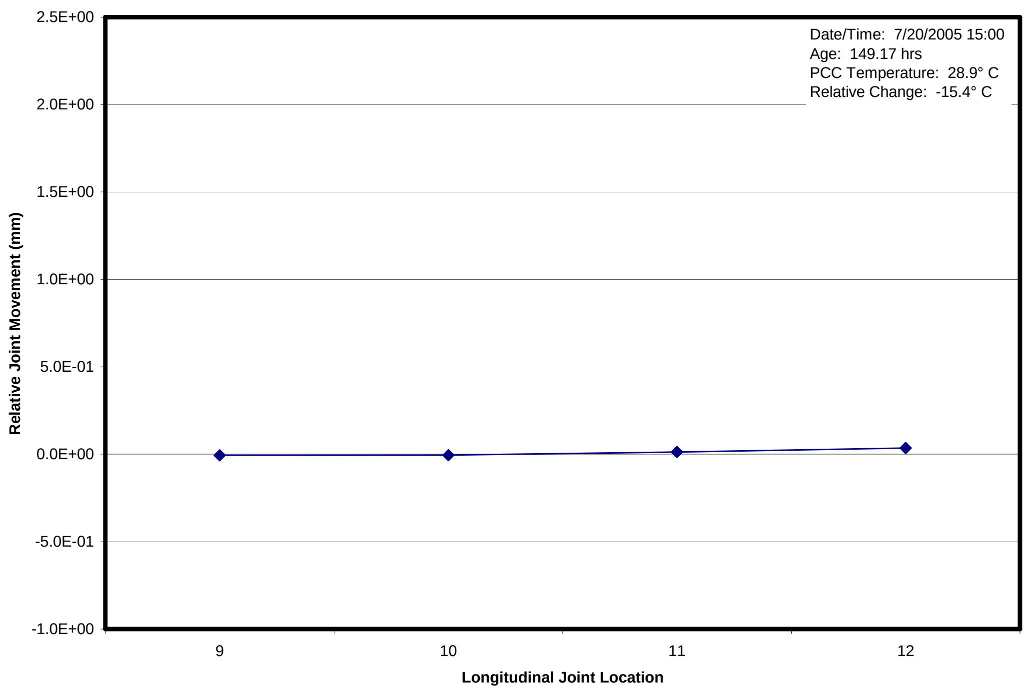


Figure H.26. Longitudinal joint relative opening

Table H.1. Level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1029	7/15/2005 10:29	24.67	39.5	29.9	73.3	165.3	3.29
15JL1635	7/15/2005 16:35	30.75	43.8	32.7	67.5	154.0	3.39
16JL0922	7/16/2005 9:22	47.50	34.9	27.8	80.6	182.5	3.15
16JL1658	7/16/2005 16:58	55.17	40.0	32.2	75.5	171.1	3.25
17JL0827	7/17/2005 8:27	70.67	32.3	26.7	80.3	169.7	3.26
17JL1427	7/17/2005 14:47	76.92	36.1	33.3	77.5	186.3	3.12
18JL0738	7/18/2015 7:38	93.83	28.5	20.6	74.9	174.4	3.22
18JL1636	7/18/2005 16:36	102.75	32.0	26.7	77.7	173.1	3.23
19JL0938	7/19/2005 9:38	119.83	25.8	25.0	76.3	163.2	3.31
19JL1719	7/19/2005 17:19	127.50	32.0	28.9	73.3	148.8	3.43
20JL0616	7/20/2005 6:16	140.42	27.8	23.3	78.1	176.8	3.20
20JL1448	7/20/2005 14:48	149.00	28.8	31.1	74.7	169.9	3.26

Table H.2. Level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1037	7/15/2005 10:37	24.75	39.5	29.9	68.6	115.0	3.74
15JL1645	7/15/2005 16:45	30.92	43.9	32.6	68.2	123.3	3.66
16JL0933	7/16/2005 9:33	47.75	35.0	27.8	66.1	108.0	3.81
16JL1707	7/16/2005 17:07	55.25	40.0	32.2	66.9	114.3	3.75
17JL0840	7/17/2005 8:40	70.83	32.3	26.7	65.9	111.8	3.77
17JL1455	7/17/2005 14:55	77.08	36.2	33.3	67.1	110.5	3.78
18JL0746	7/18/2015 7:46	93.92	28.5	20.6	67.4	117.3	3.72
18JL1646	7/18/2005 16:46	102.92	32.2	26.7	66.2	111.2	3.78
19JL0946	7/19/2005 9:46	119.92	25.8	25.0	67.8	111.3	3.78
19JL1729	7/19/2005 17:29	127.67	32.1	28.9	65.6	109.4	3.79
20JL0625	7/20/2005 6:25	140.58	27.7	23.3	68.9	119.5	3.70
20JL1456	7/20/2005 14:56	149.08	28.9	31.1	65.8	115.8	3.73

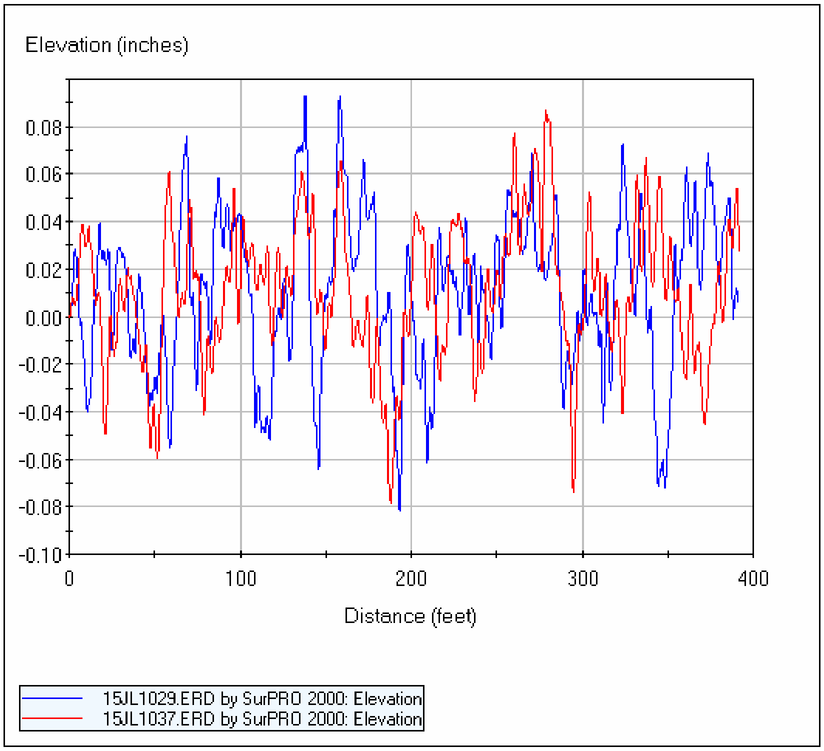


Figure H.27. Level A profile – July 15, 2005 morning

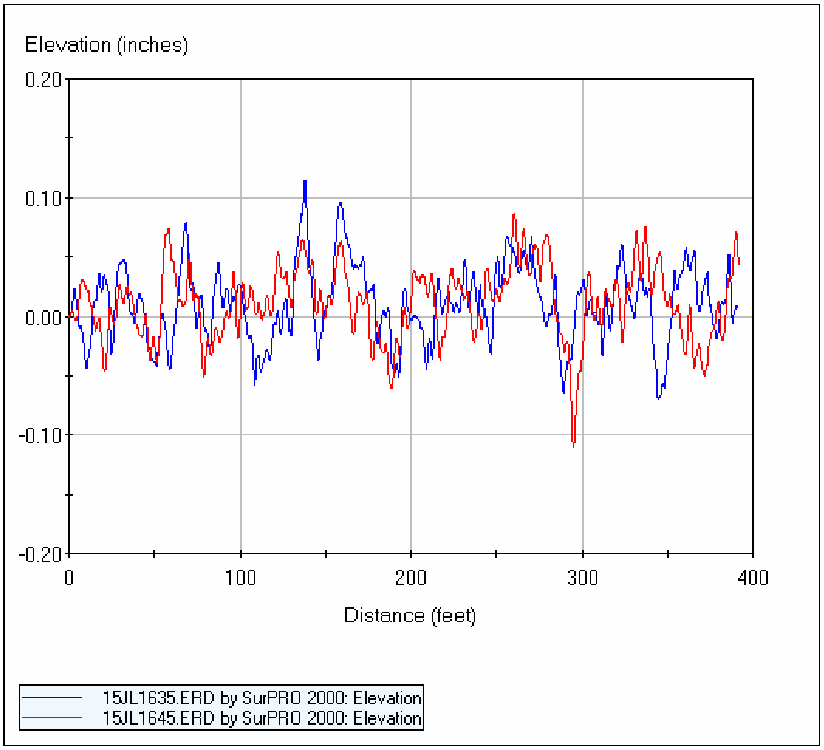


Figure H.28. Level A profile – July 15, 2005 afternoon

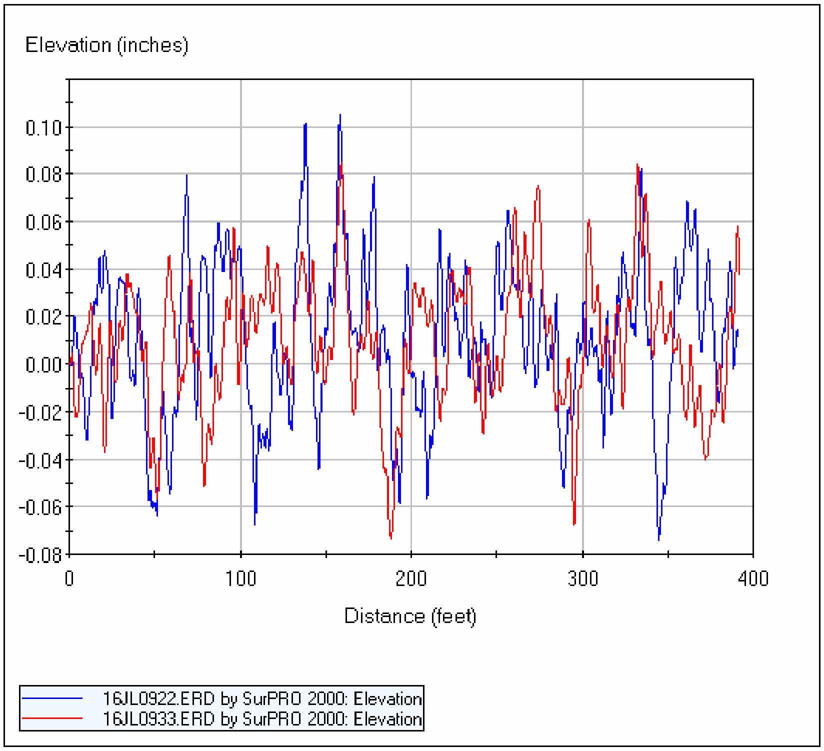


Figure H.29. Level A profile – July 16, 2005 morning

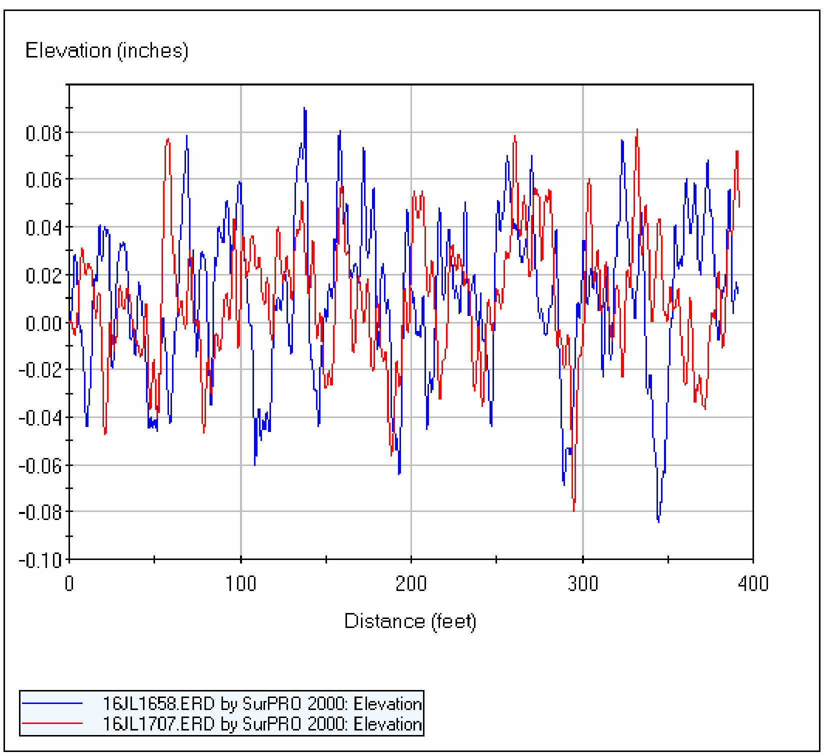


Figure H.30. Level A profile – July 16, 2005 afternoon

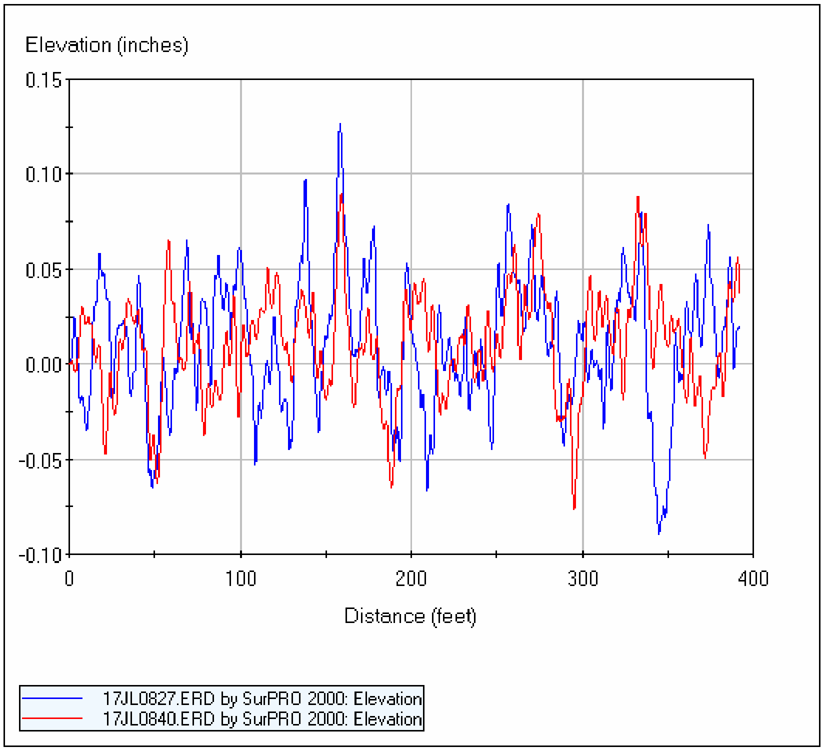


Figure H.31. Level A profile – July 17, 2005 morning

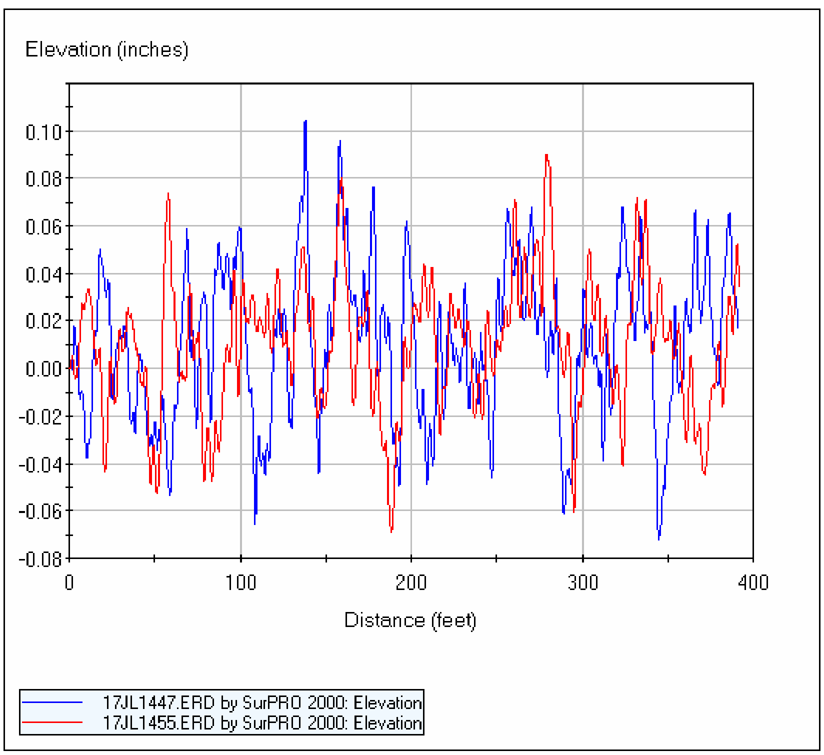


Figure H.32. Level A profile – July 17, 2005 afternoon

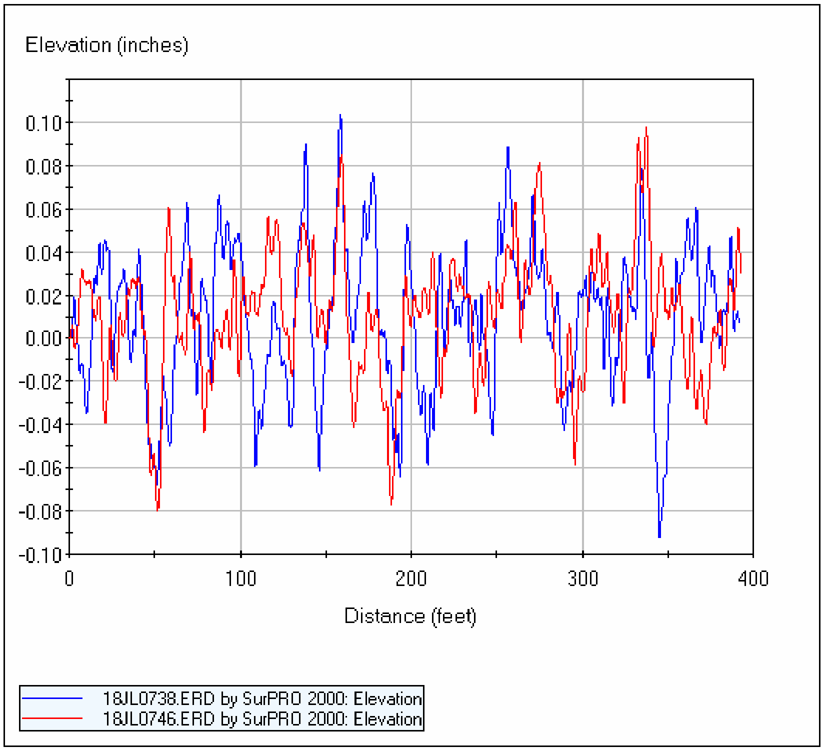


Figure H.33. Level A profile – July 18, 2005 morning

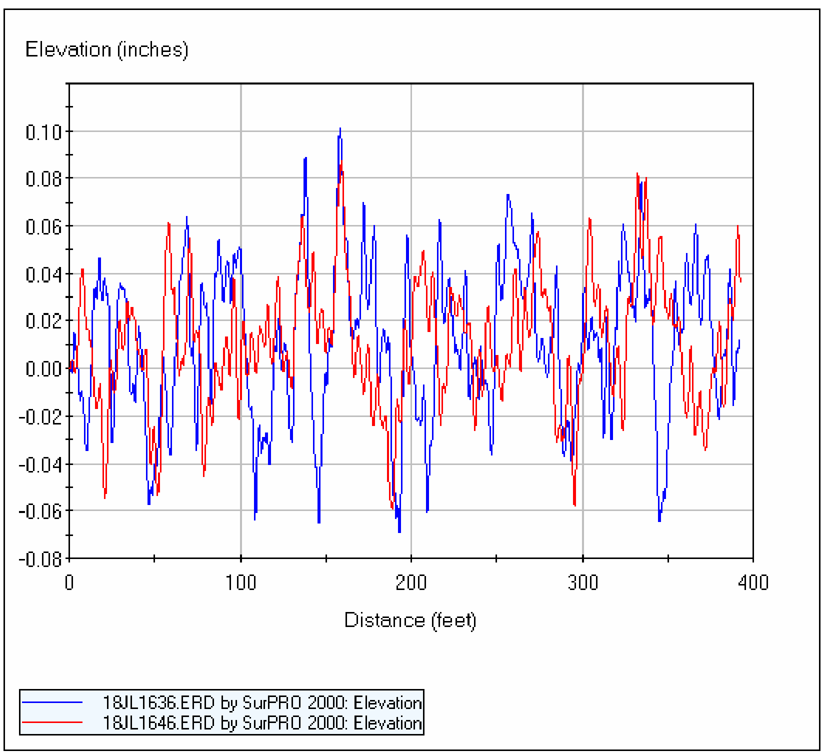


Figure H.34. Level A profile – July 18, 2005 afternoon

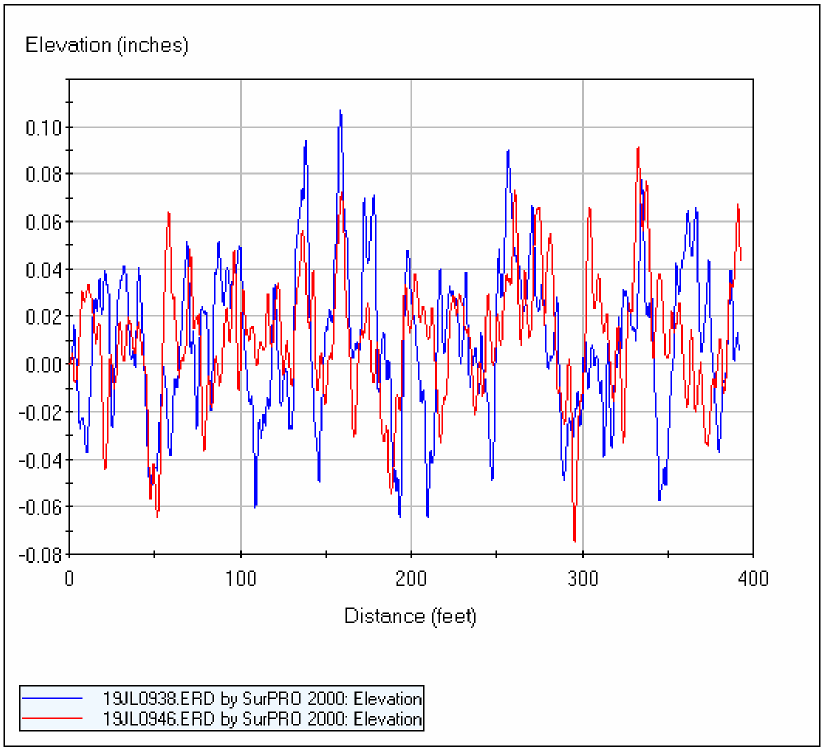


Figure H.35. Level A profile – July 19, 2005 morning

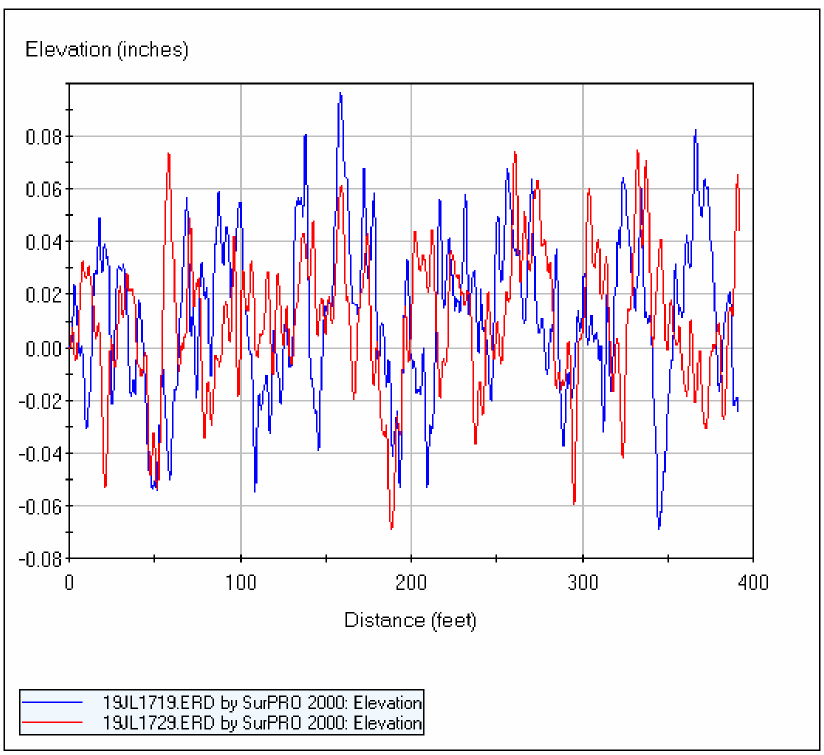


Figure H.36. Level A profile – July 19, 2005 afternoon

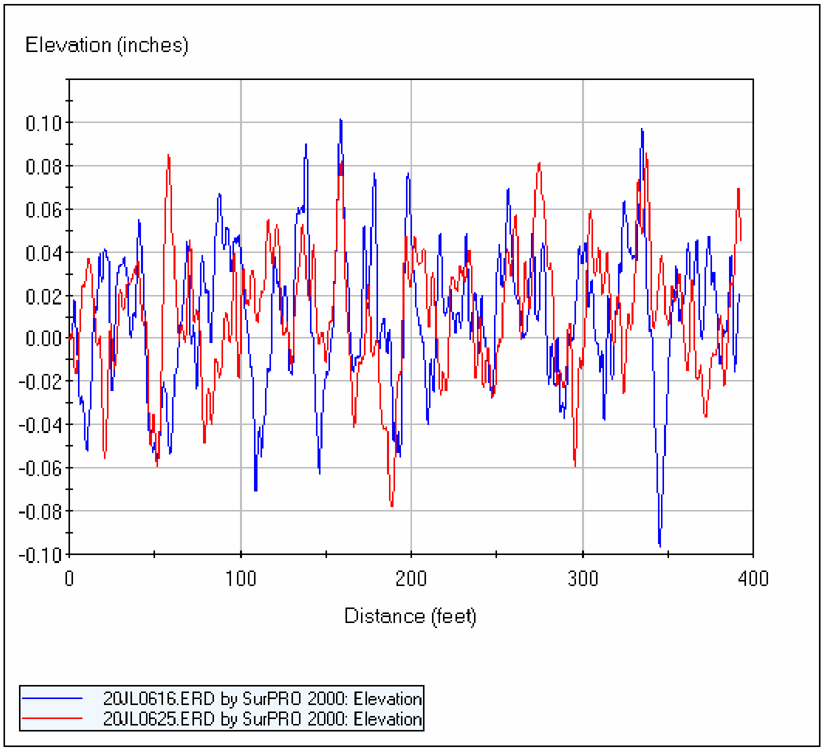


Figure H.37. Level A profile – July 20, 2005 morning

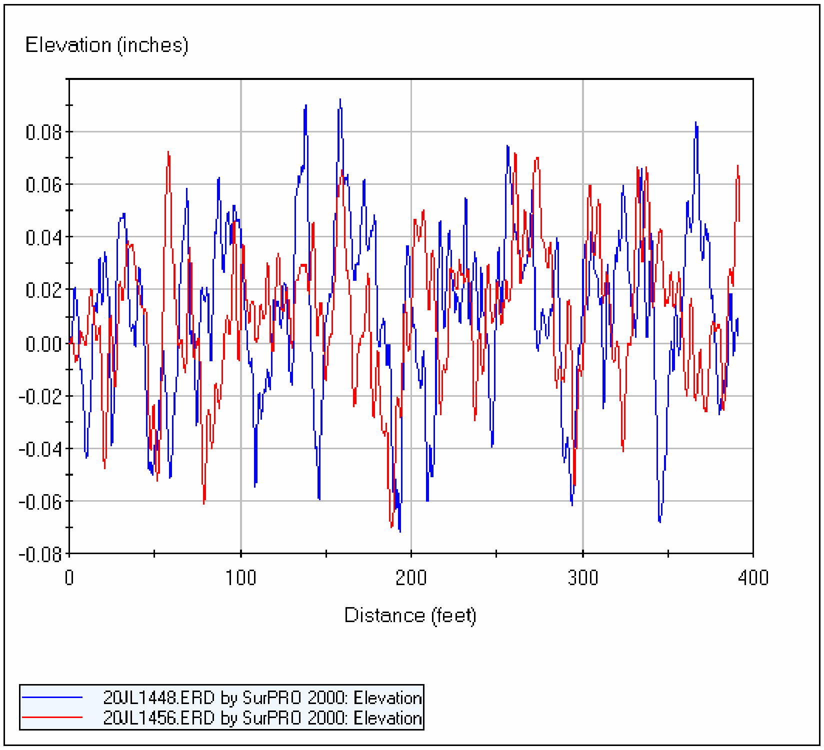


Figure H.38. Level A profile – July 20, 2005 afternoon

Table H.3. Level B profile summary (2 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1652	7/15/2005 16:52	31.00	44.1	32.2	79.7	148.8	3.43
16JL0942	7/16/2005 9:42	47.83	35.0	27.8	75.5	136.2	3.54
16JL1715	7/16/2005 17:15	55.42	40.1	32.2	76.1	135.9	3.55
17JL0848	7/17/2005 8:48	71.00	32.4	26.7	73.2	133.3	3.57
17JL1503	7/17/2005 15:03	77.25	36.3	33.3	75.0	138.1	3.53
18JL0755	7/18/2015 7:55	94.08	28.5	20.6	77.5	130.8	3.59
18JL1654	7/18/2005 16:54	103.08	32.3	26.7	74.6	135.3	3.55
19JL0955	7/19/2005 9:55	120.08	26.0	25.0	75.6	132.6	3.58
19JL1738	7/19/2005 17:38	127.83	32.1	28.9	73.0	130.0	3.60
20JL0632	7/20/2005 6:32	140.67	27.6	23.3	76.2	143.1	3.48
20JL1504	7/20/2005 15:04	149.25	29.1	31.1	79.8	146.3	3.46

Table H.4. Level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1659	7/15/2005 16:59	31.17	44.1	32.2	75.6	142.7	3.49
16JL0950	7/16/2005 9:50	48.00	35.0	27.8	75.4	127.1	3.63
16JL1723	7/16/2005 17:23	55.58	40.2	32.2	75.4	137.3	3.53
17JL0856	7/17/2005 8:56	71.08	32.4	26.7	75.2	134.3	3.56
17JL1511	7/17/2005 15:11	77.33	36.3	33.3	74.6	134.5	3.56
18JL0802	7/18/2015 8:02	94.17	28.5	20.6	73.7	136.1	3.55
18JL1702	7/18/2005 17:02	103.17	32.3	26.7	70.4	138	3.53
19JL1003	7/19/2005 10:03	120.25	25.9	25.0	72.1	126.9	3.63
19JL1745	7/19/2005 17:45	127.92	32.1	28.9	72.6	128.1	3.62
20JL0639	7/20/2005 6:39	140.83	27.5	23.3	73.1	131.2	3.59
20JL1513	7/20/2005 15:13	149.42	29.3	31.1	74.3	134.2	3.56

Table H.5. Level B profile summary (3 ft. from longitudinal joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1706	7/15/2005 17:06	31.25	44.1	32.2	70.8	140.7	3.50
16JL1006	7/16/2005 10:06	48.25	35.2	27.8	66.3	121.5	3.68
16JL1738	7/16/2005 17:38	55.83	40.3	31.7	67.6	120.4	3.69
17JL0912	7/17/2005 9:12	71.33	32.5	26.7	67.9	119.1	3.70
17JL1527	7/17/2005 15:27	77.58	36.7	33.3	67.9	121.3	3.68
18JL0817	7/18/2015 8:17	94.42	28.4	20.6	65.6	115.1	3.74
18JL1720	7/18/2005 17:20	103.50	32.3	26.7	64.7	114.4	3.75
19JL1021	7/19/2005 10:21	120.50	26.0	25.0	65.6	112.1	3.77
19JL1802	7/19/2005 18:02	128.17	32.1	28.9	66.9	117.5	3.72
20JL0655	7/20/2005 6:55	141.08	27.3	23.3	63.3	113.5	3.75
20JL1528	7/20/2005 15:28	149.67	29.5	31.1	66.8	121.9	3.67

Table H.6. Level B profile summary (1 ft. from longitudinal joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
15JL1714	7/15/2005 17:14	31.42	44.1	32.2	49.3	127.4	3.62
16JL0959	7/16/2005 9:59	48.17	35.0	27.8	44.7	107.4	3.81
16JL1731	7/16/2005 17:31	55.67	40.2	31.7	52.2	128.4	3.62
17JL0905	7/17/2005 9:05	71.25	32.5	26.7	51.8	125.4	3.64
17JL1519	7/17/2005 15:19	77.50	36.5	33.3	47.7	116.7	3.72
18JL0810	7/18/2015 8:10	94.33	28.4	20.6	55.8	129.2	3.61
18JL1713	7/18/2005 17:13	103.42	32.3	26.7	45.6	107.1	3.81
19JL1012	7/19/2005 10:12	120.33	25.9	25.0	44.6	100.5	3.88
19JL1755	7/19/2005 17:55	128.08	32.1	28.9	44.6	118.0	3.71
20JL0647	7/20/2005 6:47	140.92	27.4	23.3	50.4	119.8	3.69
20JL1521	7/20/2005 15:21	149.50	29.3	31.1	50.4	122.3	3.67

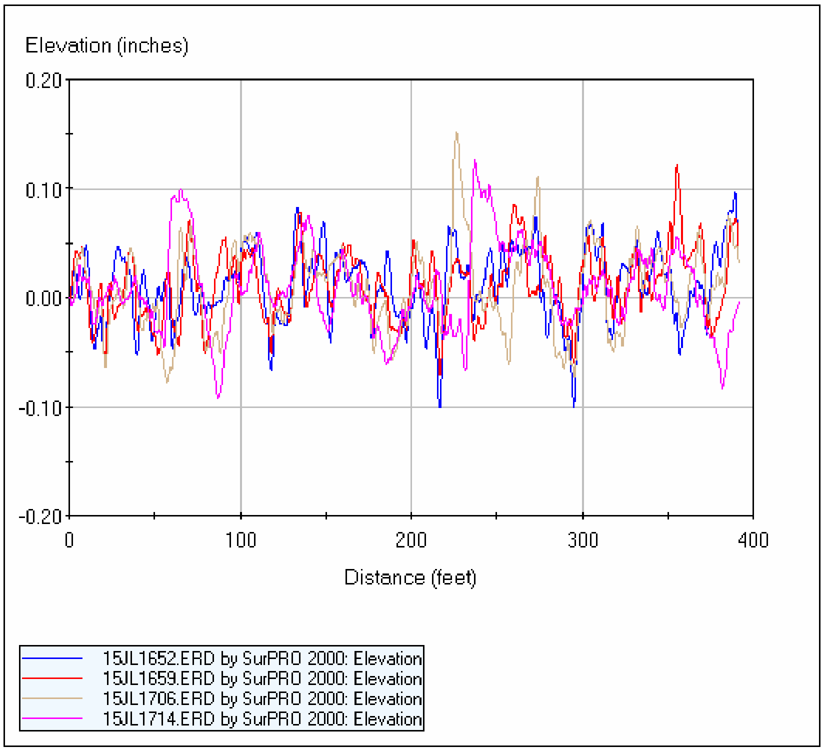


Figure H.39. Level B profile – July 15, 2005 afternoon

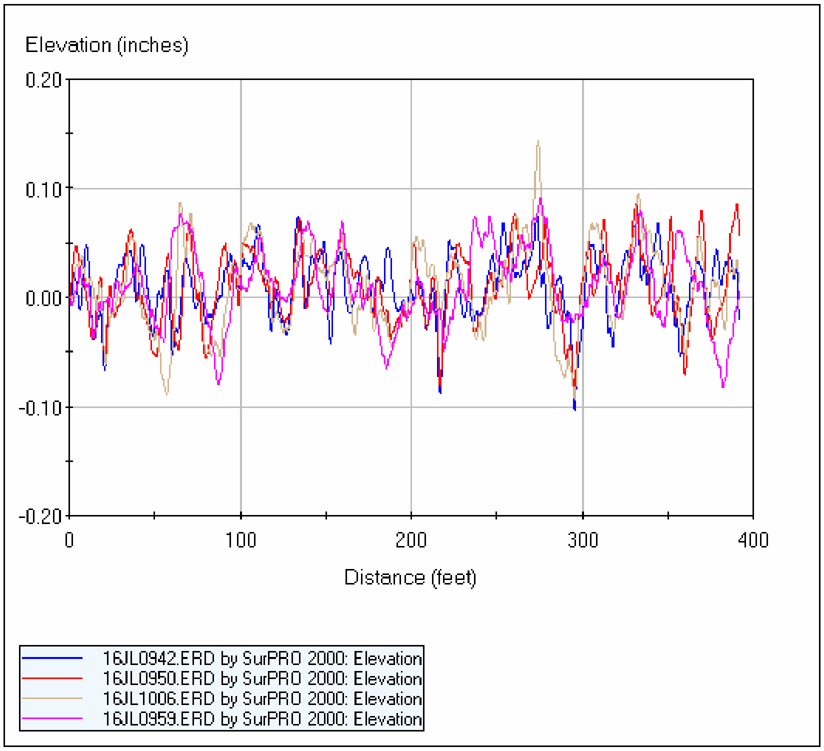


Figure H.40. Level B profile – July 16, 2005 morning

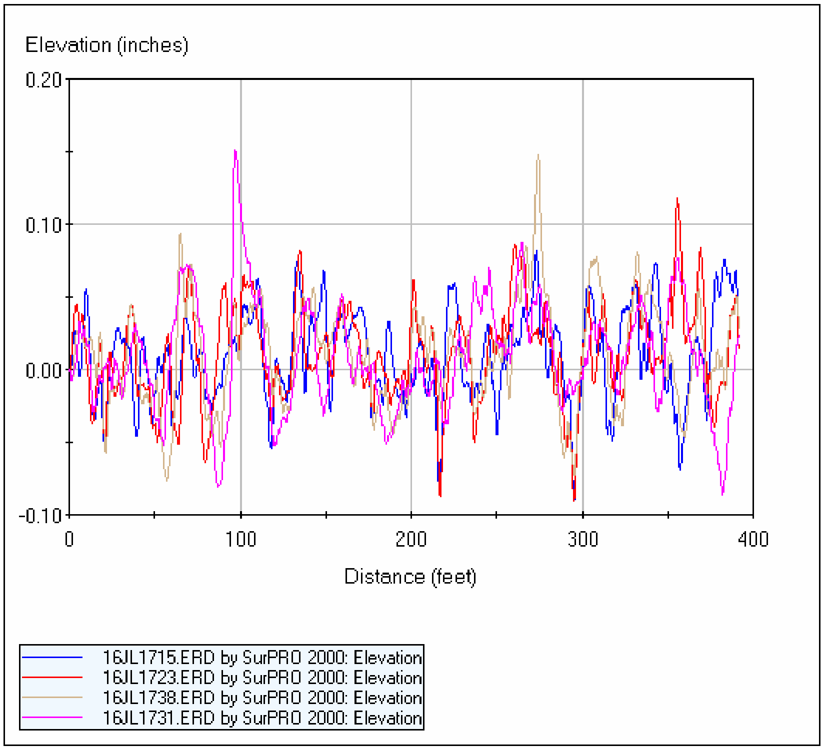


Figure H.41. Level B profile – July 16, 2005 afternoon

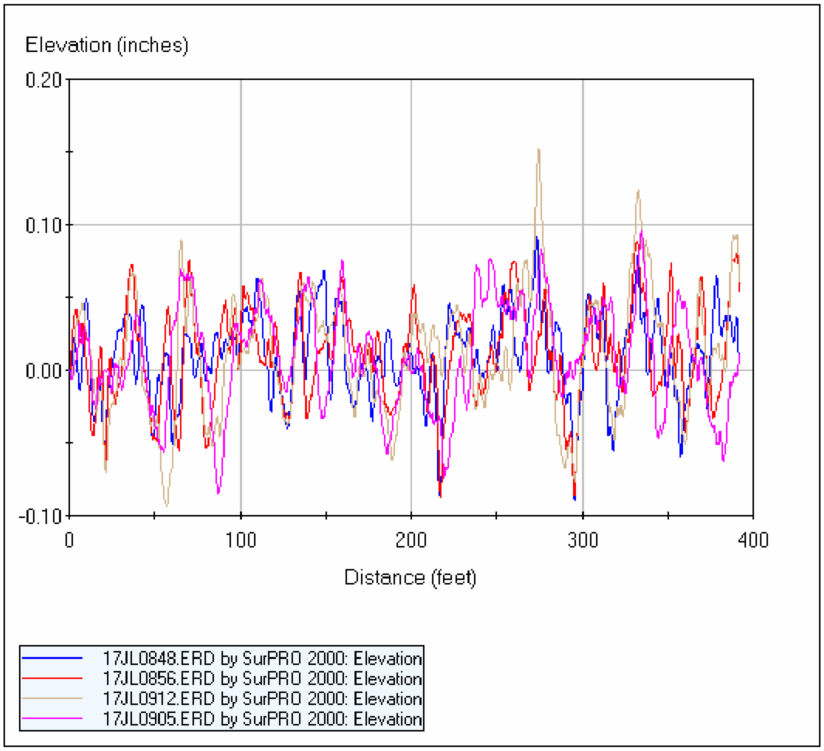


Figure H.42. Level B Profile – July 17, 2005 morning

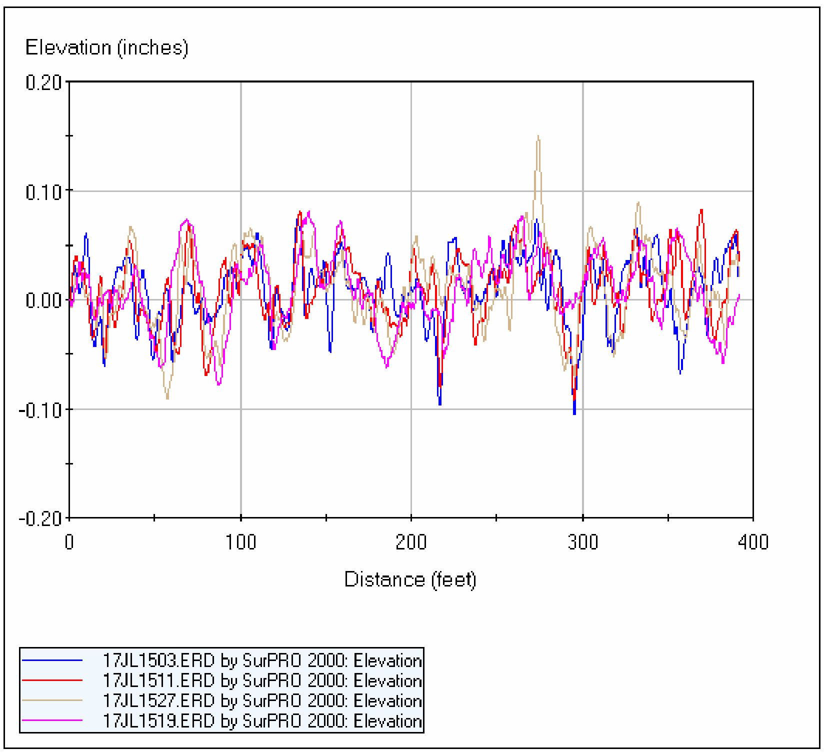


Figure H.43. Level B Profile – July 17, 2005 afternoon

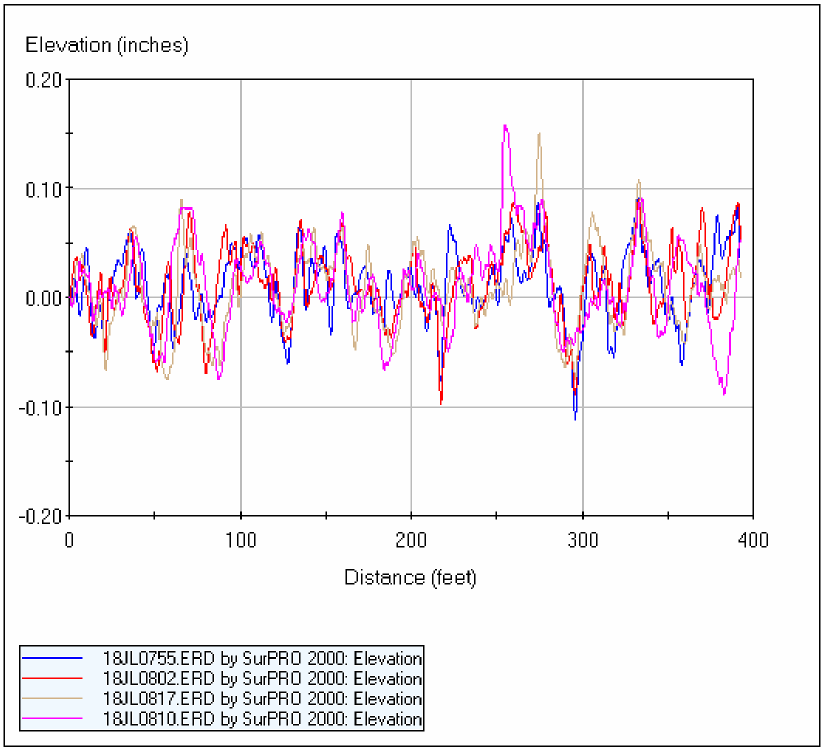


Figure H.44. Level B profile – July 18, 2005 morning

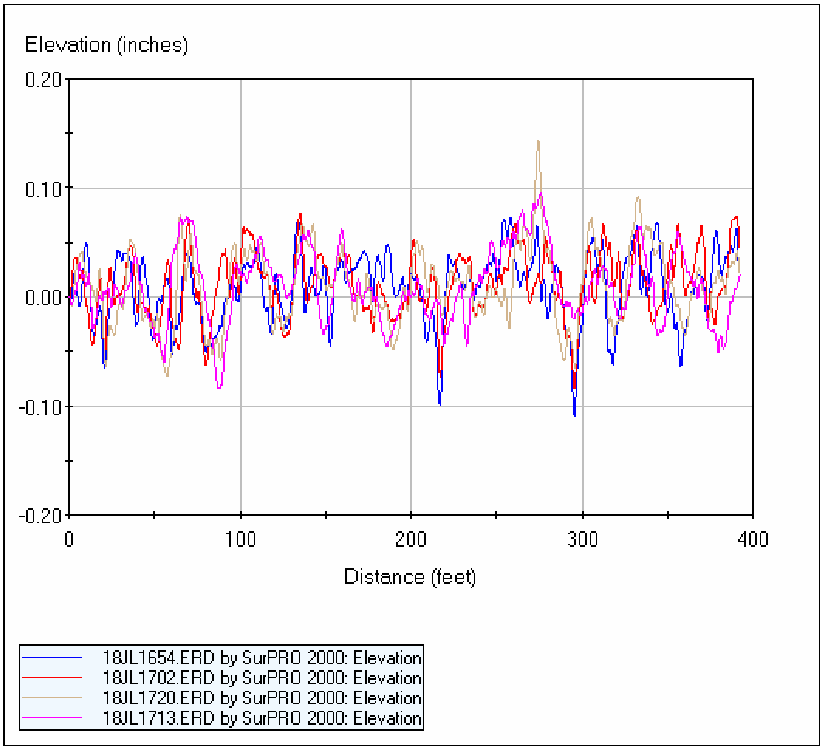


Figure H.45. Level B profile – July 18, 2005 afternoon

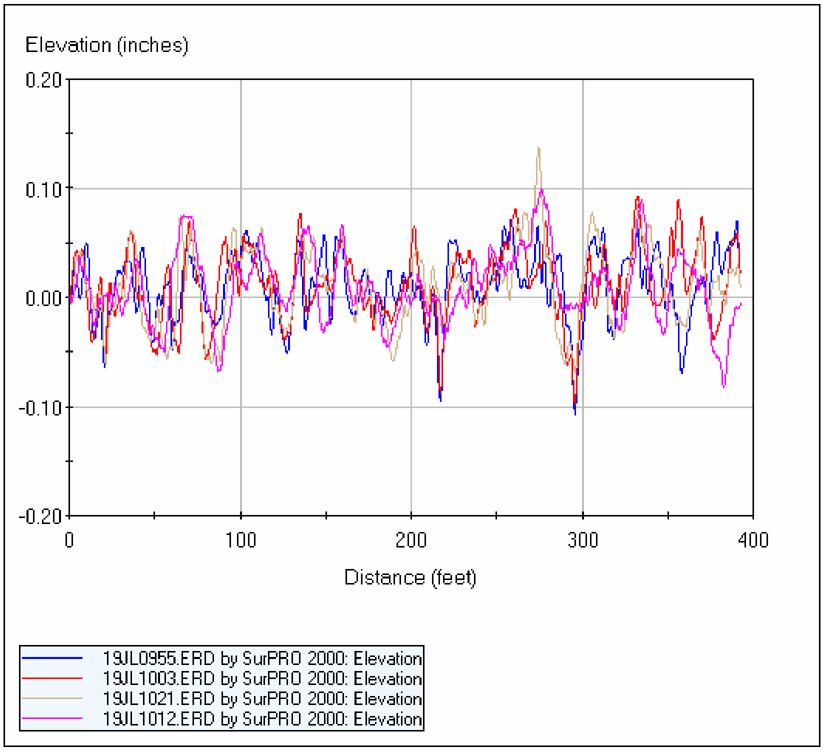


Figure H.46. Level B profile – July 19, 2005 morning

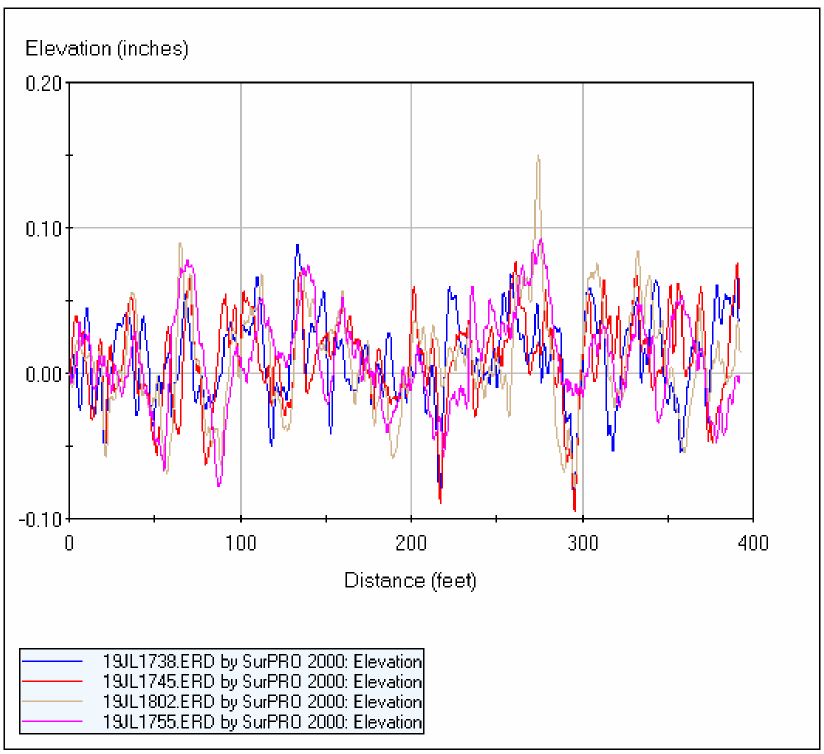


Figure H.47. Level B profile – July 19, 2005 afternoon

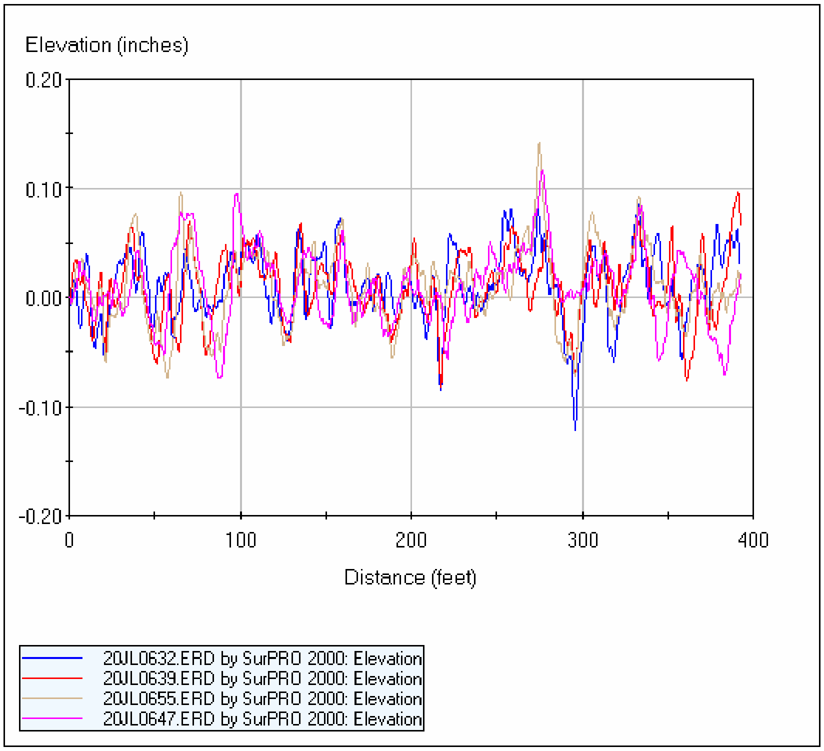


Figure H.48. Level B profile – July 20, 2005 morning

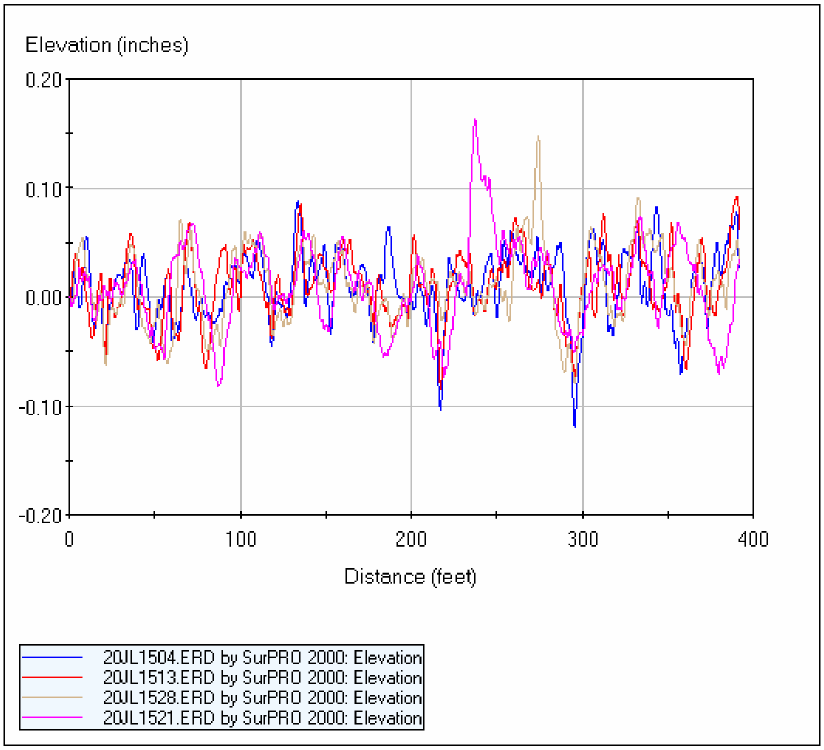


Figure H.49. Level B profile – July 20, 2005 afternoon

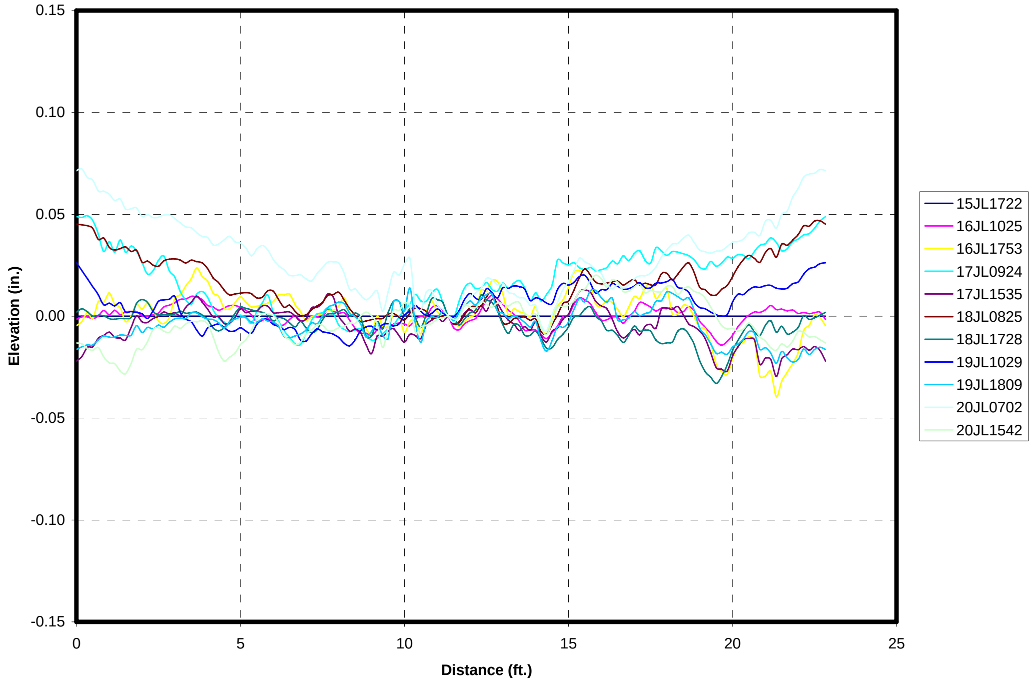


Figure H.50. Level C profiles path 1 – slab 9

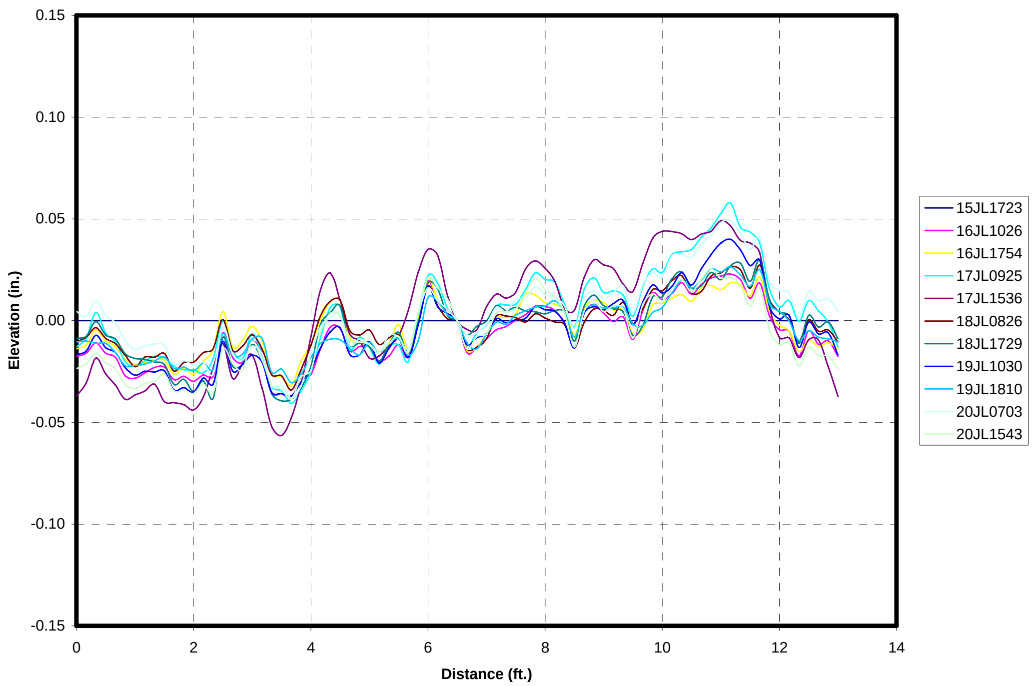


Figure H.51. Level C profiles path 2 – slab 9

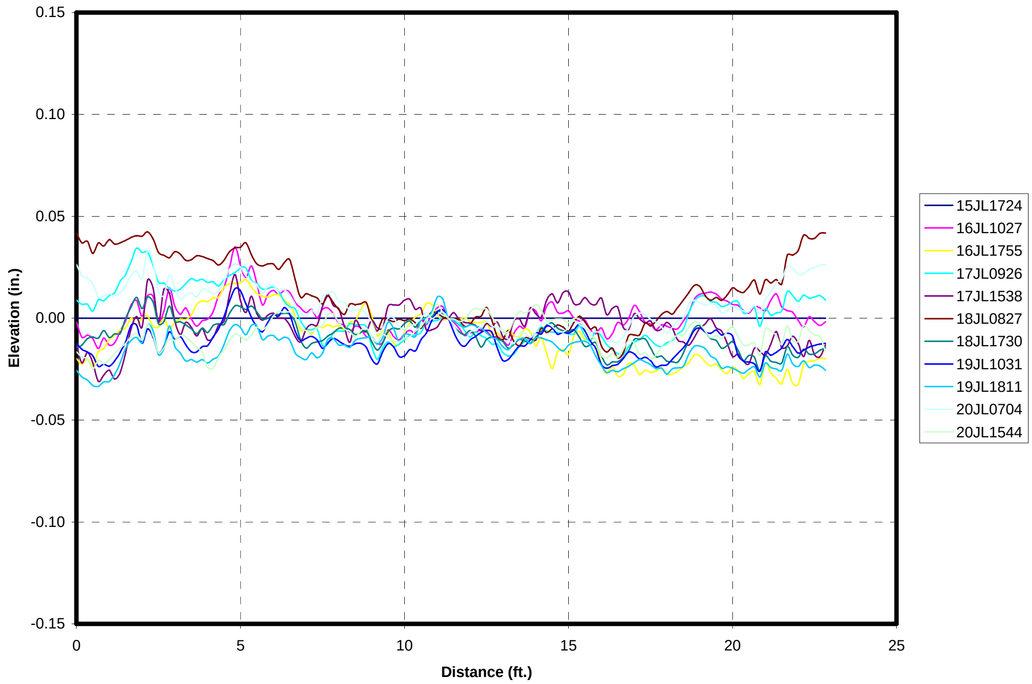


Figure H.52. Level C profiles path 3 – slab 9

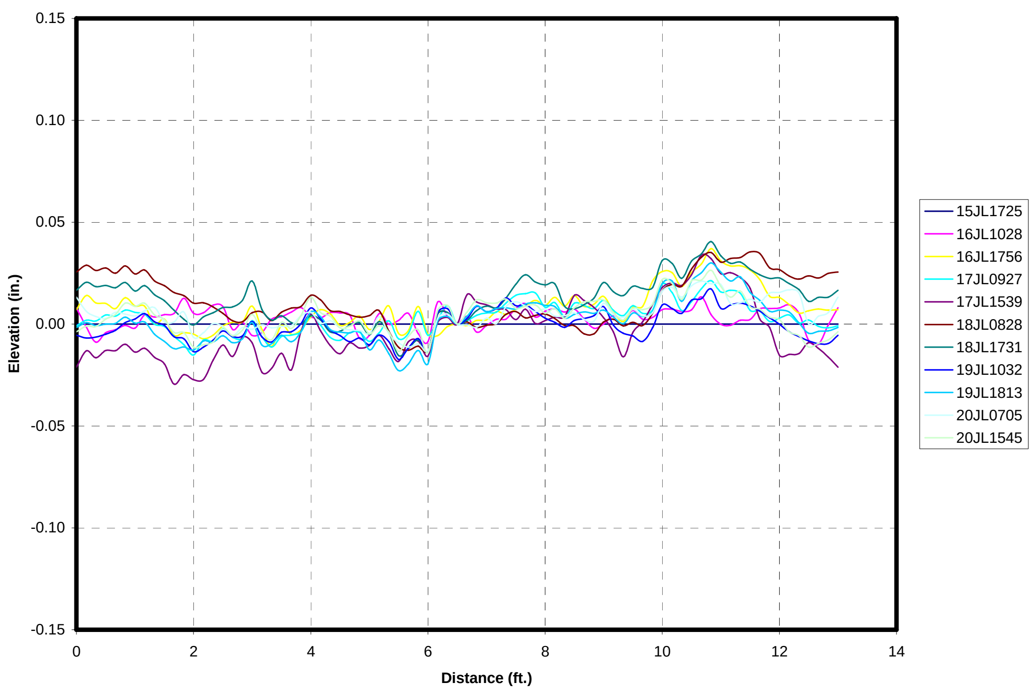


Figure H.53. Level C profiles path 4 – slab 9

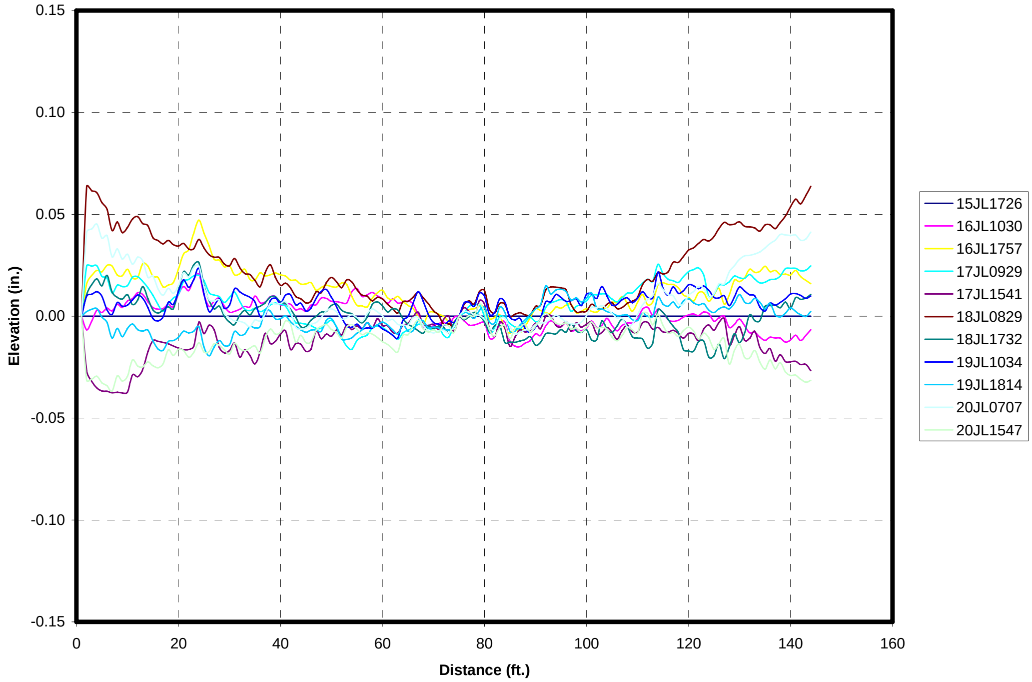


Figure H.54. Level C profiles path 1 – slab 10

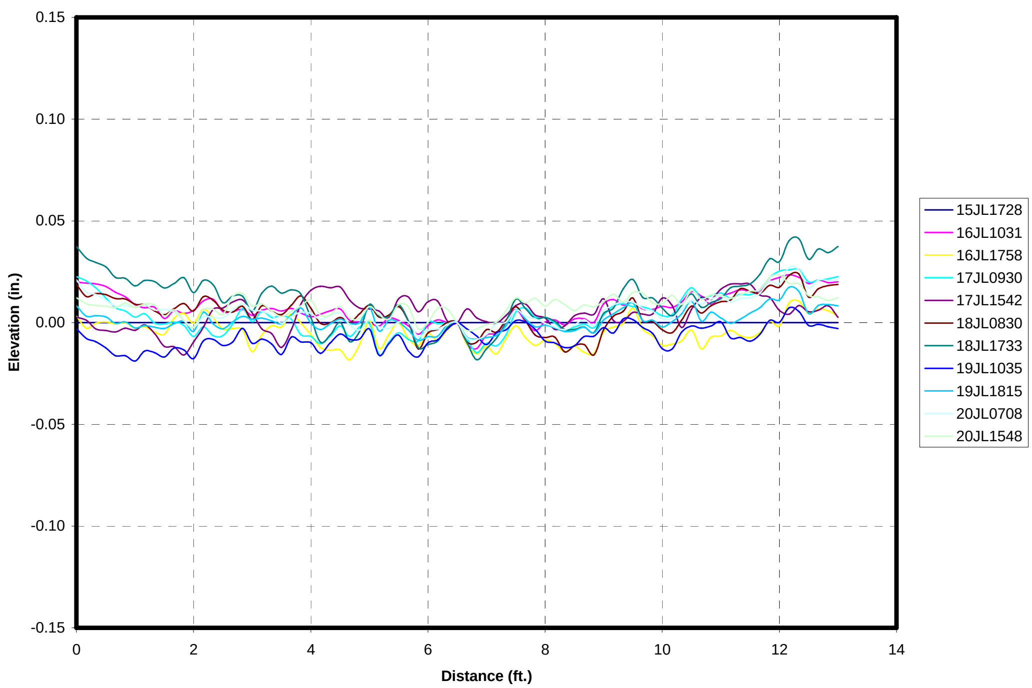


Figure H.55. Level C profiles path 2 – slab 10

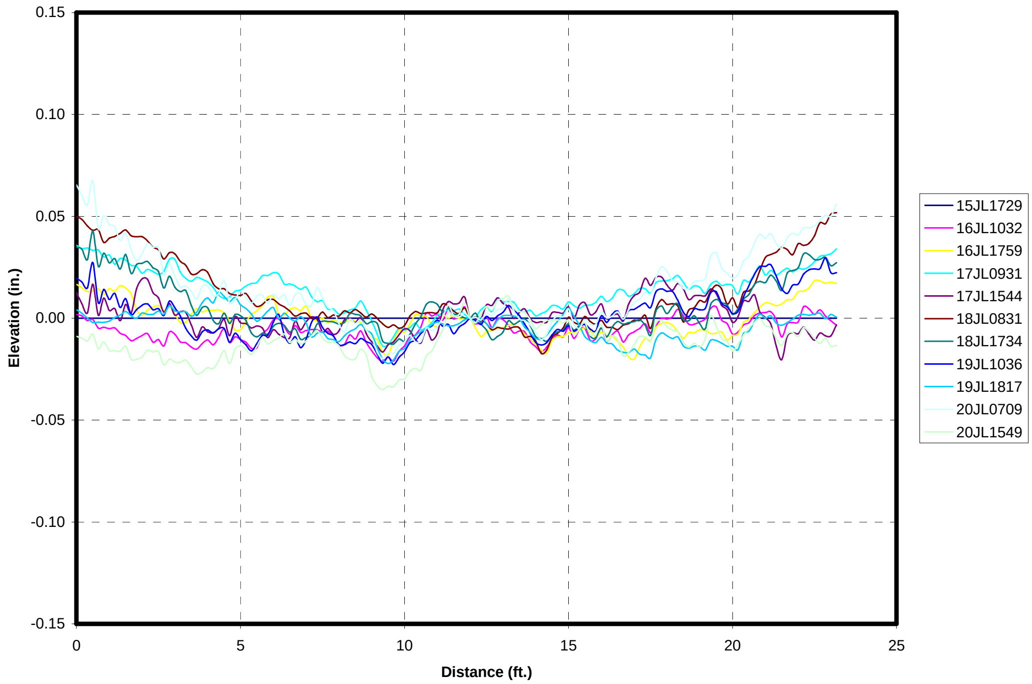


Figure H.56. Level C profiles path 3 – slab 10

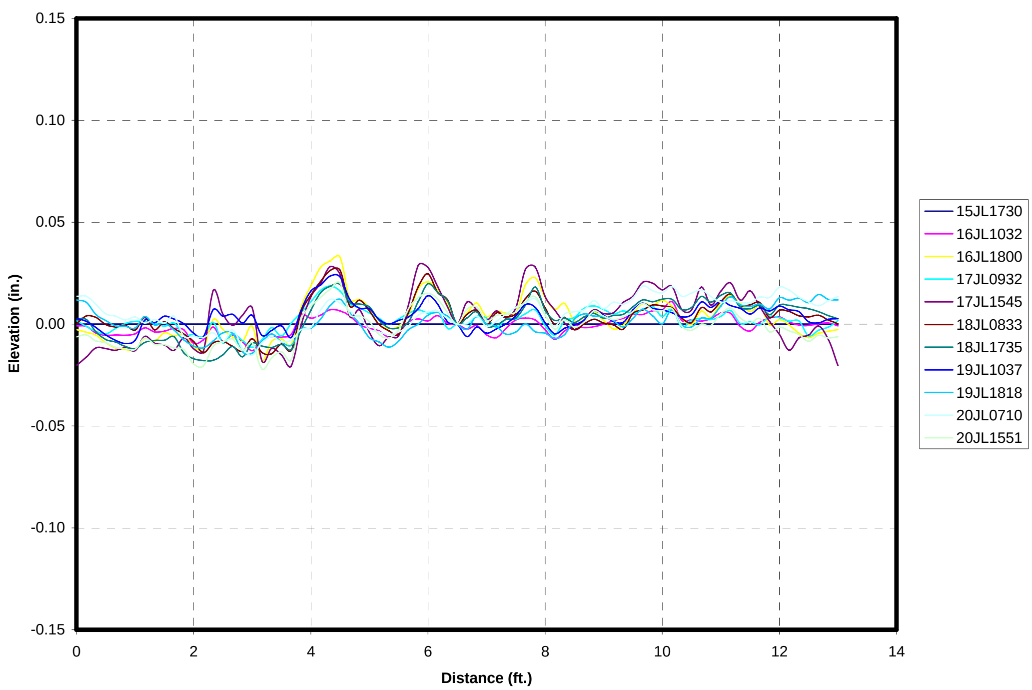


Figure H.57. Level C profiles path 4 – slab 10

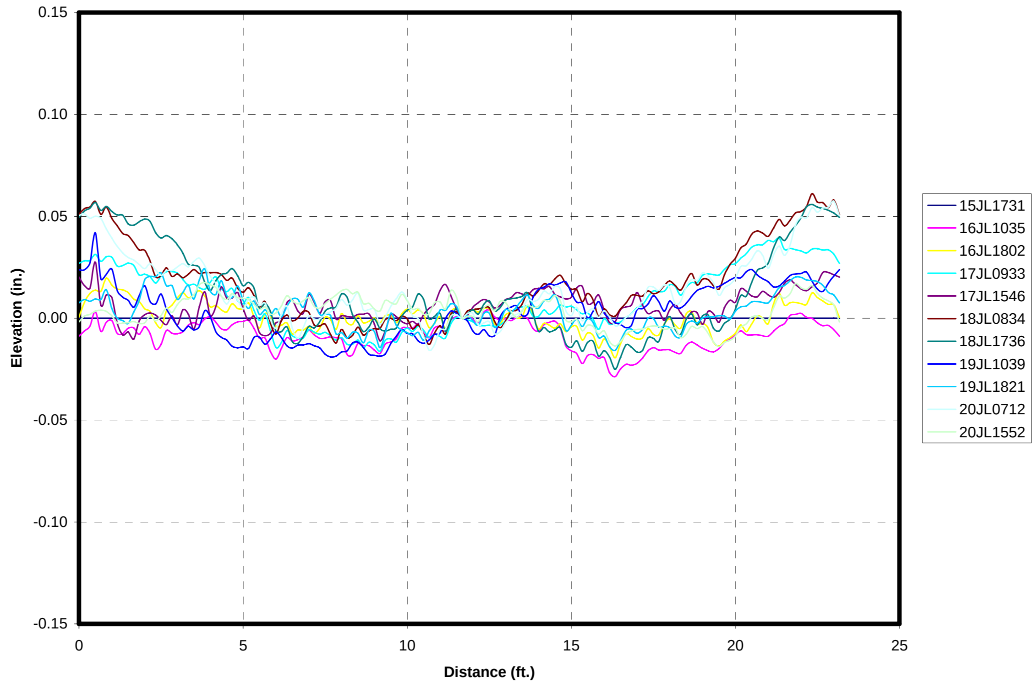


Figure H.58. Level C profiles path 1 – slab 11

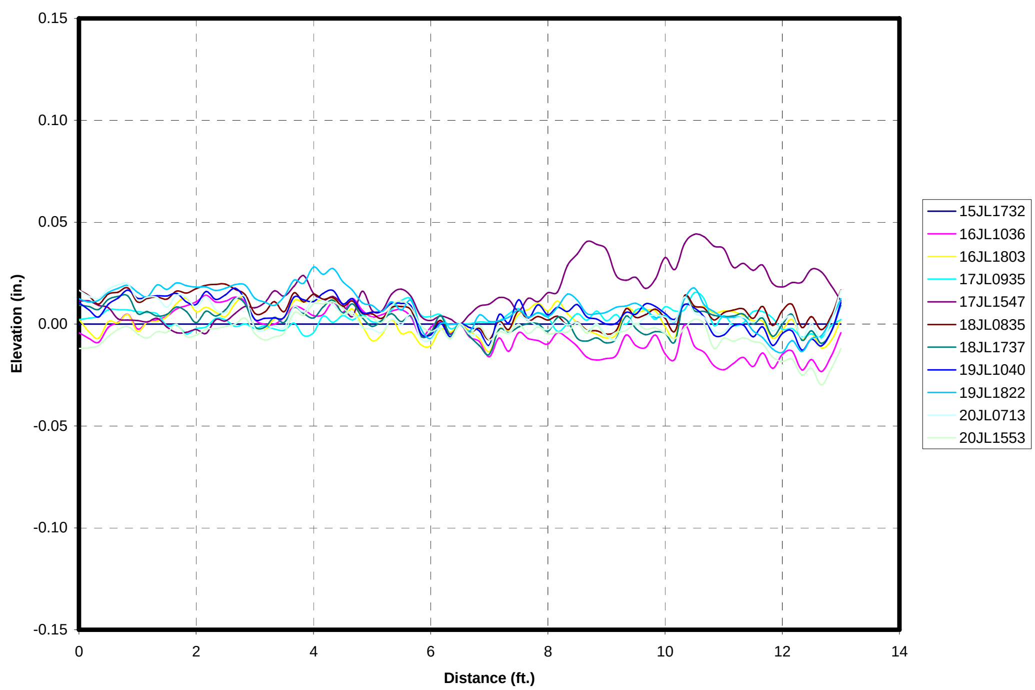


Figure H.59. Level C profiles path 2 – slab 11

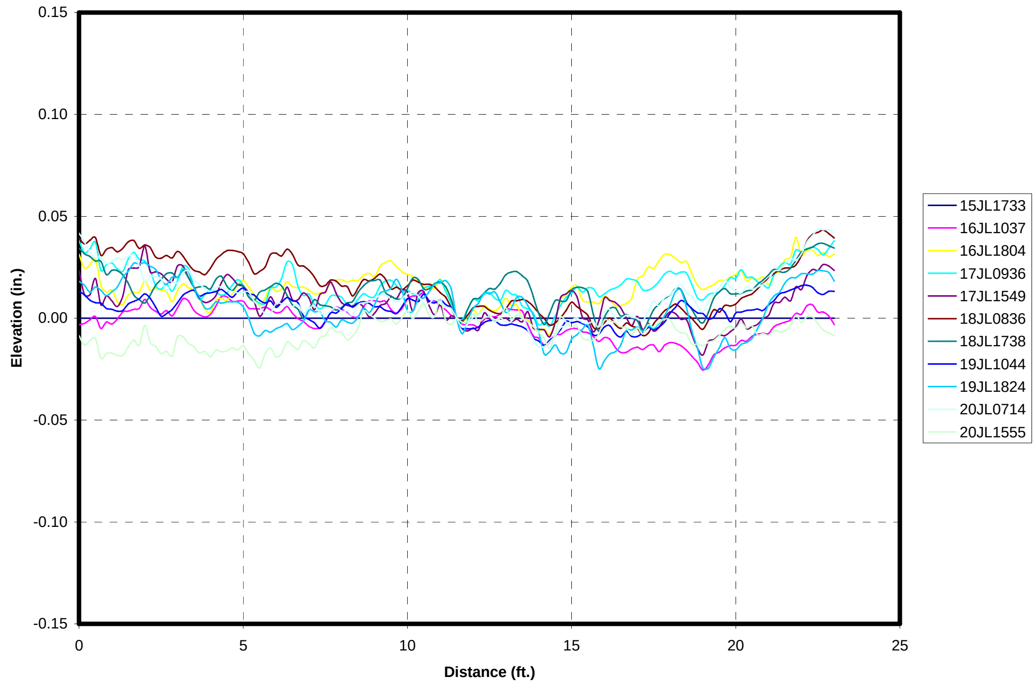


Figure H.60. Level C profiles path 3 – slab 11

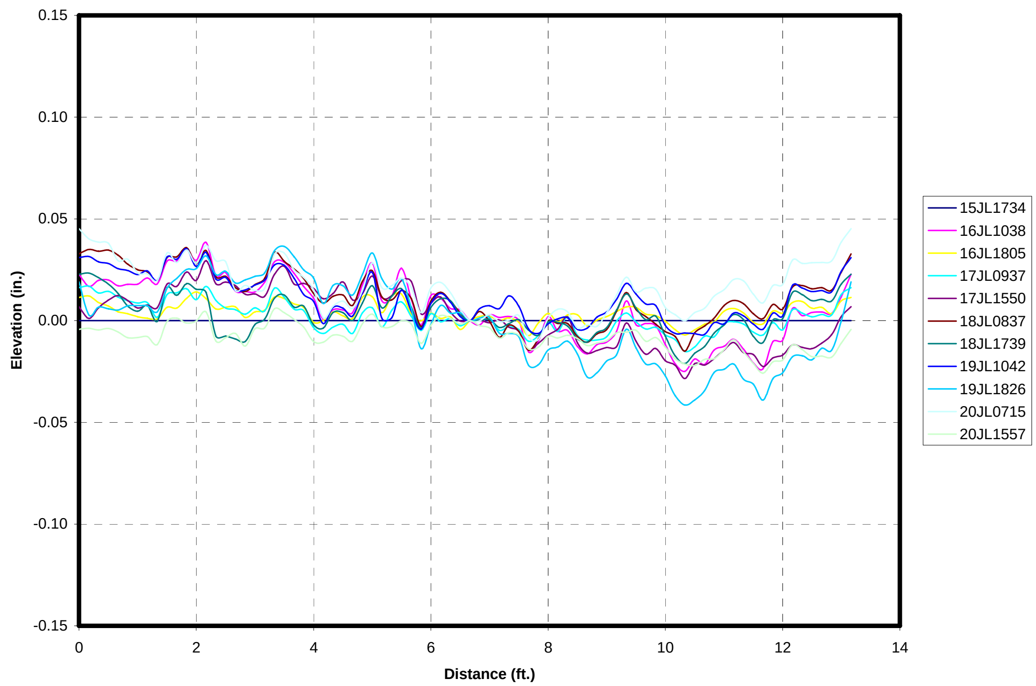


Figure H.61. Level C profiles path 4 – slab 11

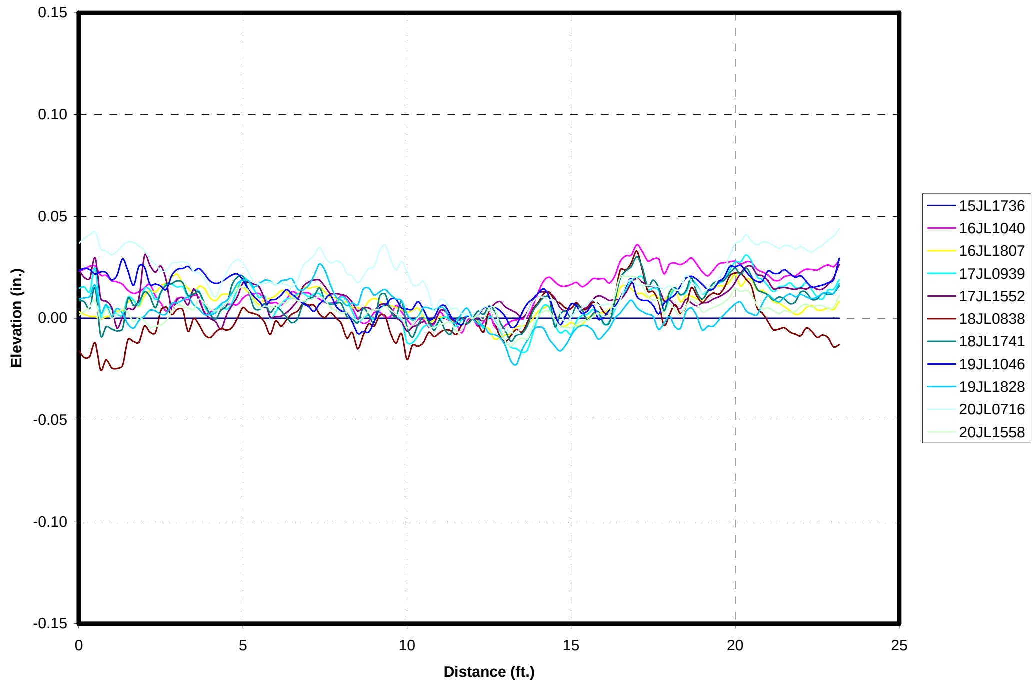


Figure H.62. Level C profiles path 1 – slab 12

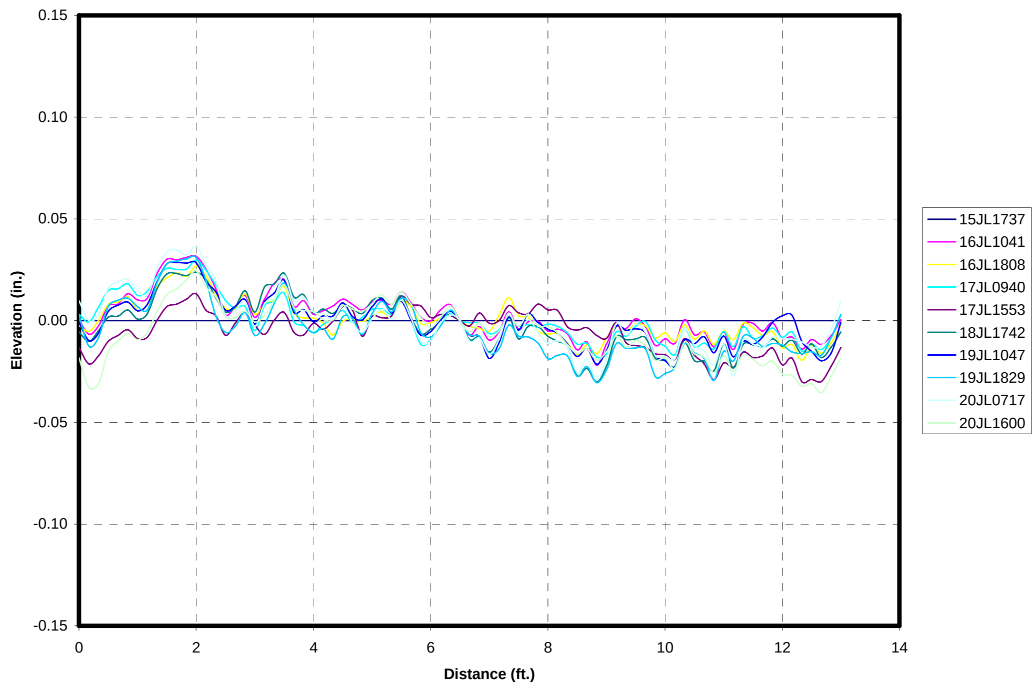


Figure H.63. Level C profiles path 2 – slab 12

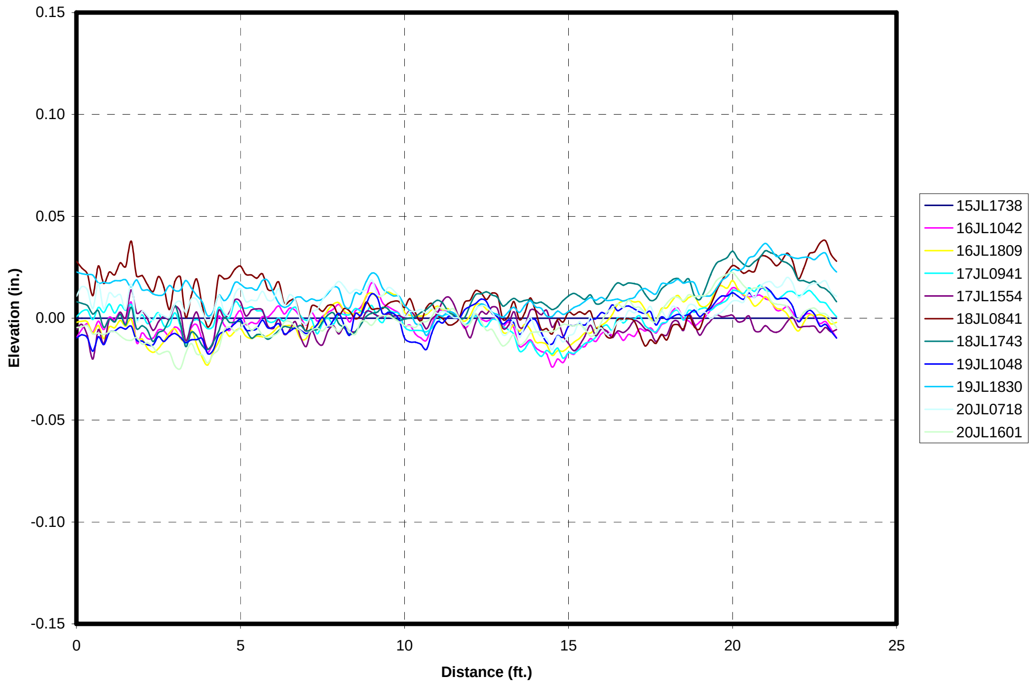


Figure H.64. Level C profiles path 3 – slab 12

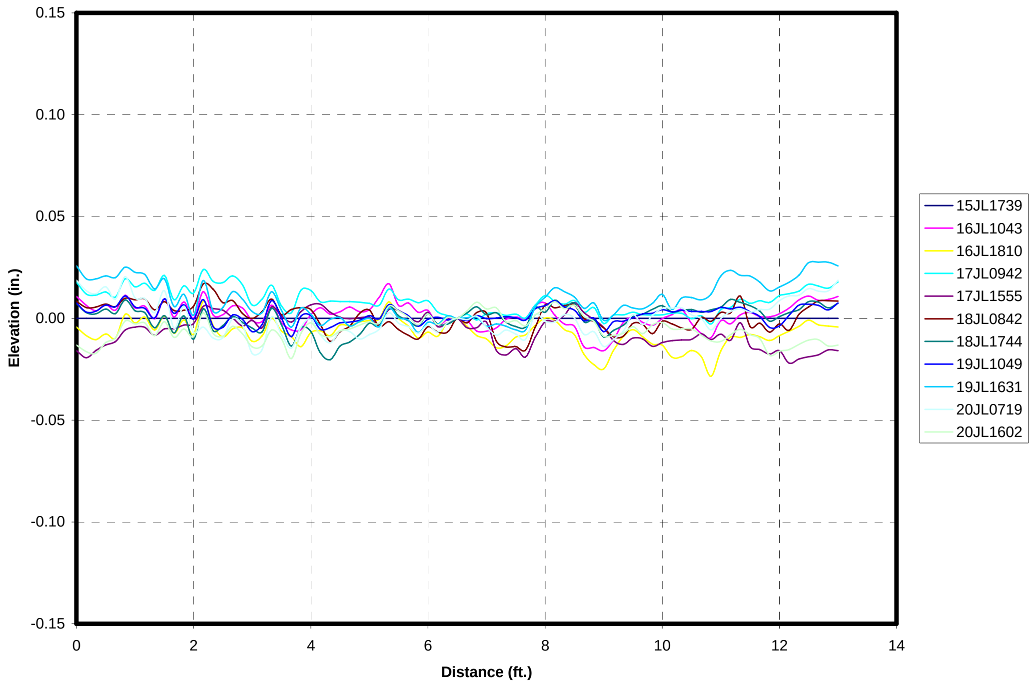


Figure H.65. Level C profiles path 4 – slab 12

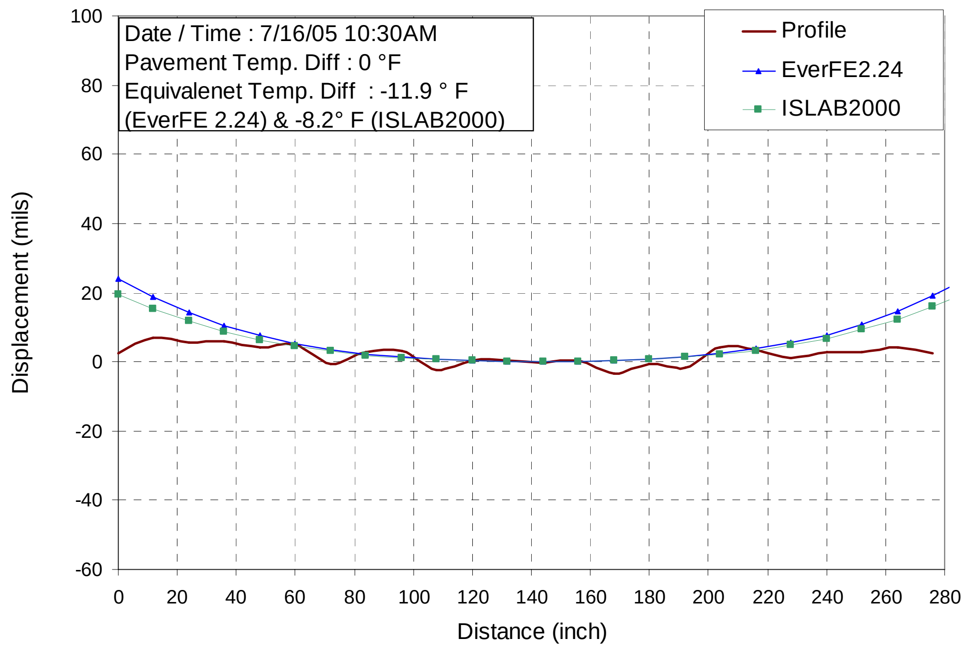


Figure H.66. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 16 morning

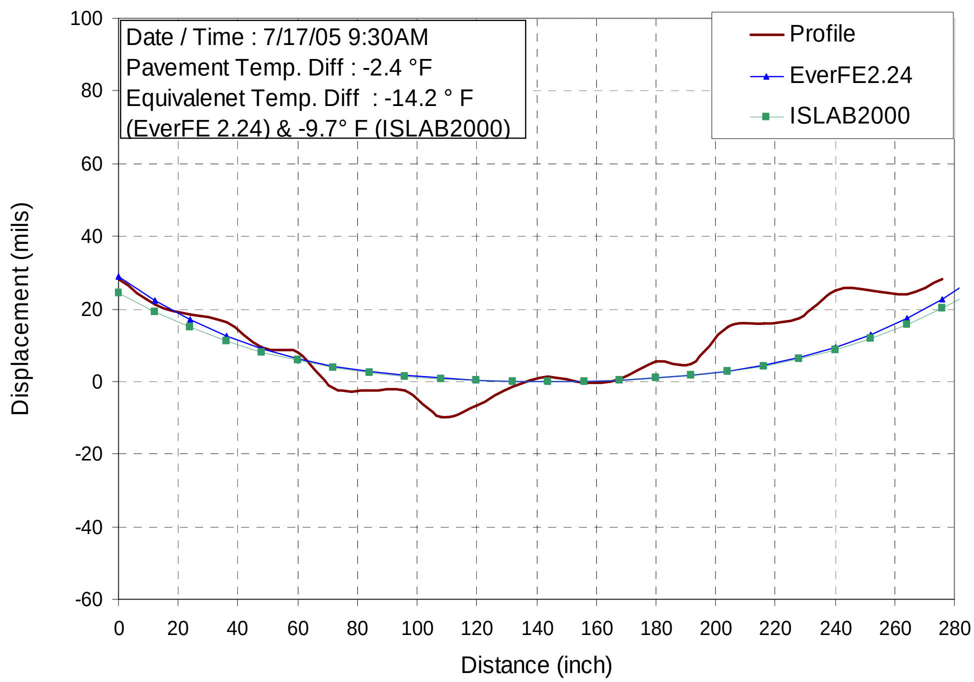


Figure H.67. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 17 morning

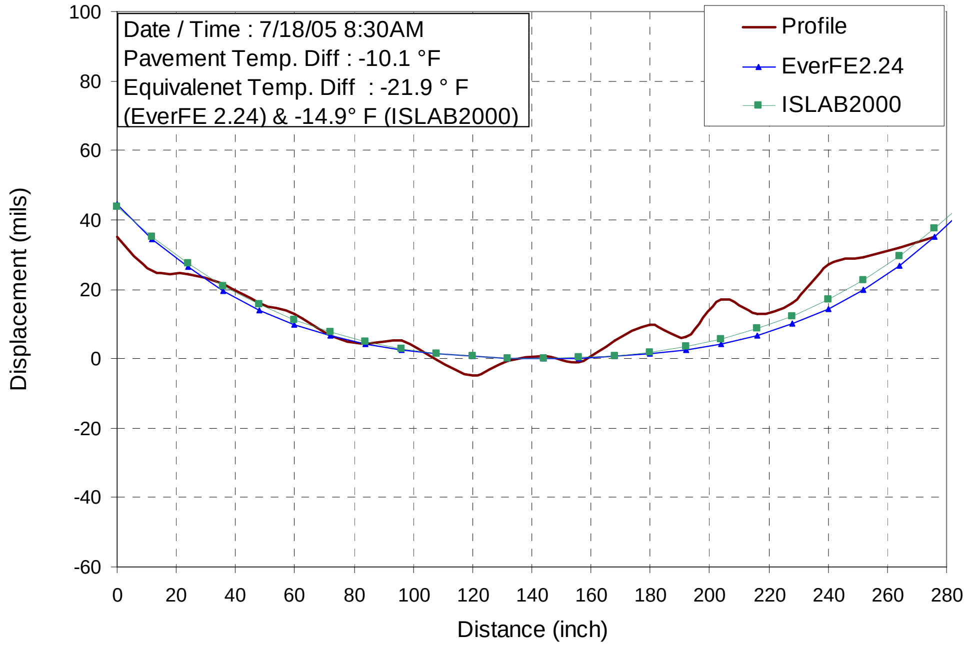


Figure H.68. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 18 morning

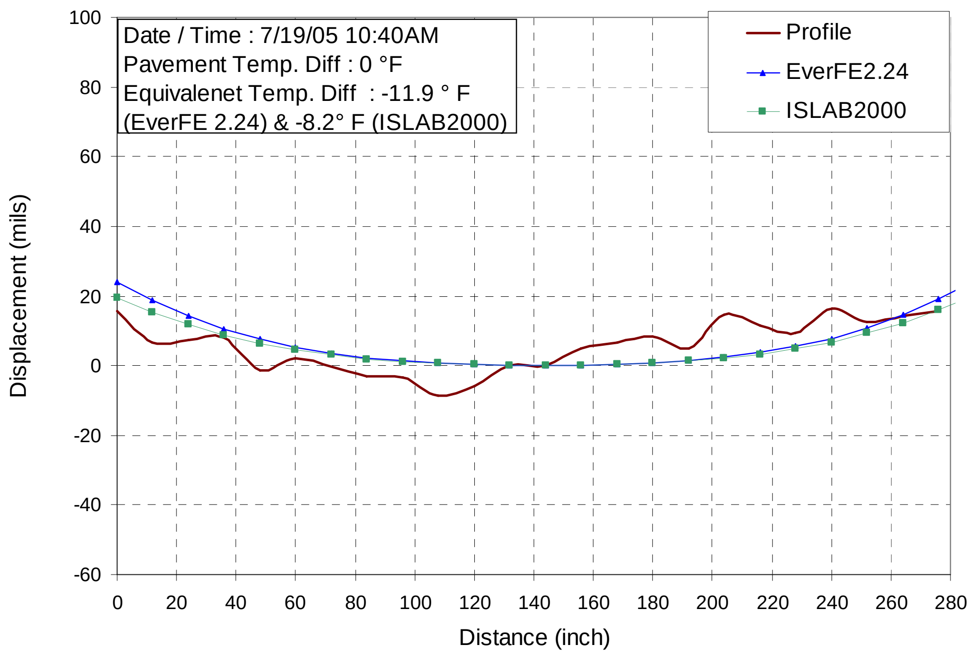


Figure H.69. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 19 morning

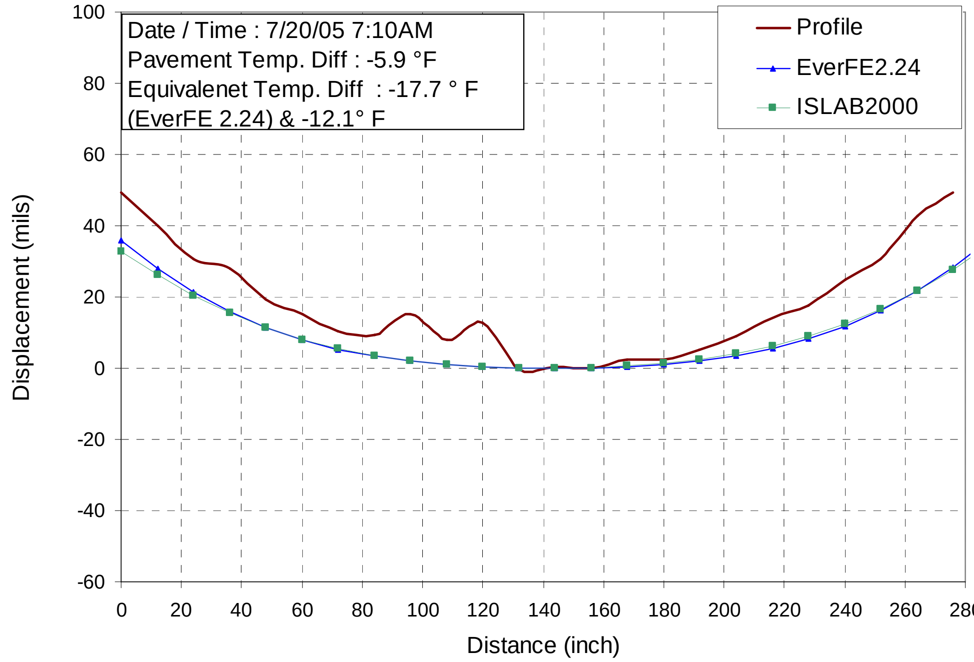


Figure H.70. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 20 morning

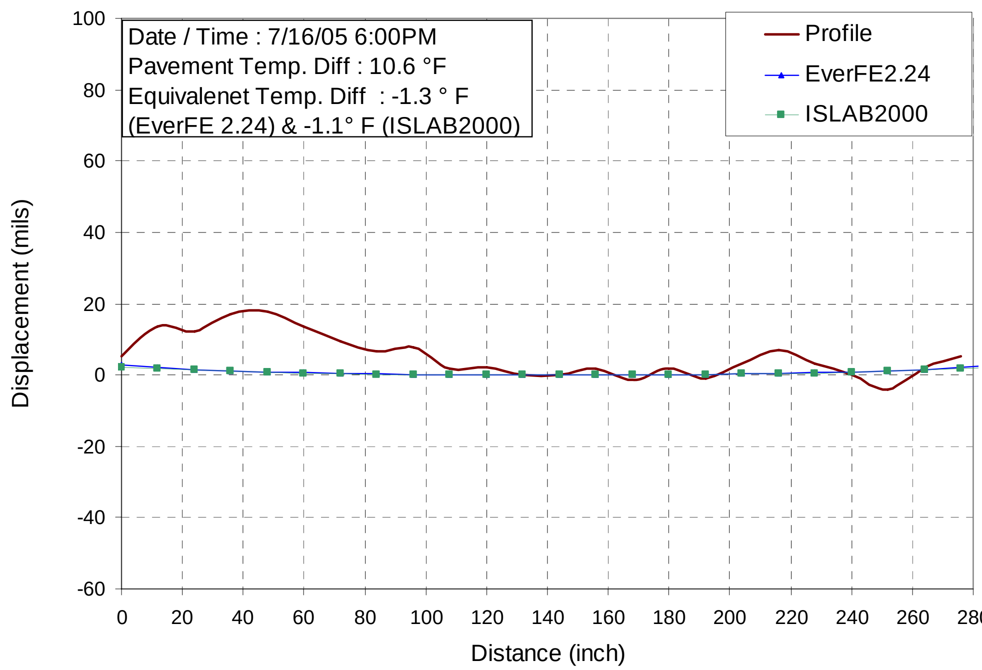


Figure H.71. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 16 afternoon

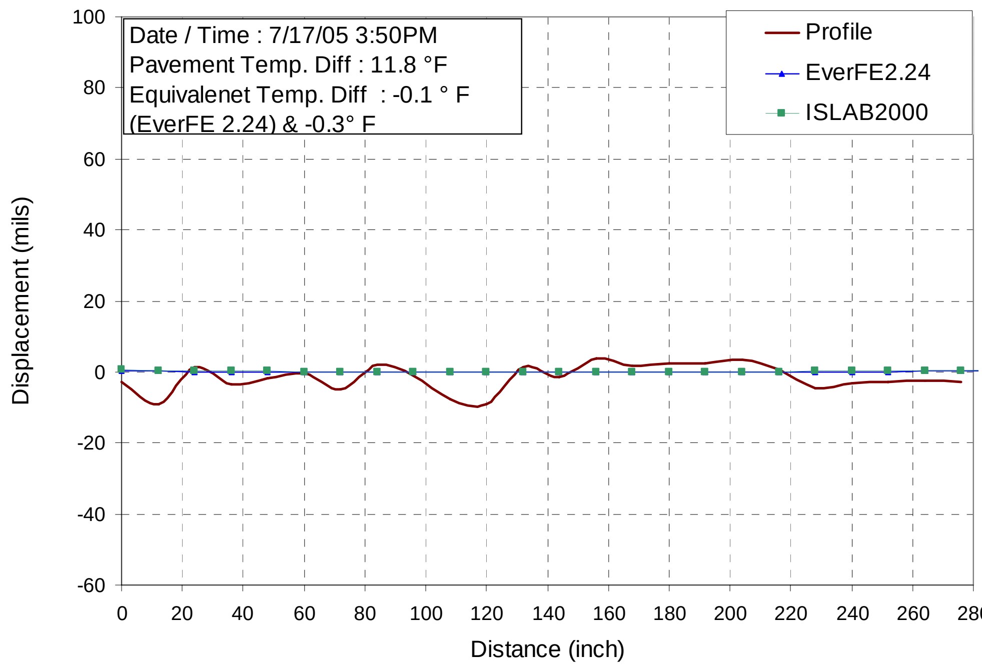


Figure H.72. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 17 afternoon

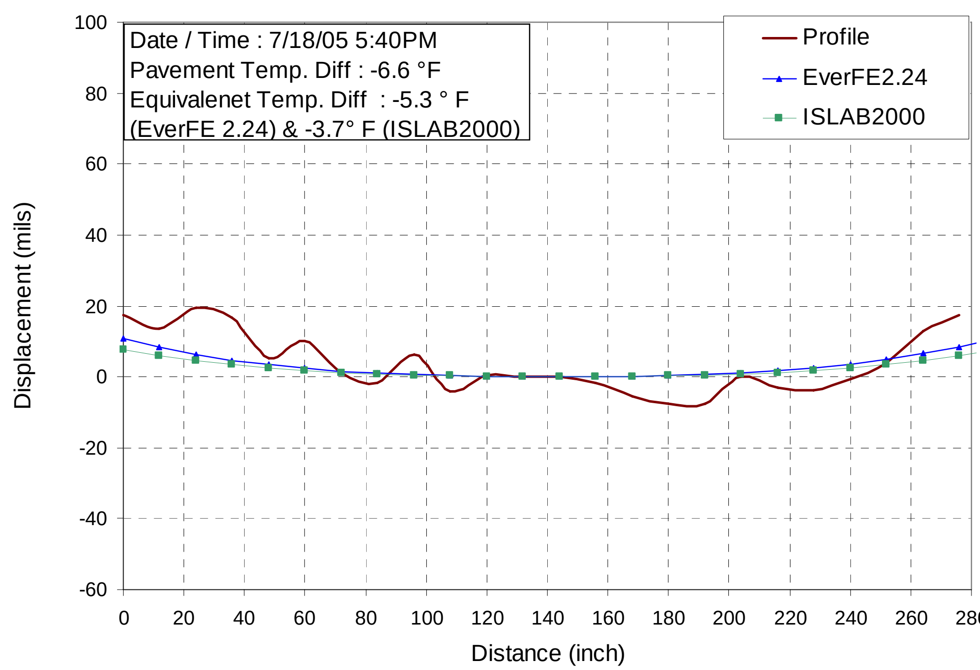


Figure H.73. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 18 afternoon

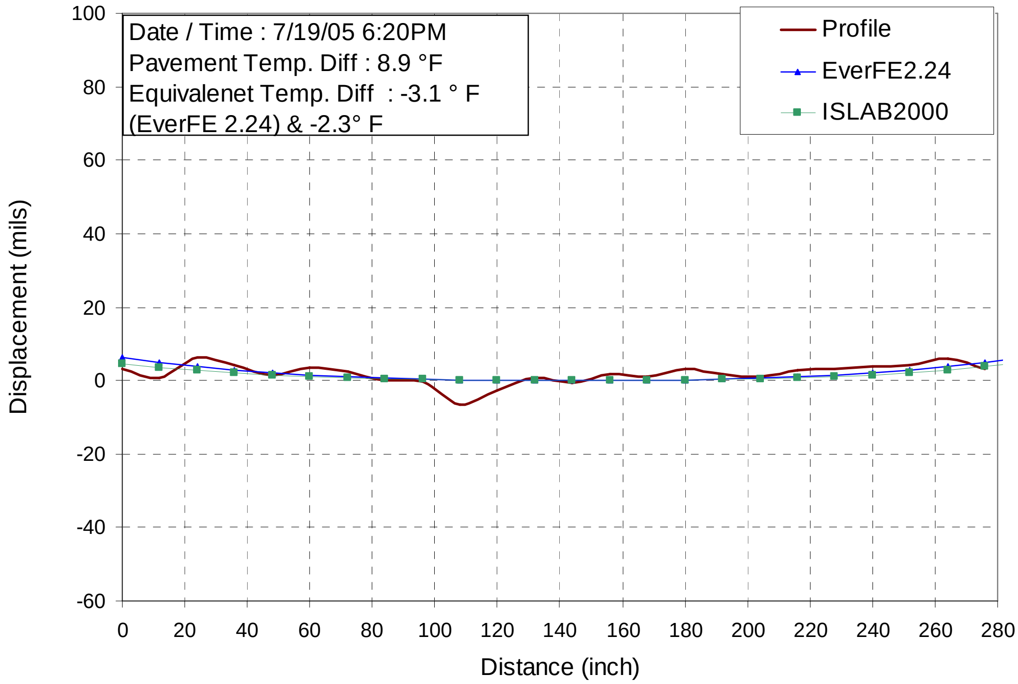


Figure H.74. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 19 afternoon

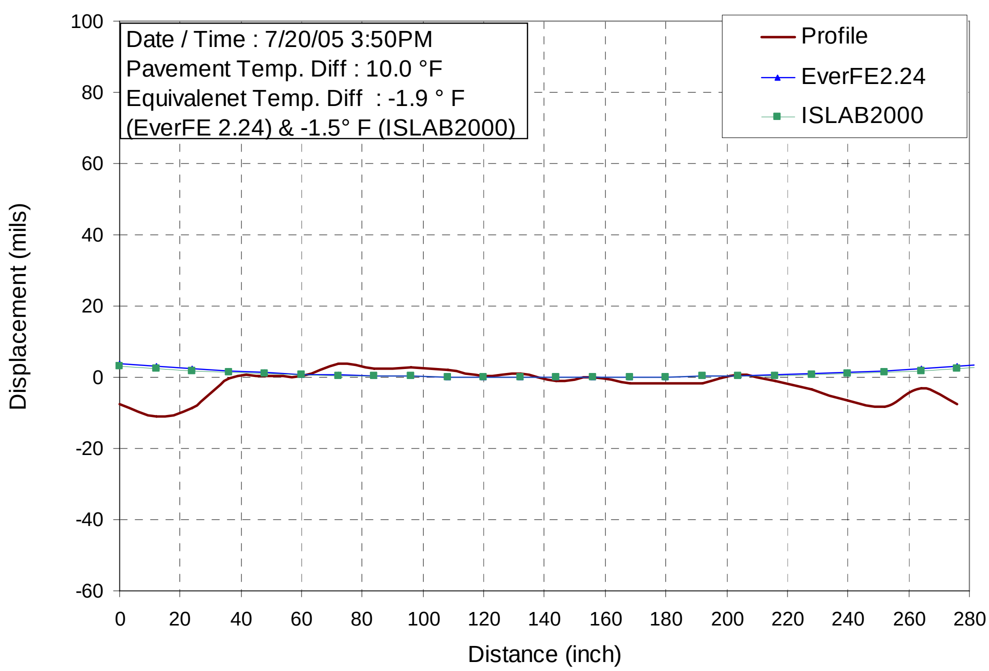


Figure H.75. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 20 afternoon

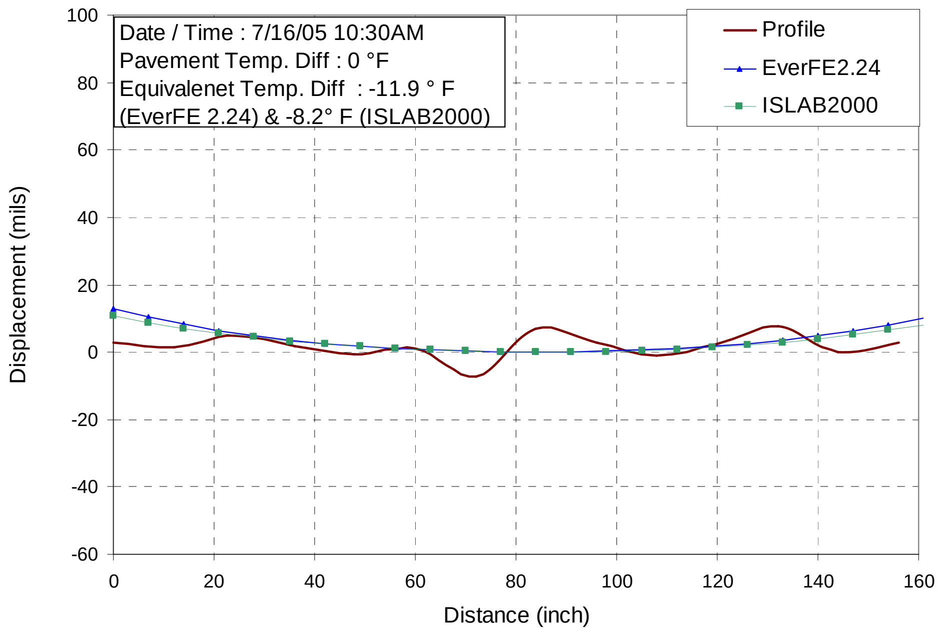


Figure H.76. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 16 morning

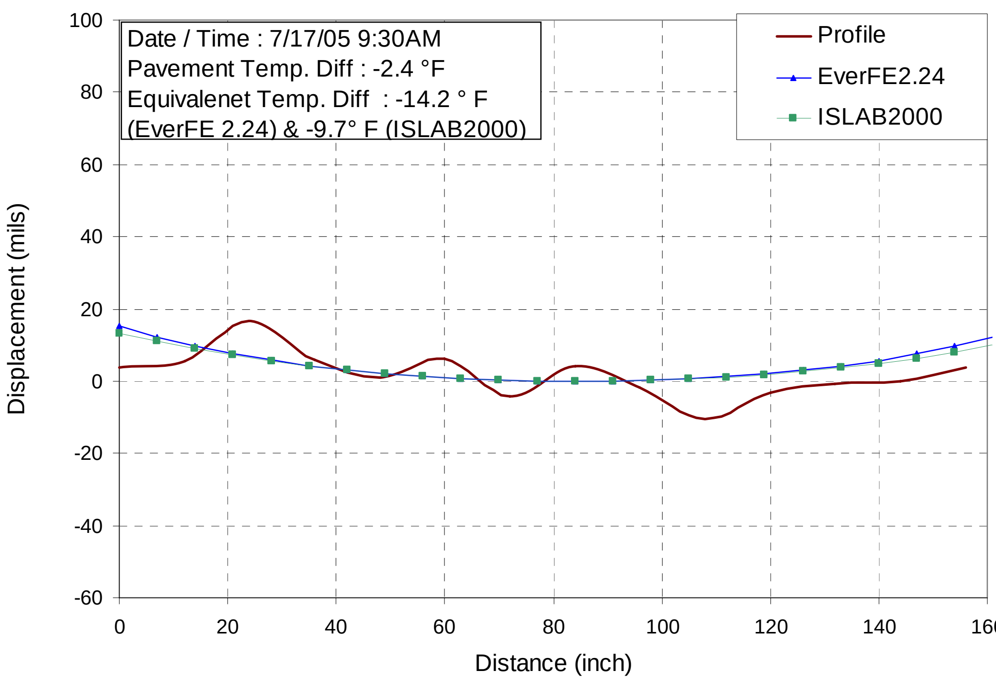


Figure H.77. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 17 morning

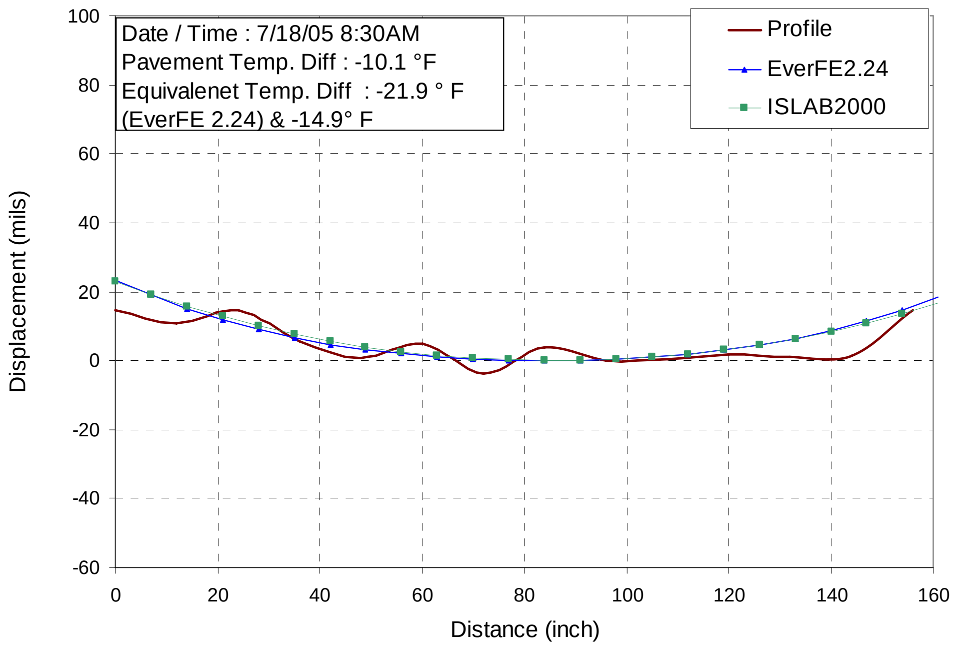


Figure H.78. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 18 morning

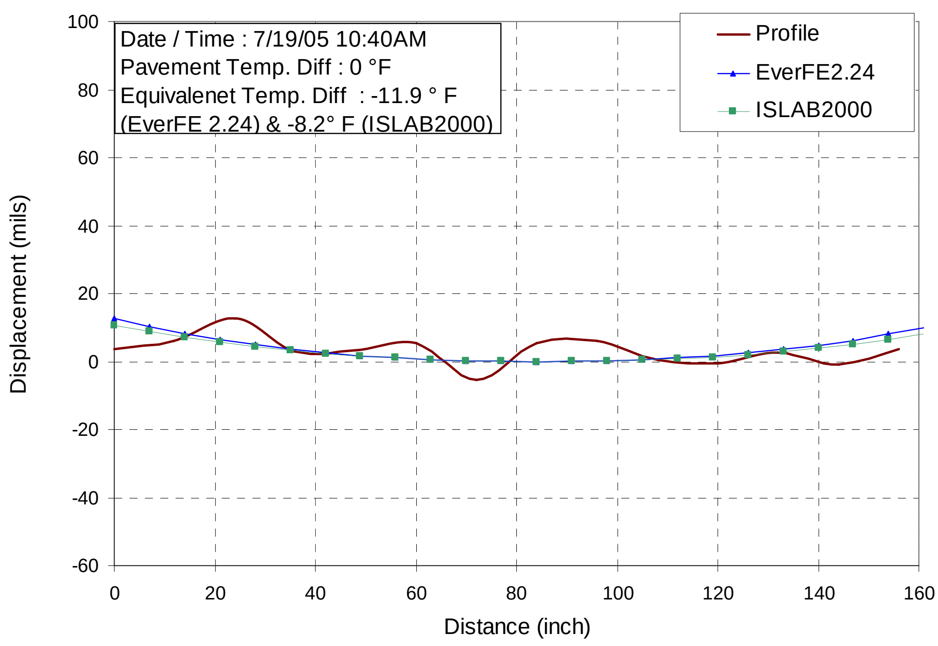


Figure H.79. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 19 morning

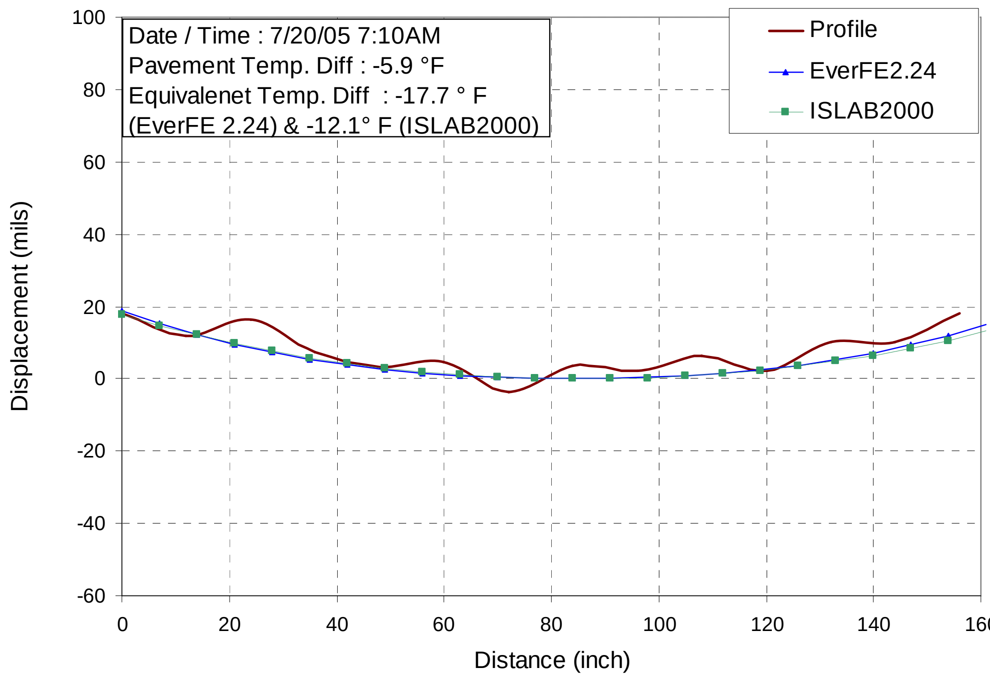


Figure H.80. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 20 morning

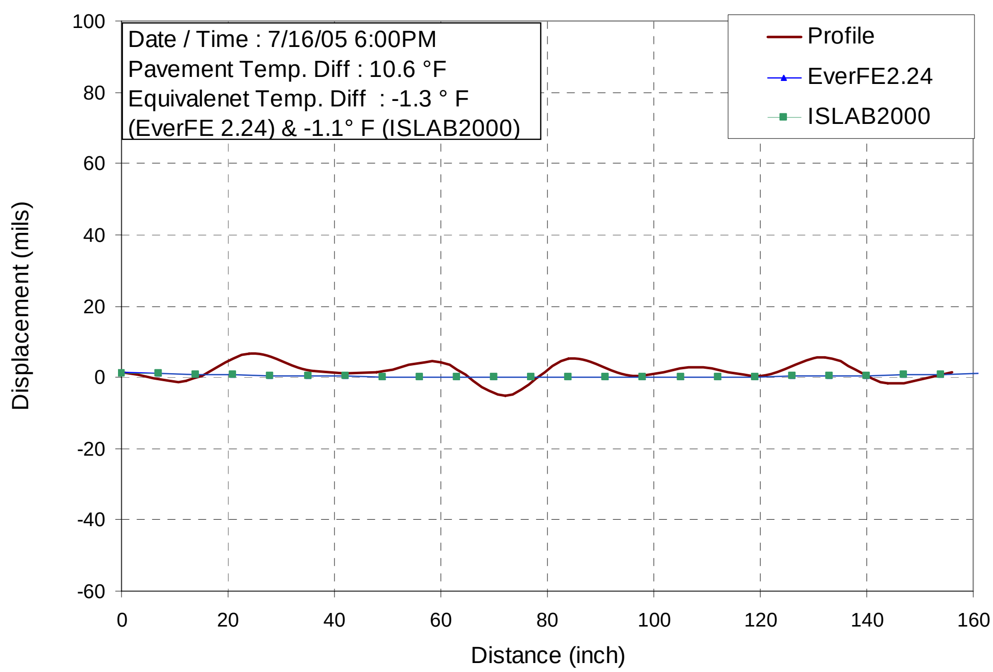


Figure H.81. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 16 afternoon

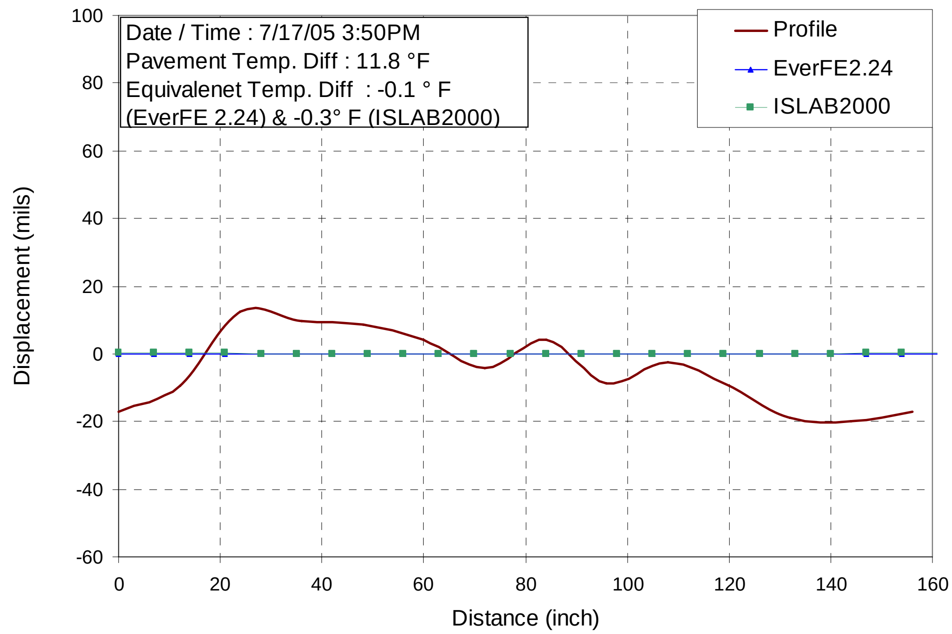


Figure H.82. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 17 afternoon

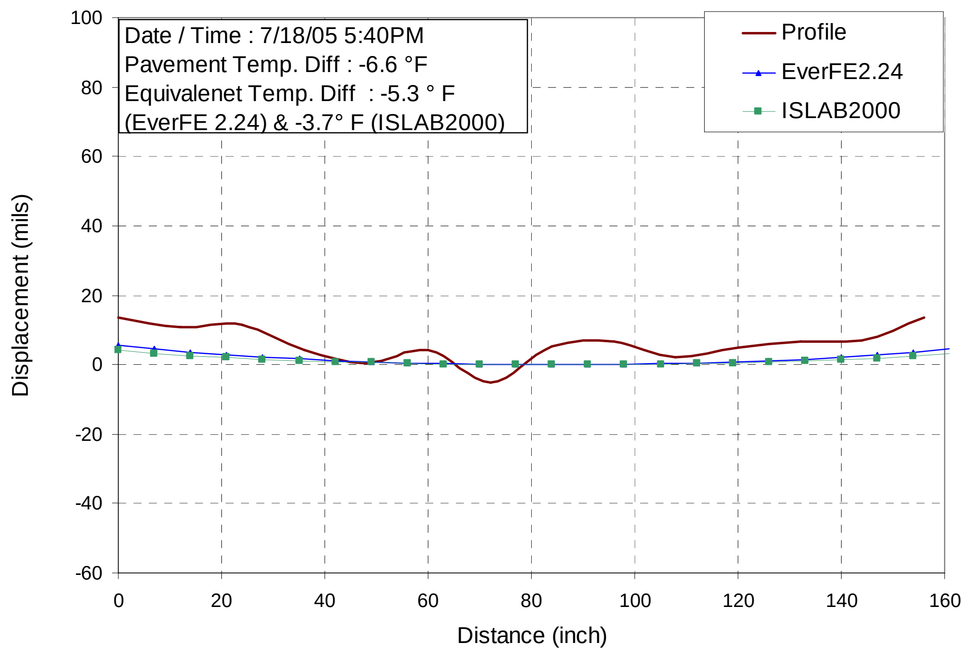


Figure H.83. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 18 afternoon

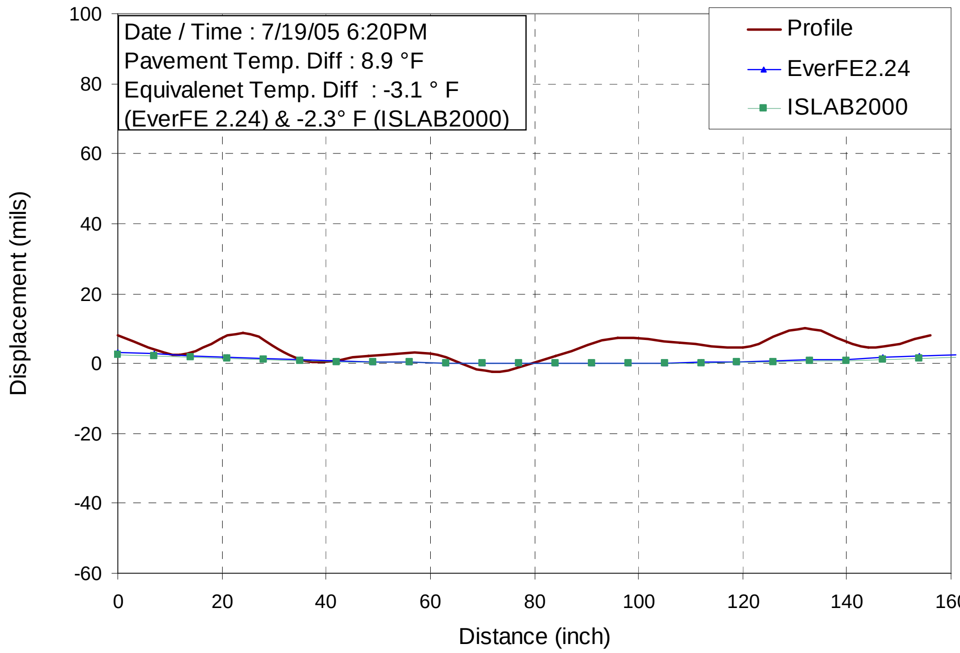


Figure H.84. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 19 afternoon

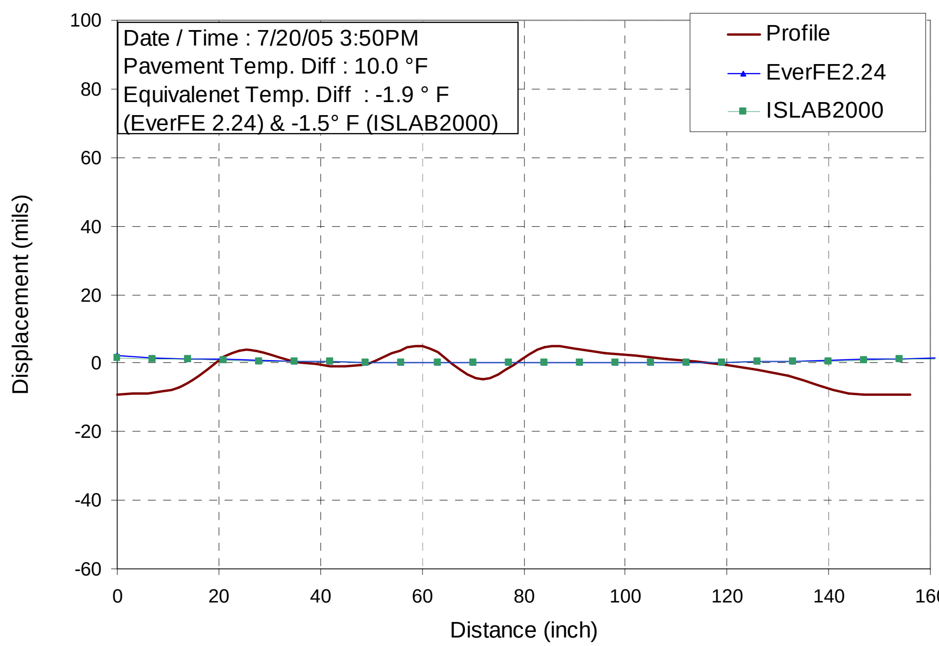


Figure H.85. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 20 afternoon

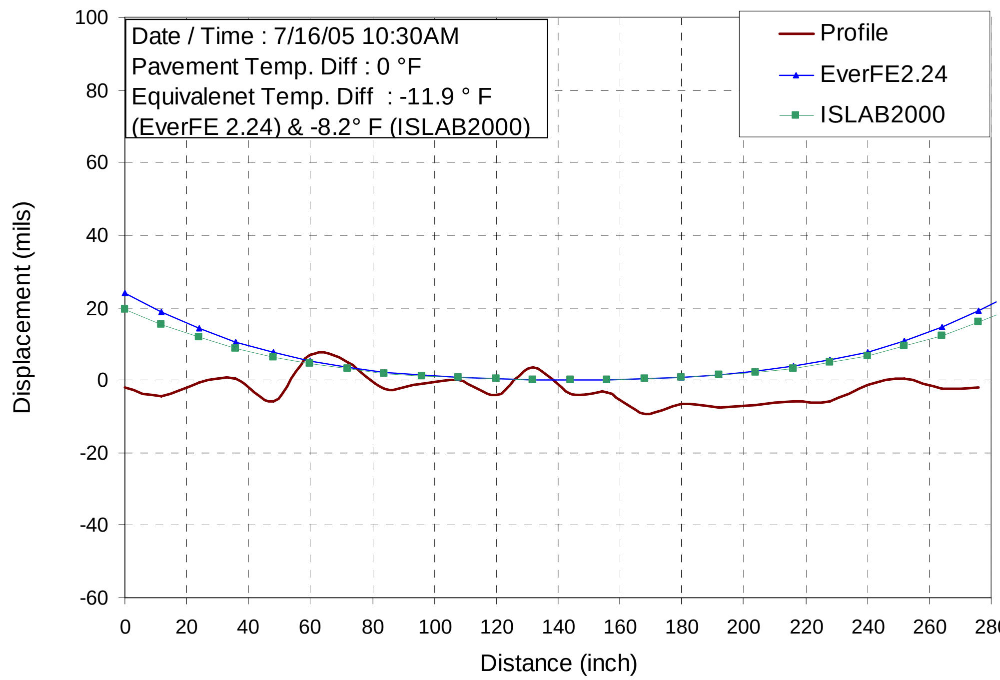


Figure H.86. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 16 morning

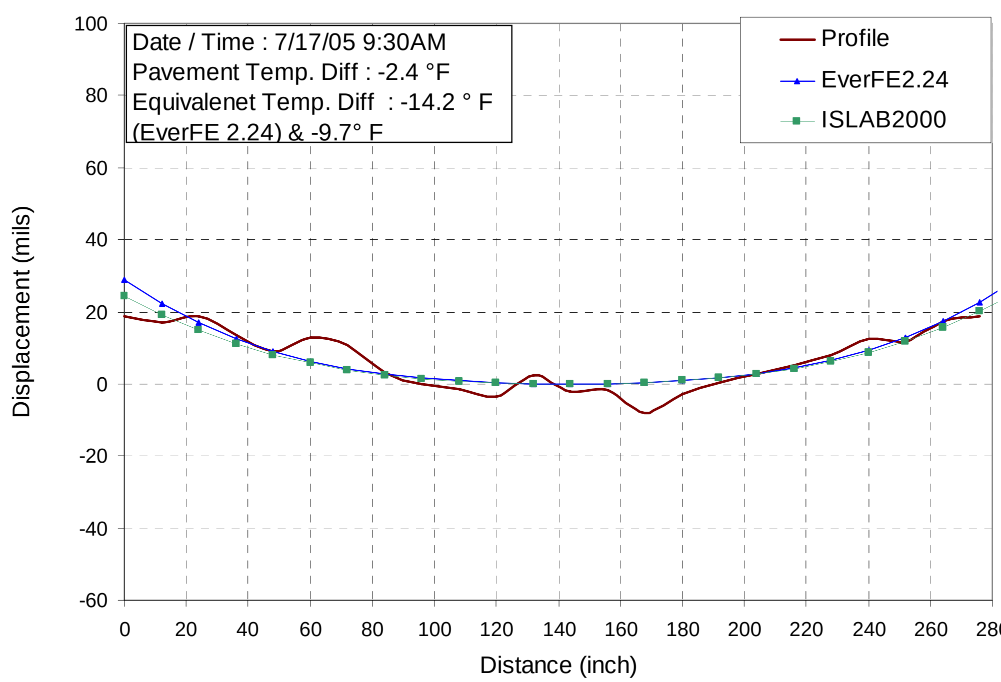


Figure H.87. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 17 morning

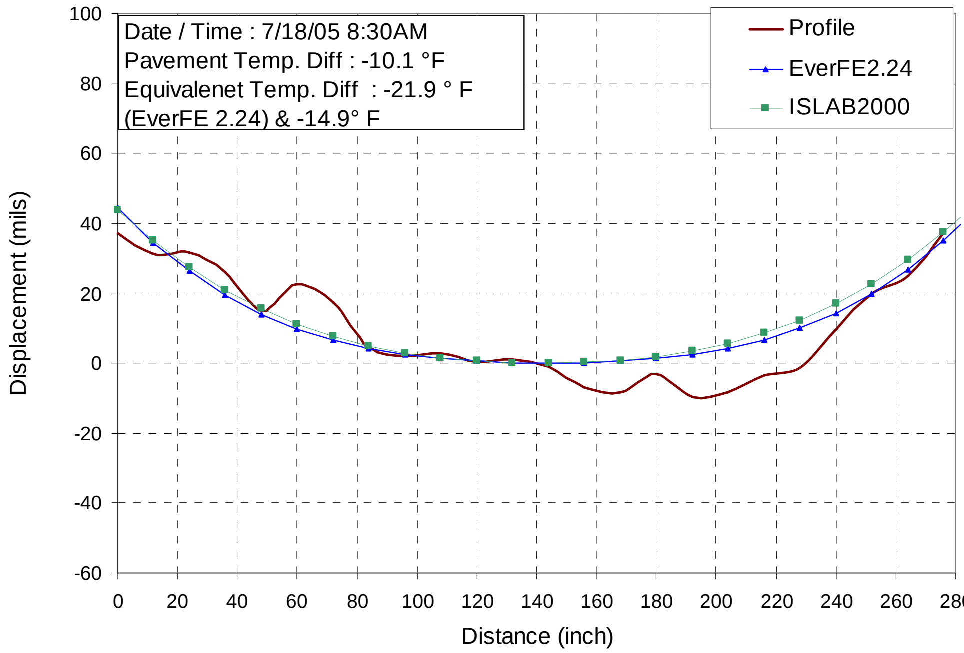


Figure H.88. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 18 morning

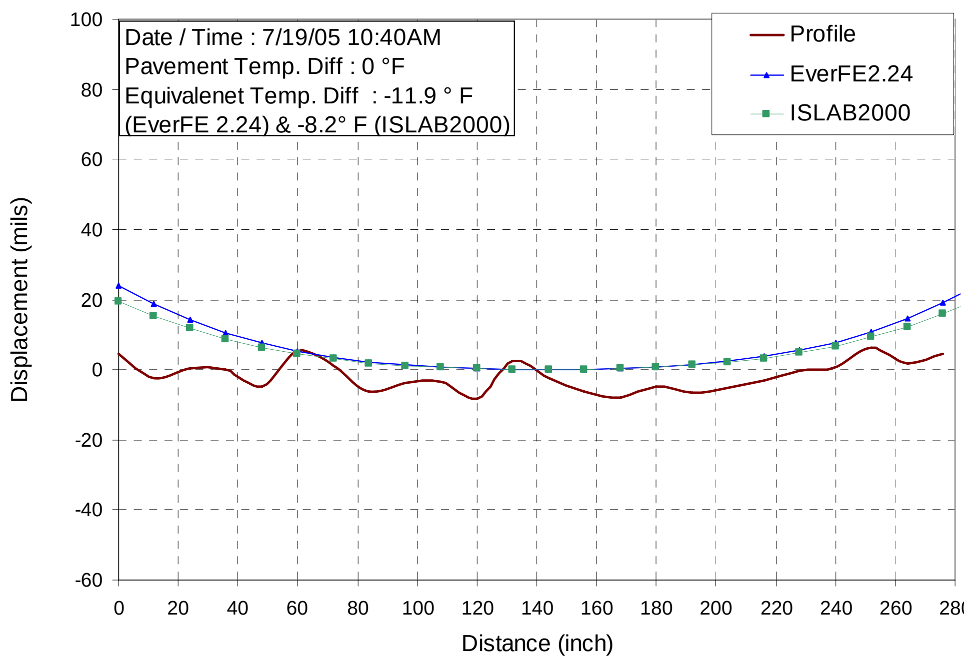


Figure H.89. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 19 morning

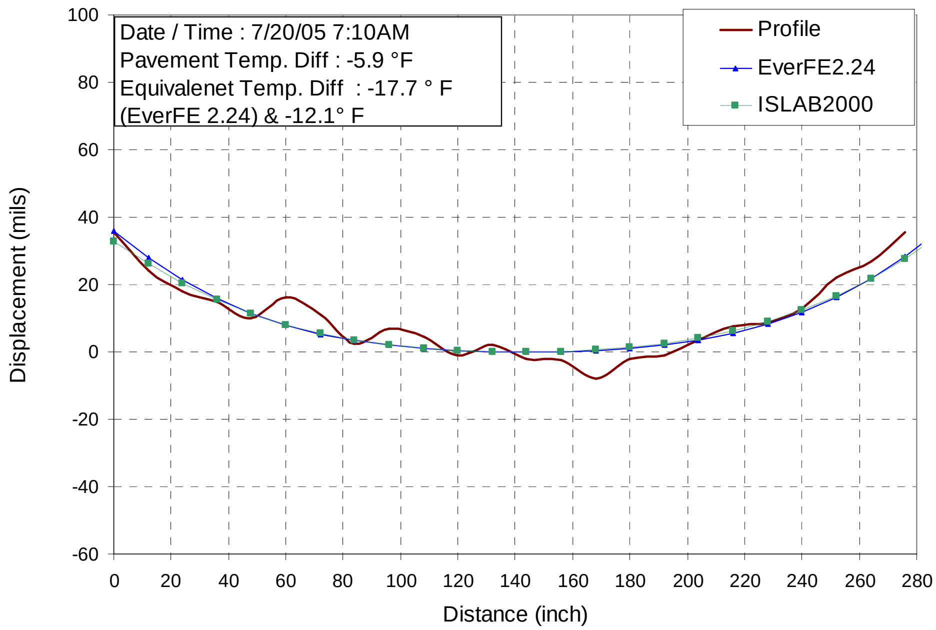


Figure H.90. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 20 morning

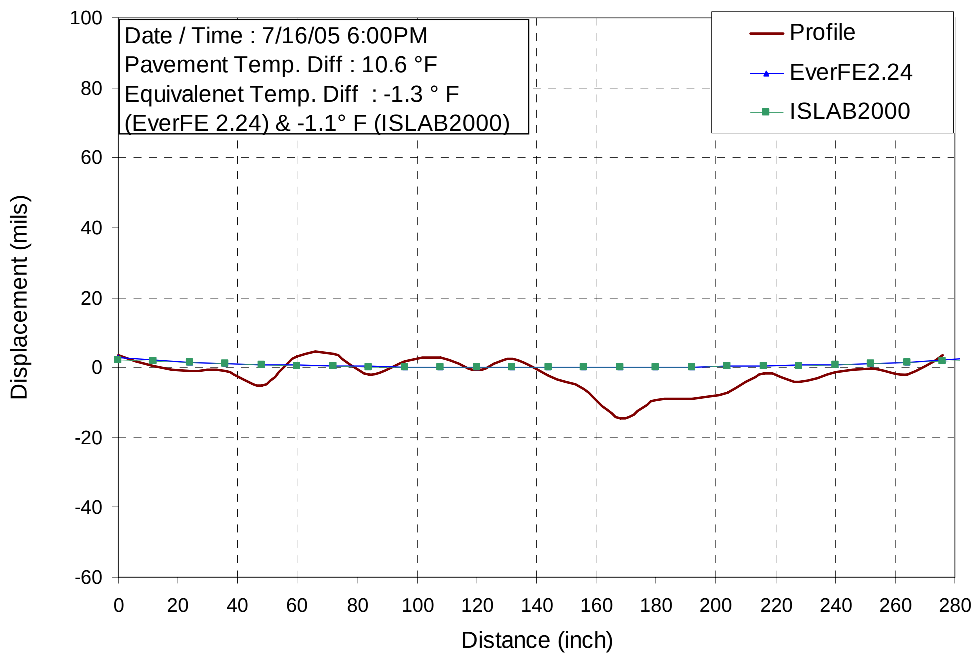


Figure H.91. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 16 afternoon

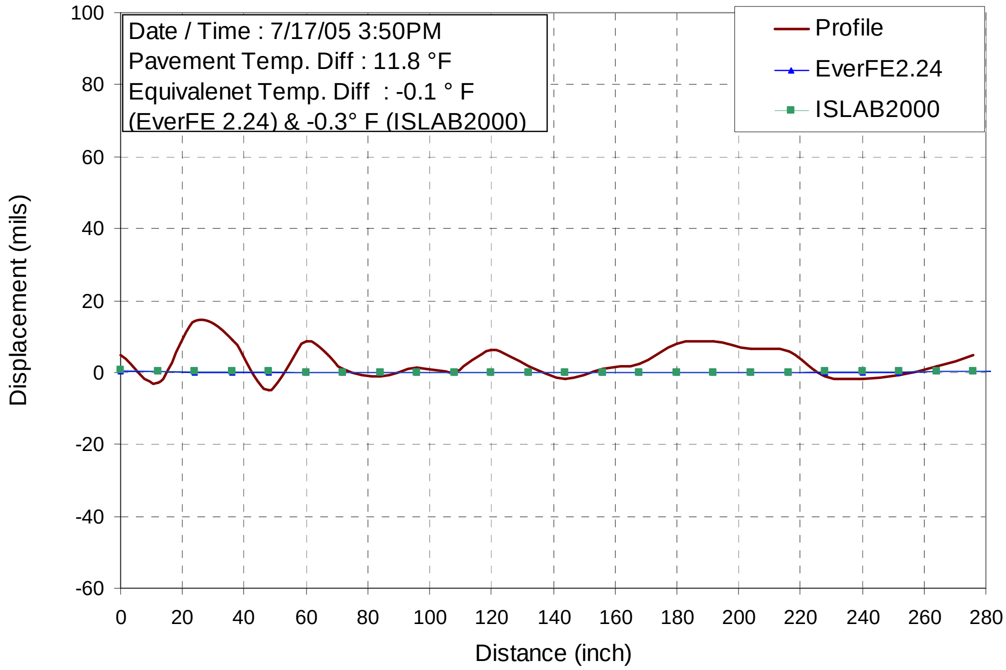


Figure H.92. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 17 afternoon

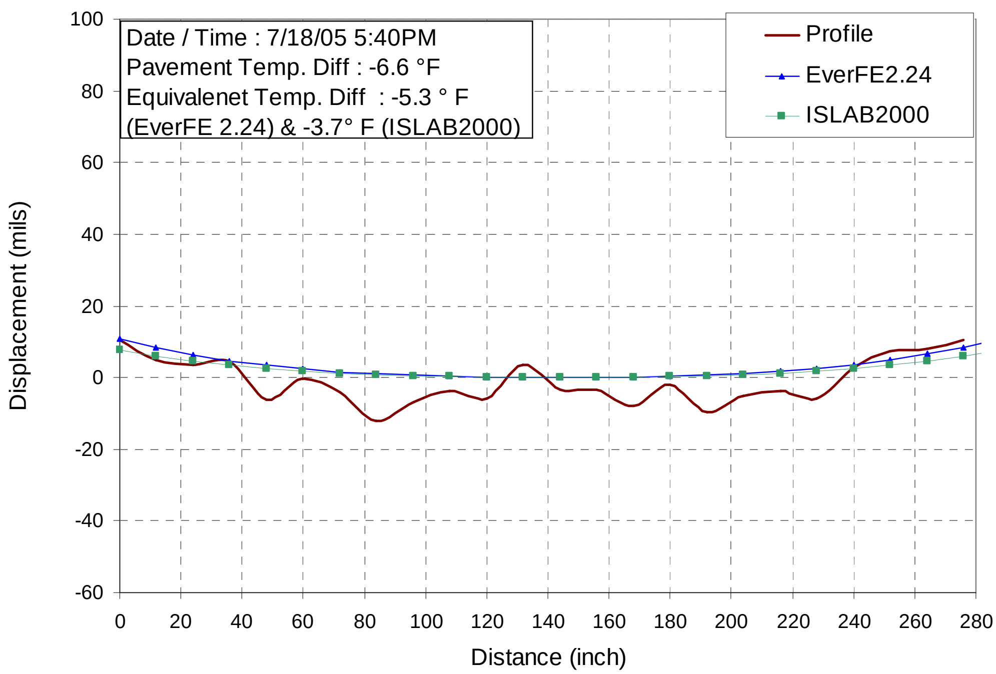


Figure H.93. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 18 afternoon

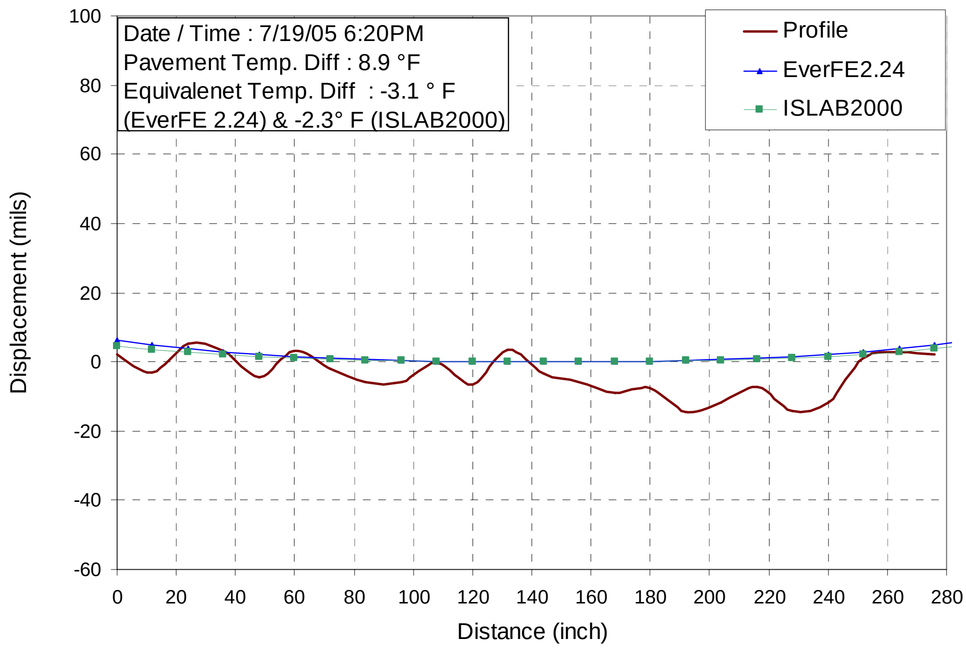


Figure H.94. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 19 afternoon

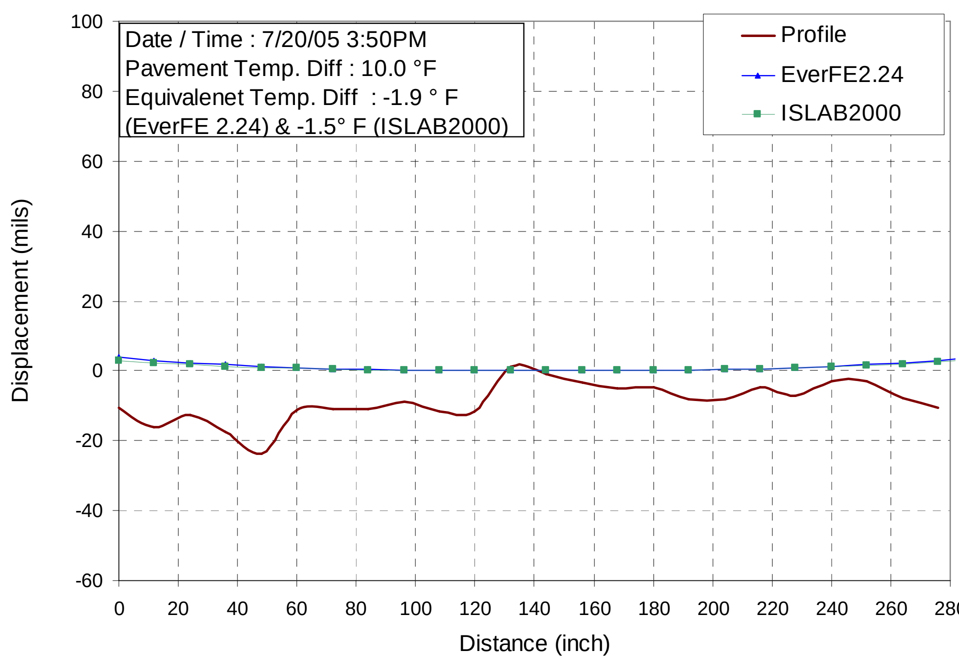


Figure H.95. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 20 afternoon

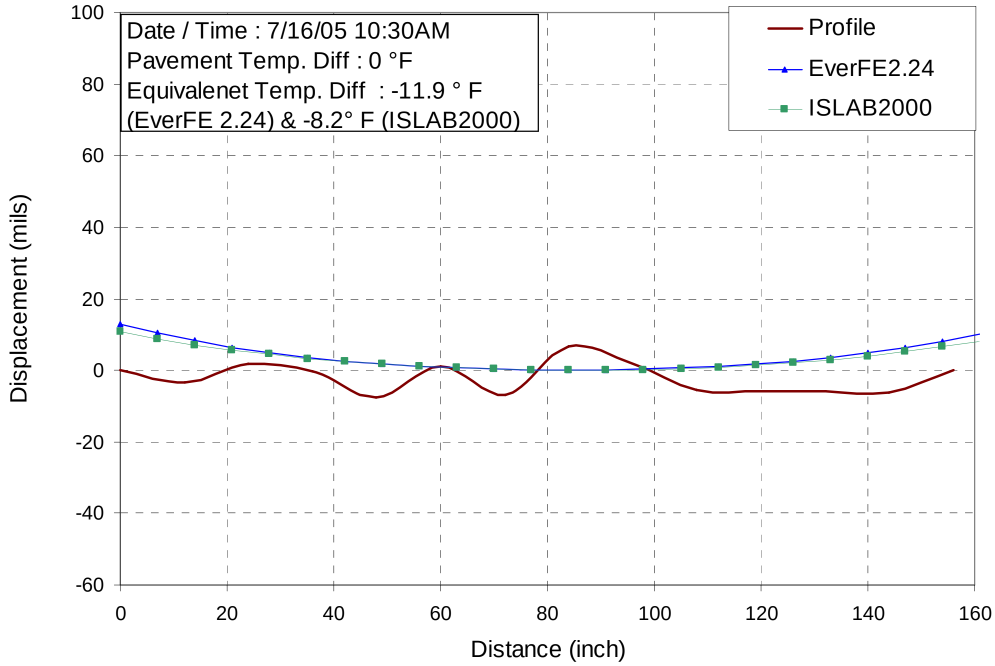


Figure H.96. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 16 morning

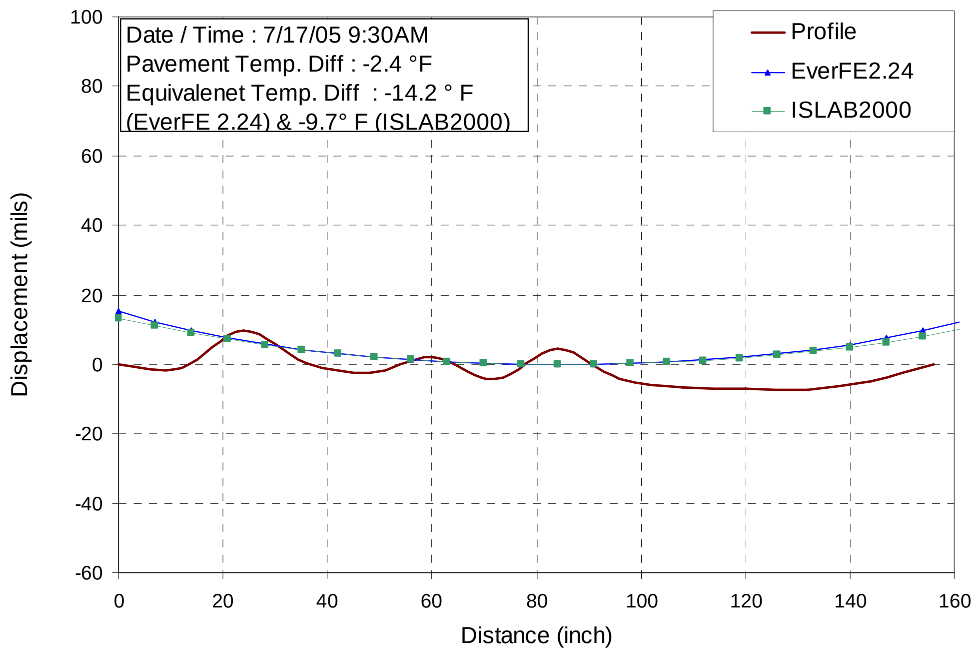


Figure H.97. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 17 morning

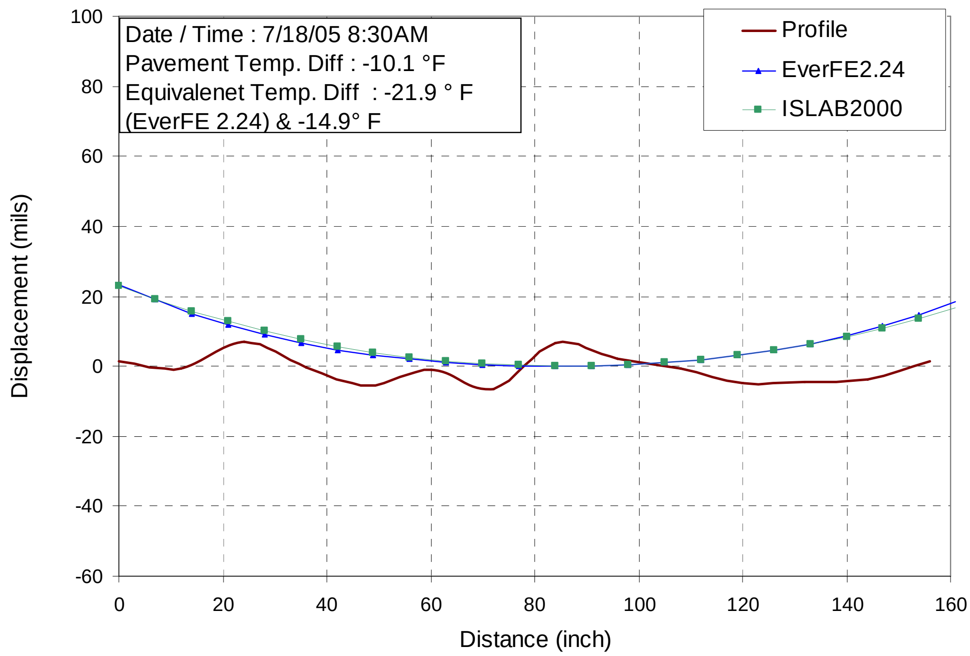


Figure H.98. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 18 morning

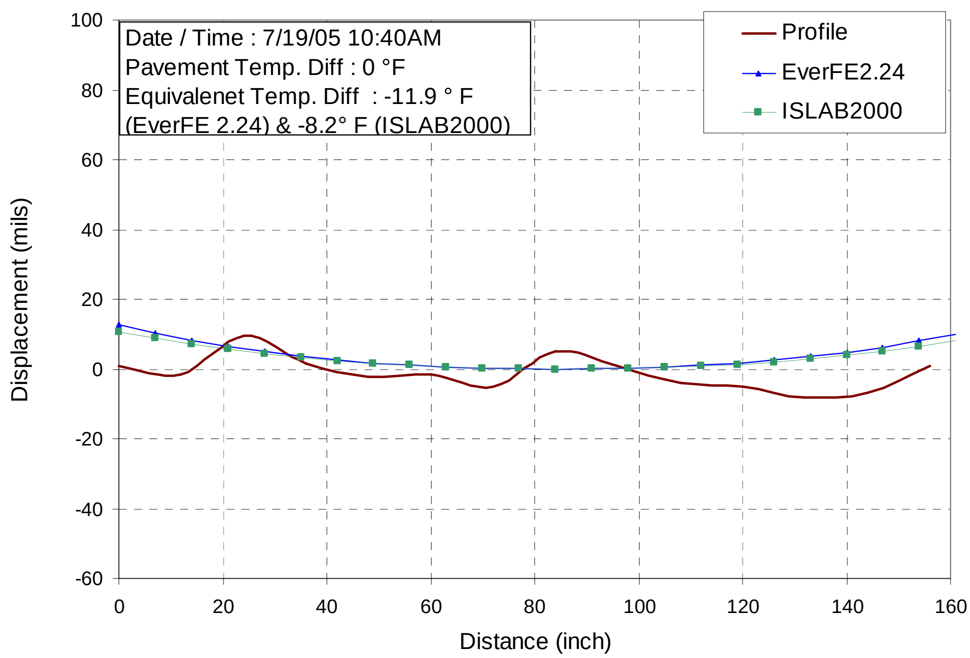


Figure H.99. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 19 morning

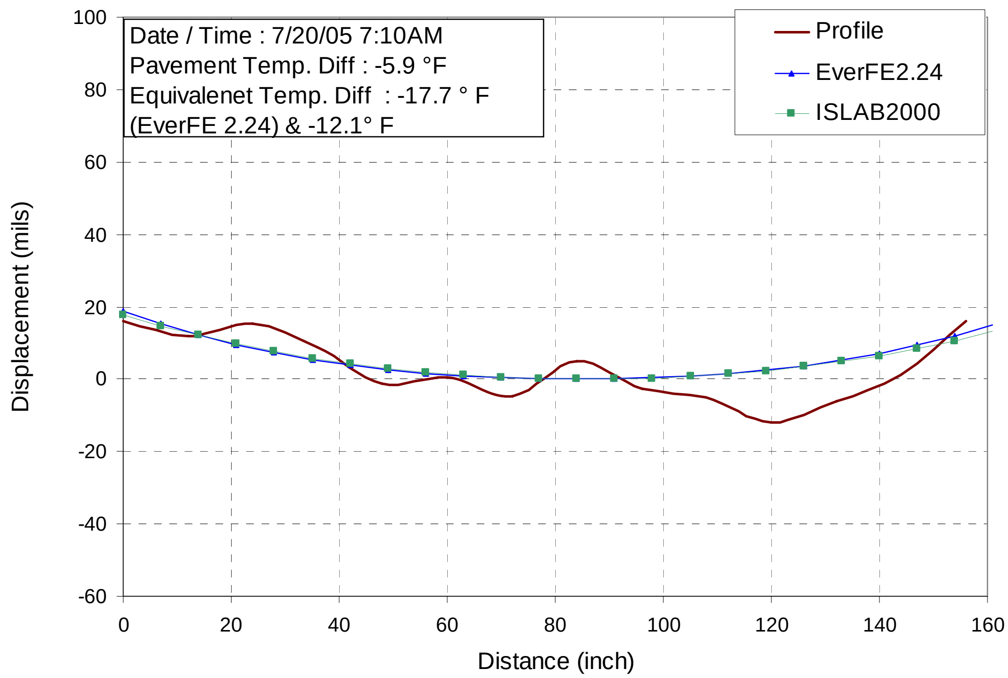


Figure H.100. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 20 morning

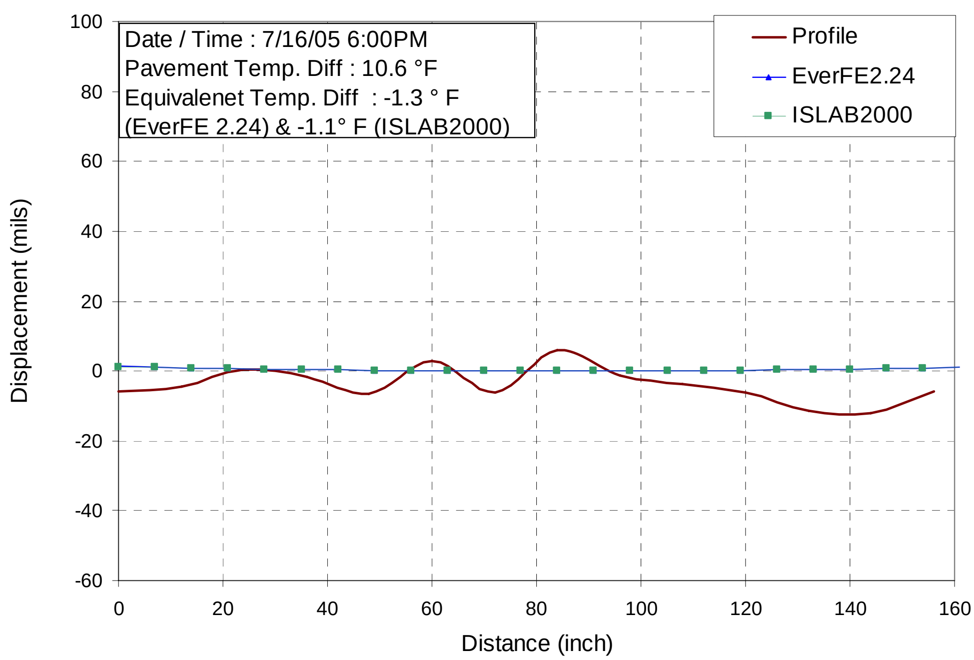


Figure H.101. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 16 afternoon

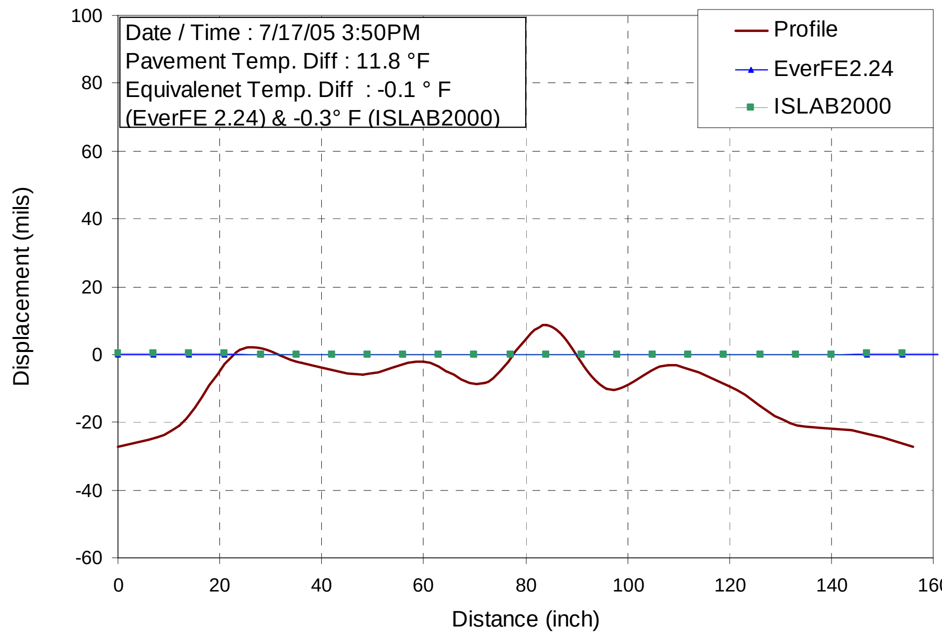


Figure H.102. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 17 afternoon

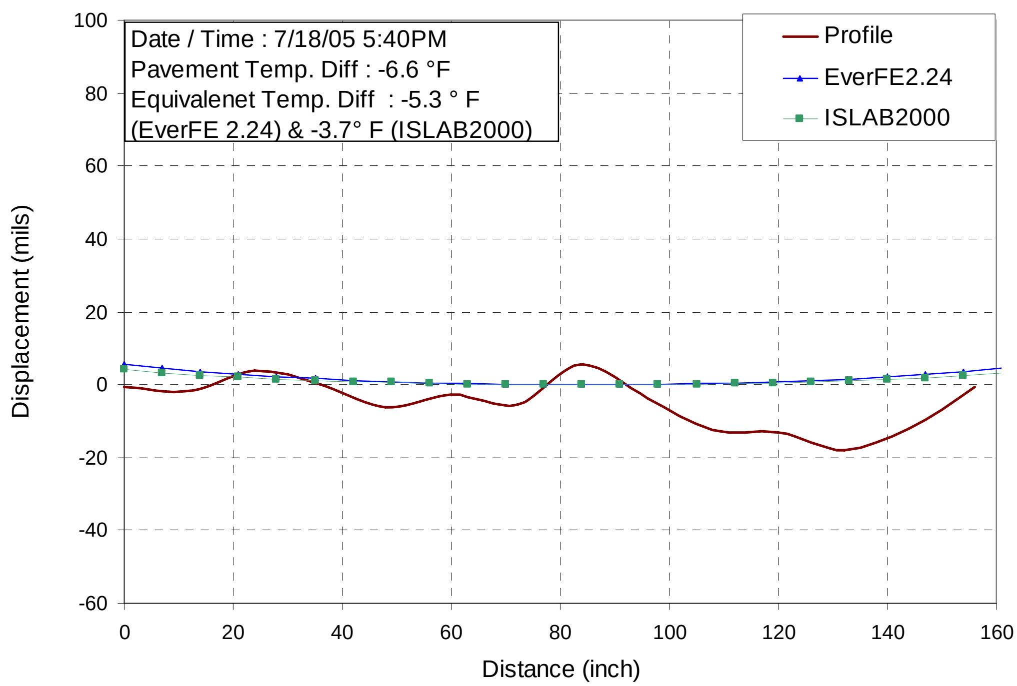


Figure H.103. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 18 afternoon

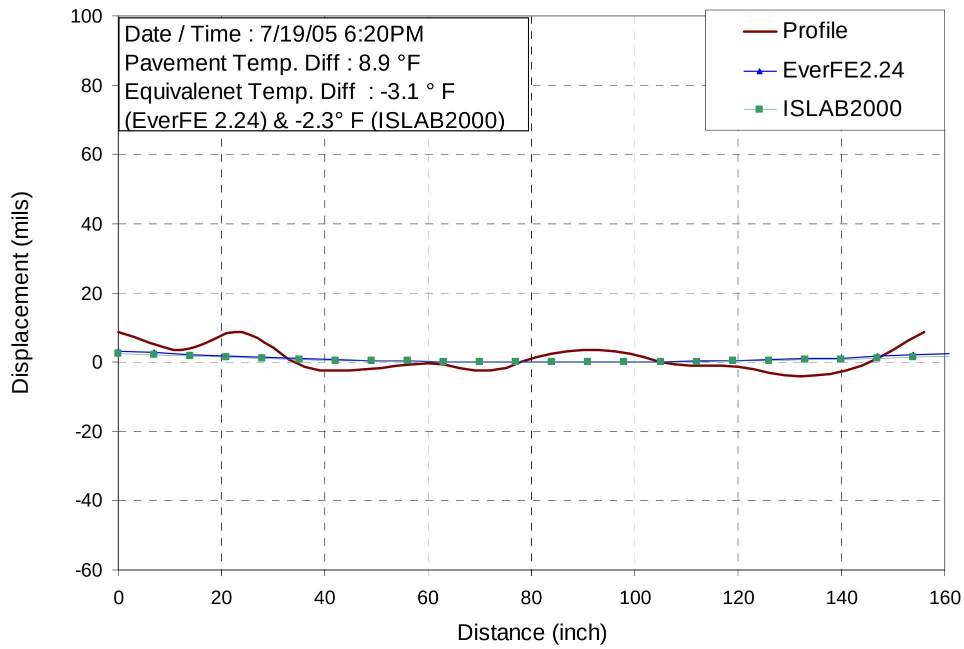


Figure H.104. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 19 afternoon

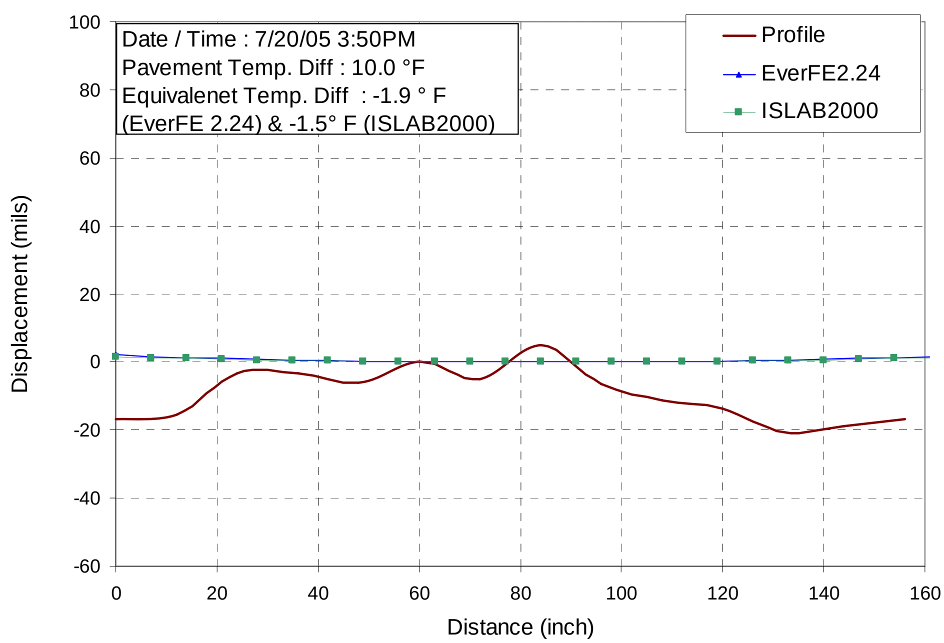


Figure H.105. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 20 afternoon

APPENDIX I: MARSHALLTOWN SITE AFTERNOON PAVING TEST SECTION

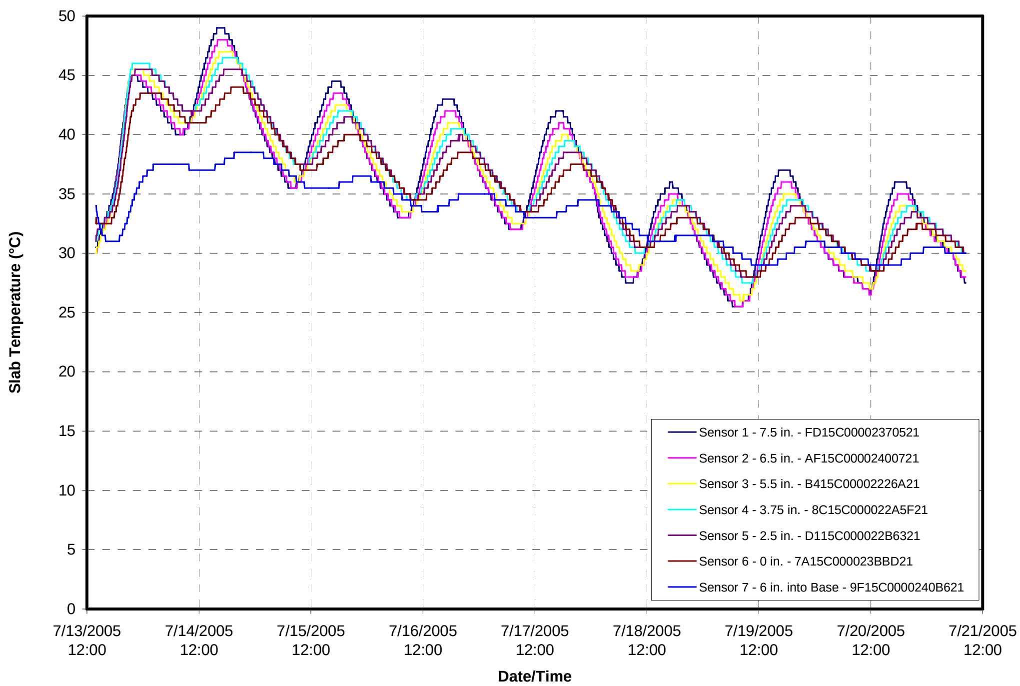


Figure I.1. Slab temperature data

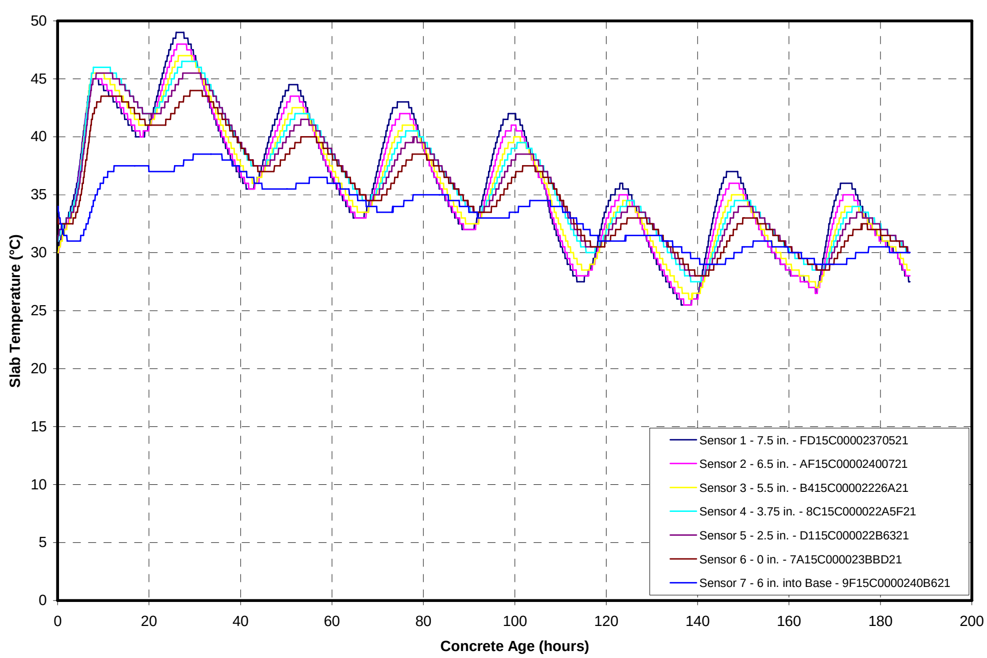


Figure I.2. Slab temperature data

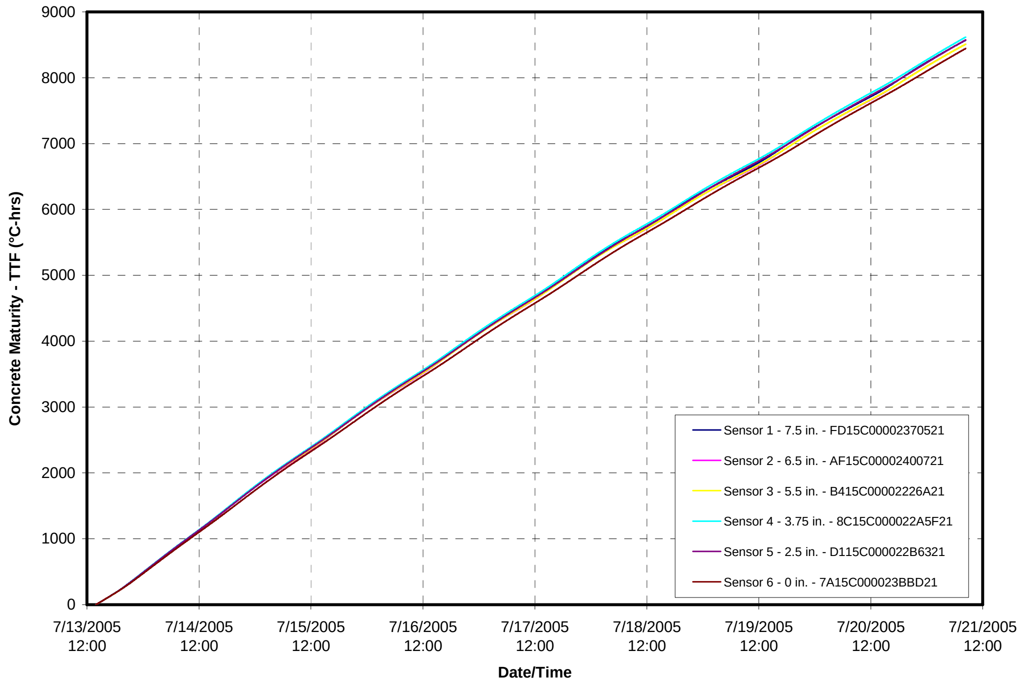


Figure I.3. Slab maturity data

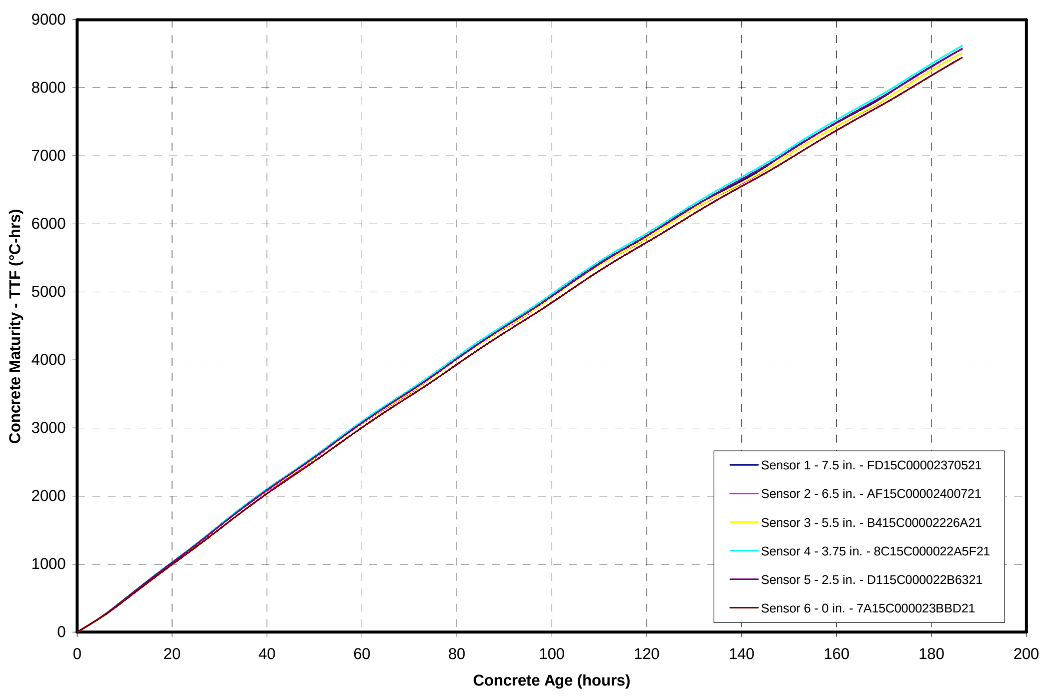


Figure I.4. Slab maturity data

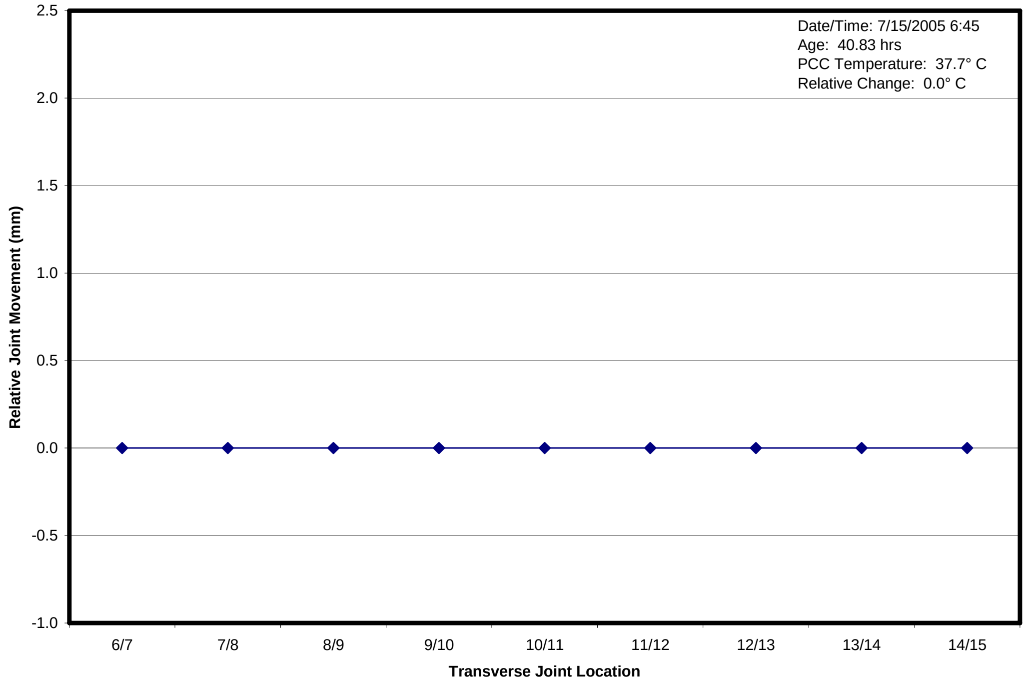


Figure I.5. Transverse joint relative opening

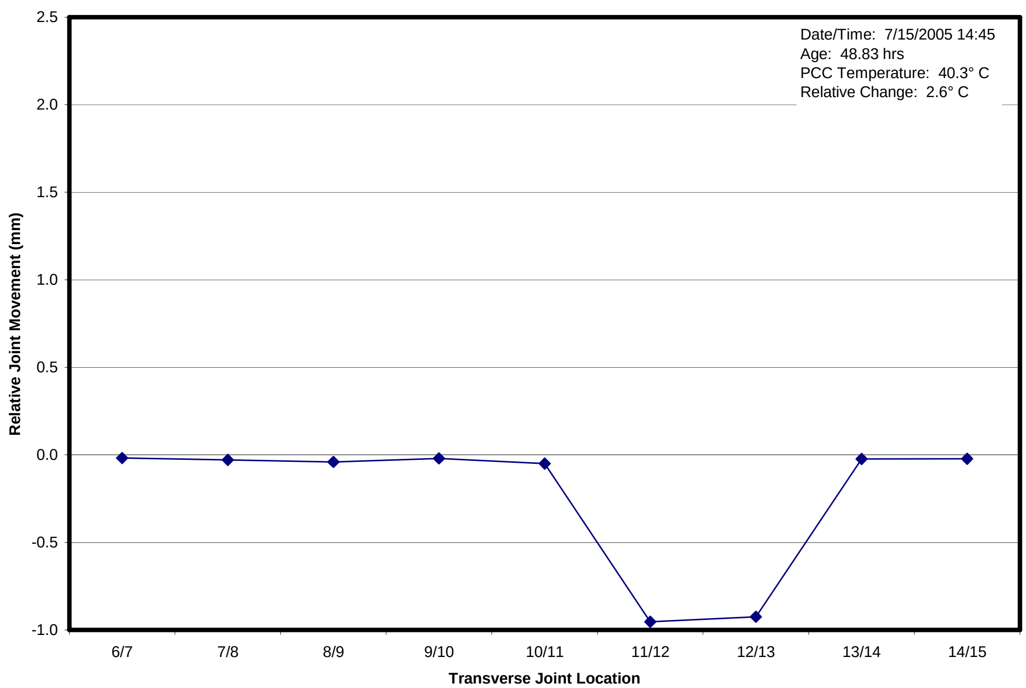


Figure I.6. Transverse joint relative opening

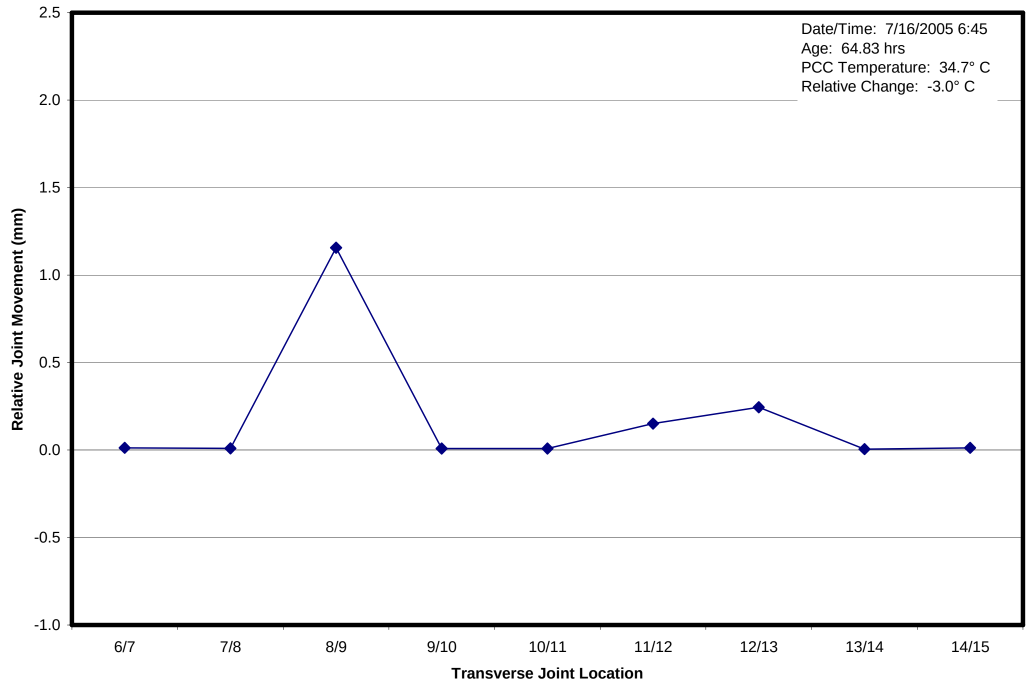


Figure I.7. Transverse joint relative opening

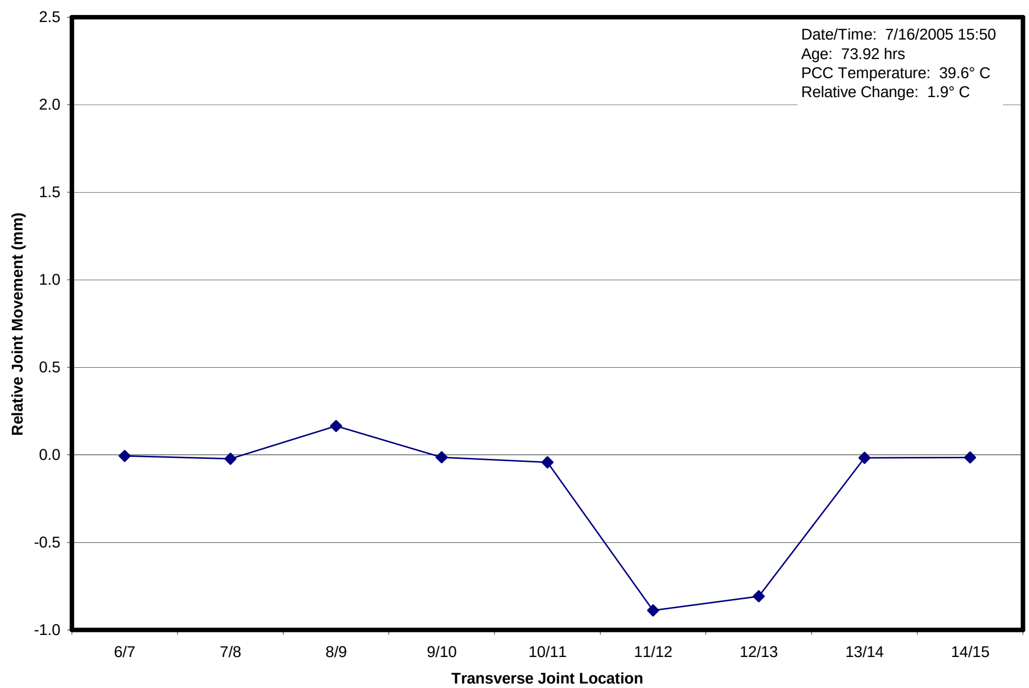


Figure I.8. Transverse joint relative opening

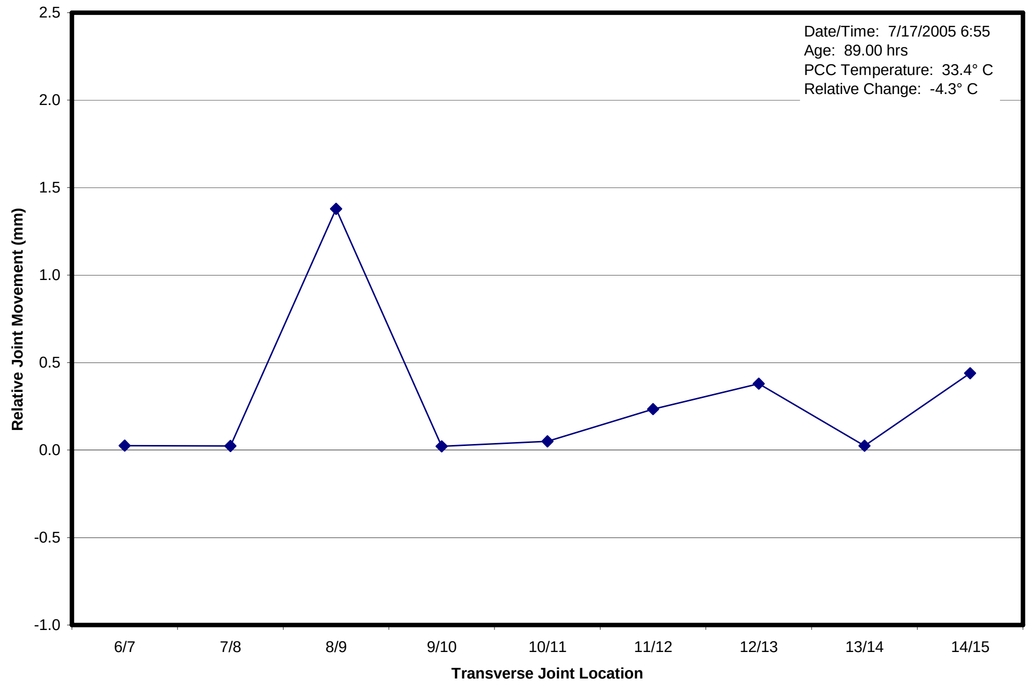


Figure I.9. Transverse joint relative opening

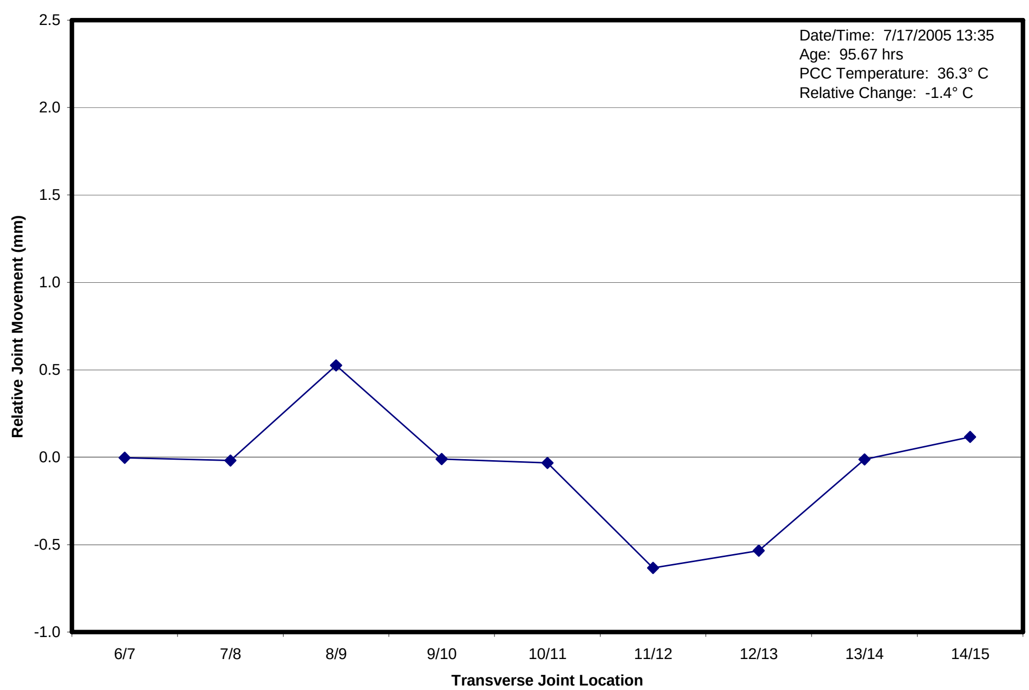


Figure I.10. Transverse joint relative opening

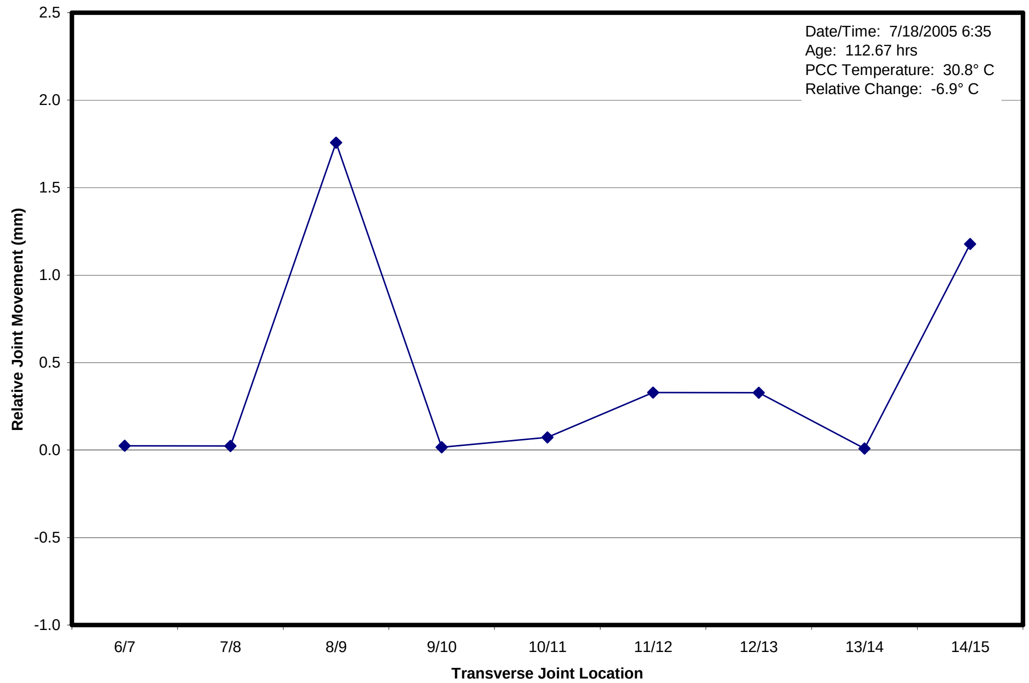


Figure I.11. Transverse joint relative opening

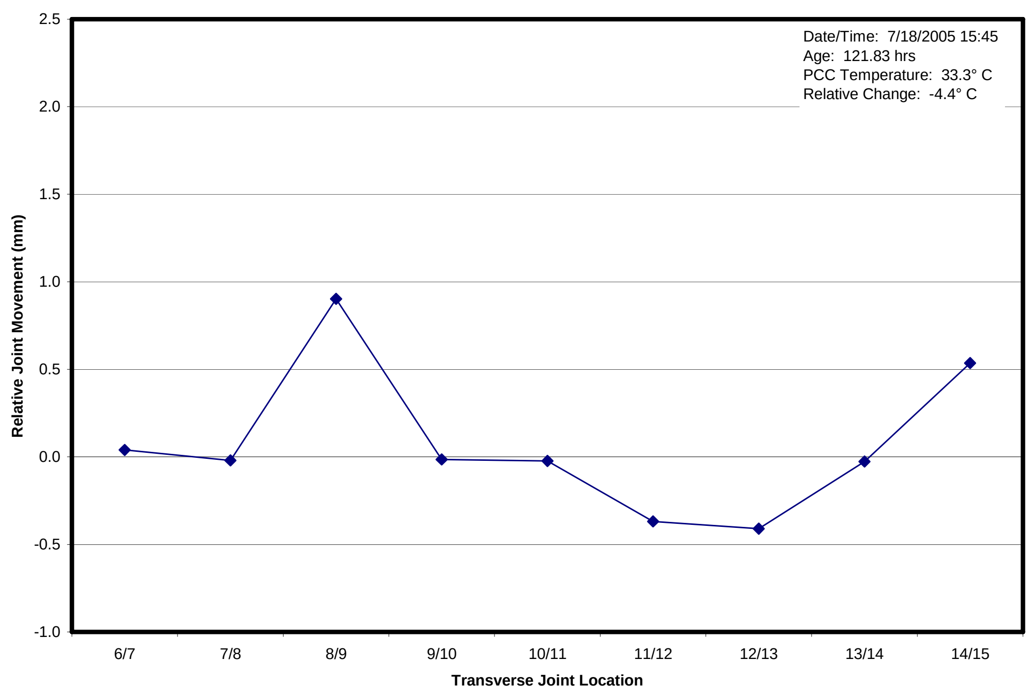


Figure I.12. Transverse joint relative opening

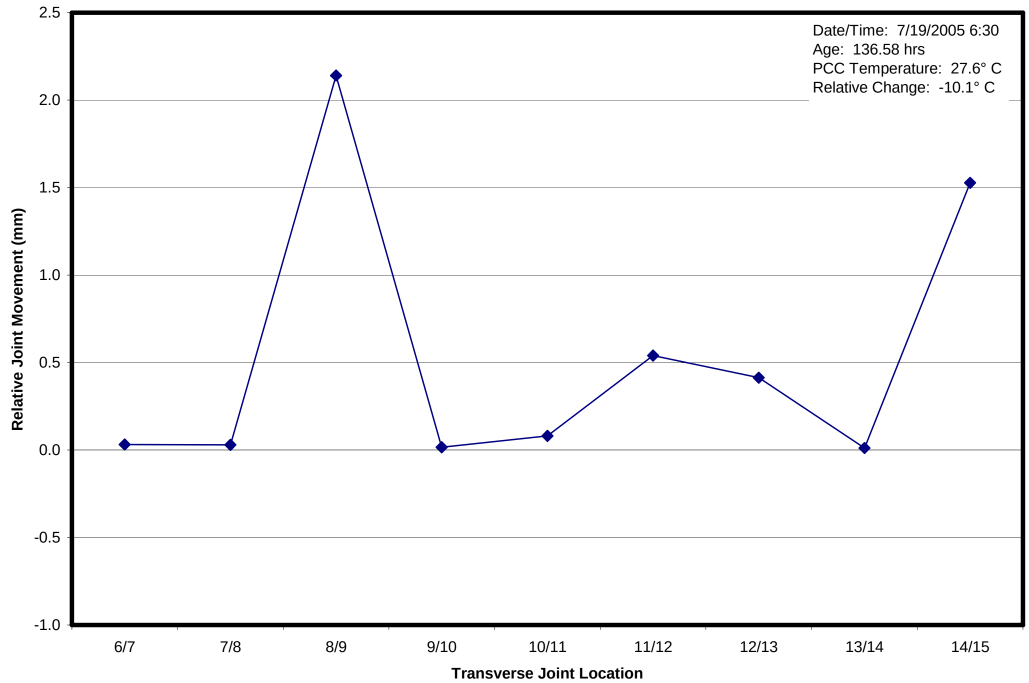


Figure I.13. Transverse joint relative opening

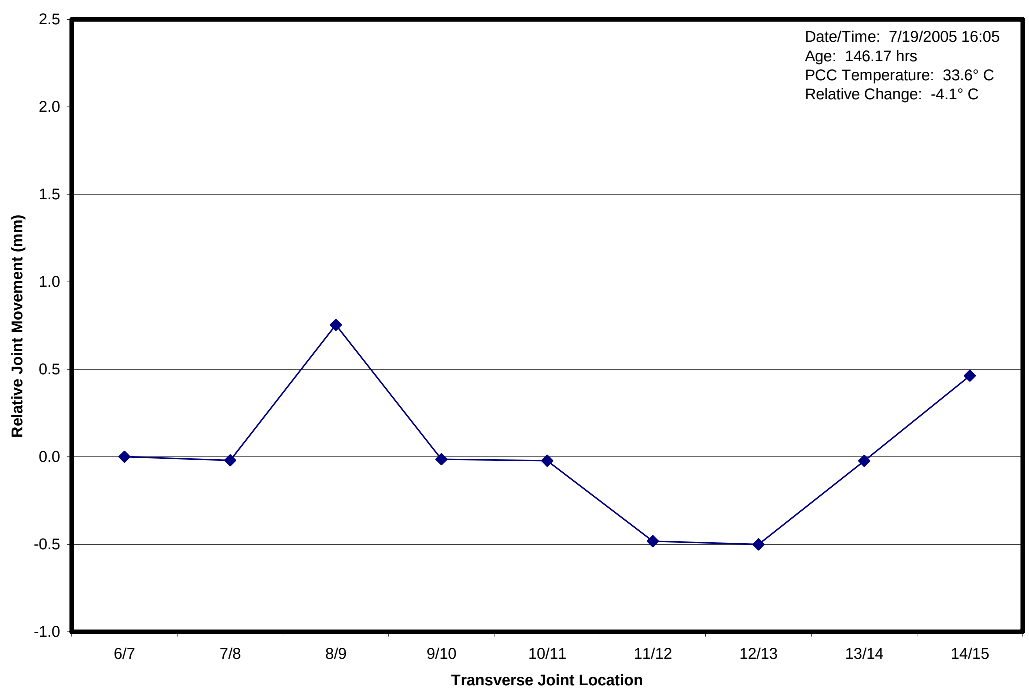


Figure I.14. Transverse joint relative opening

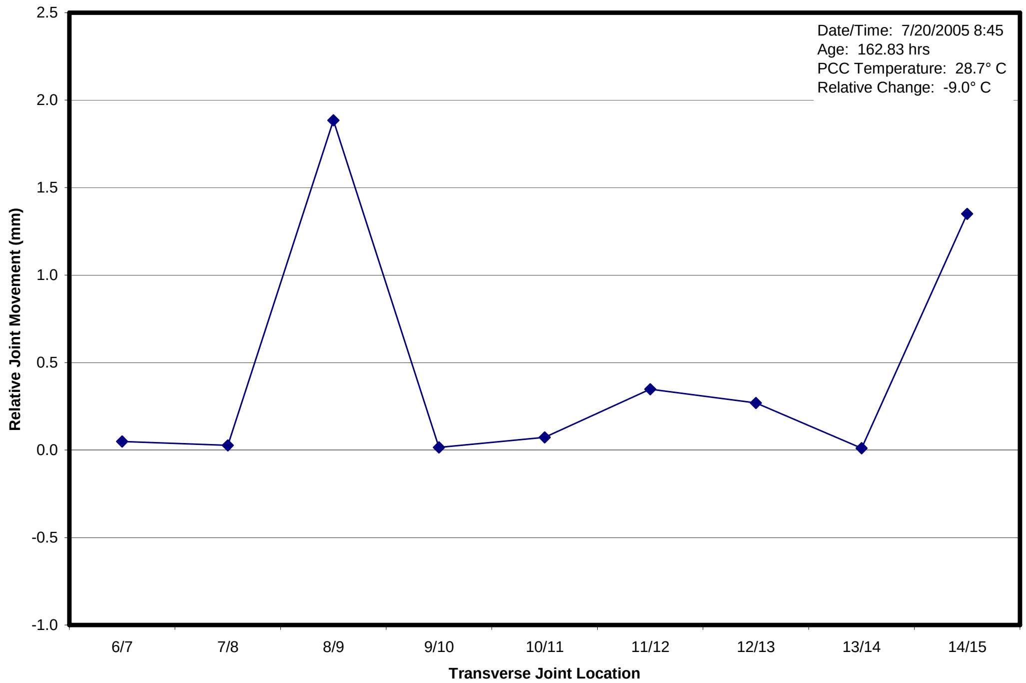


Figure I.15. Transverse joint relative opening

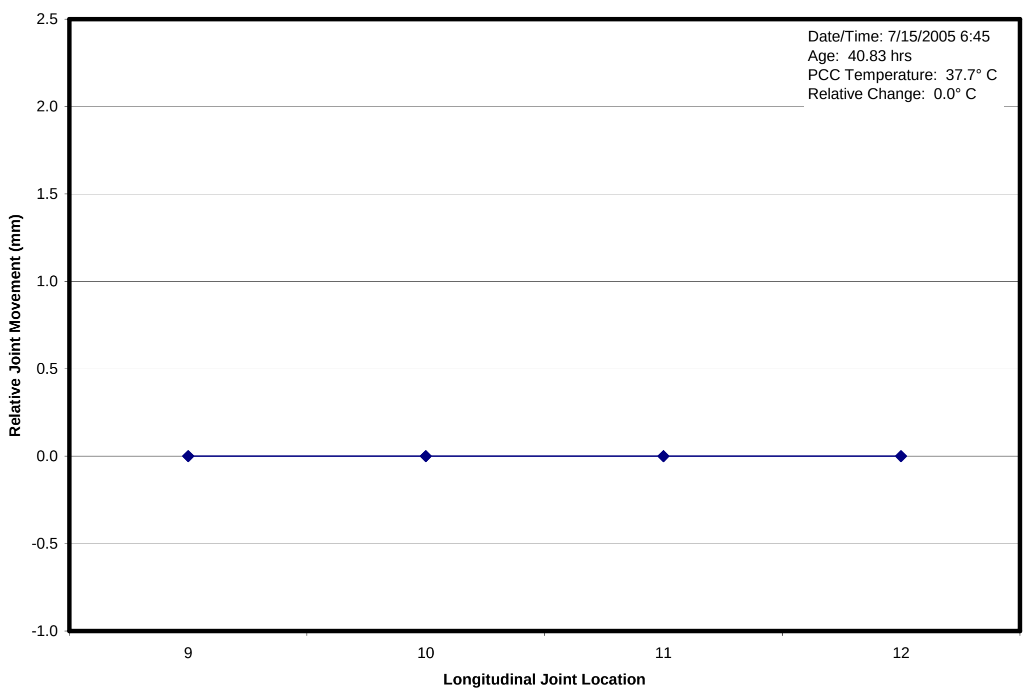


Figure I.16. Longitudinal joint relative opening

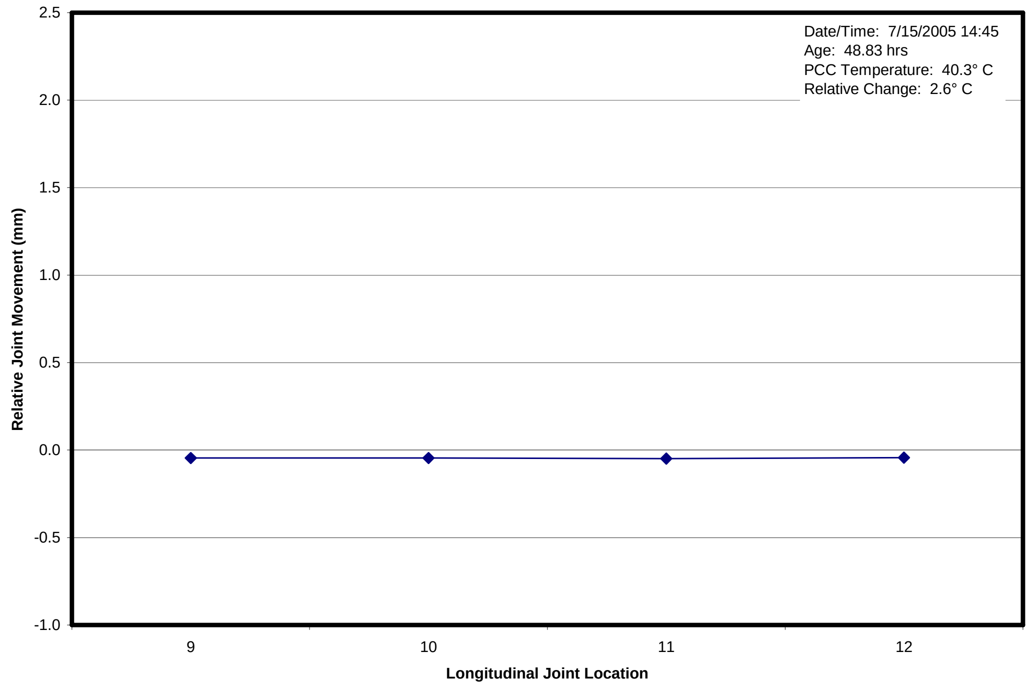


Figure I.17. Longitudinal joint relative opening

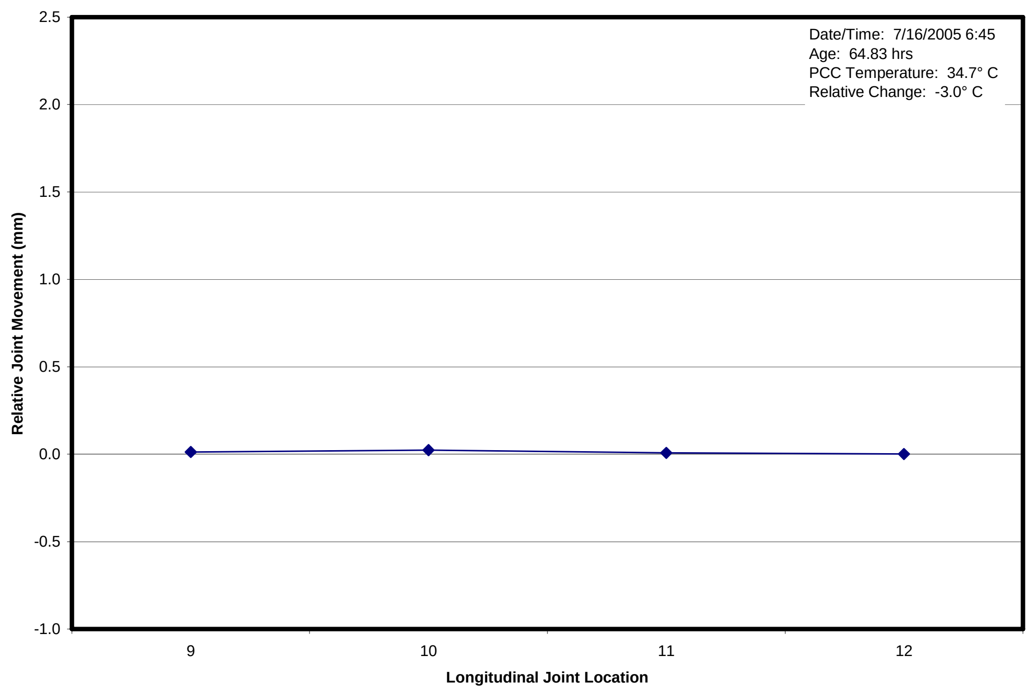


Figure I.18. Longitudinal joint relative opening

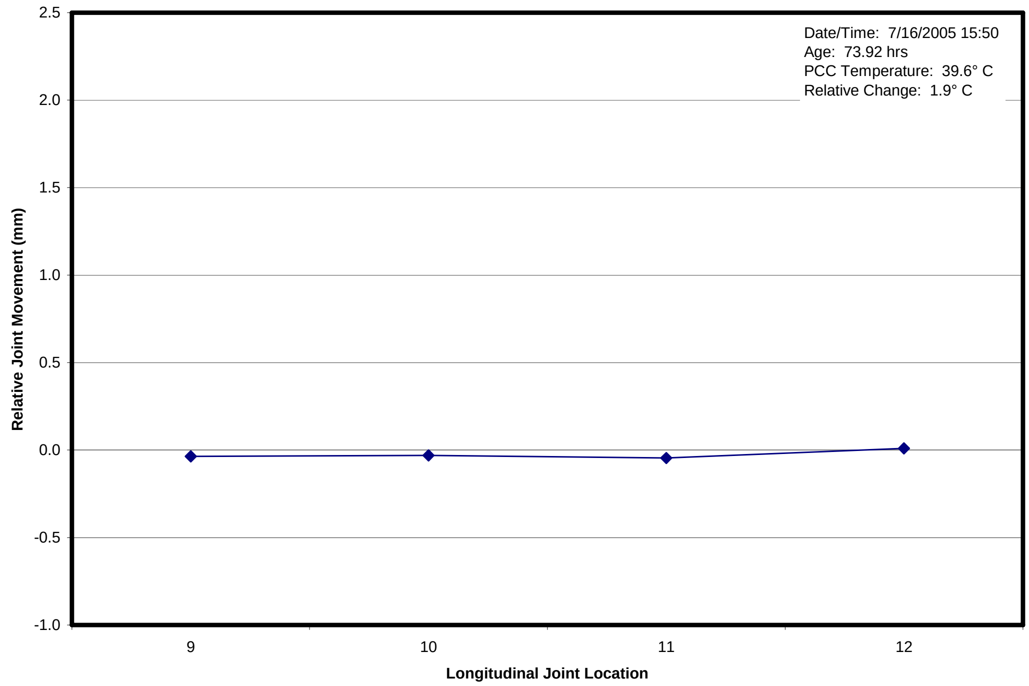


Figure I.19. Longitudinal joint relative opening

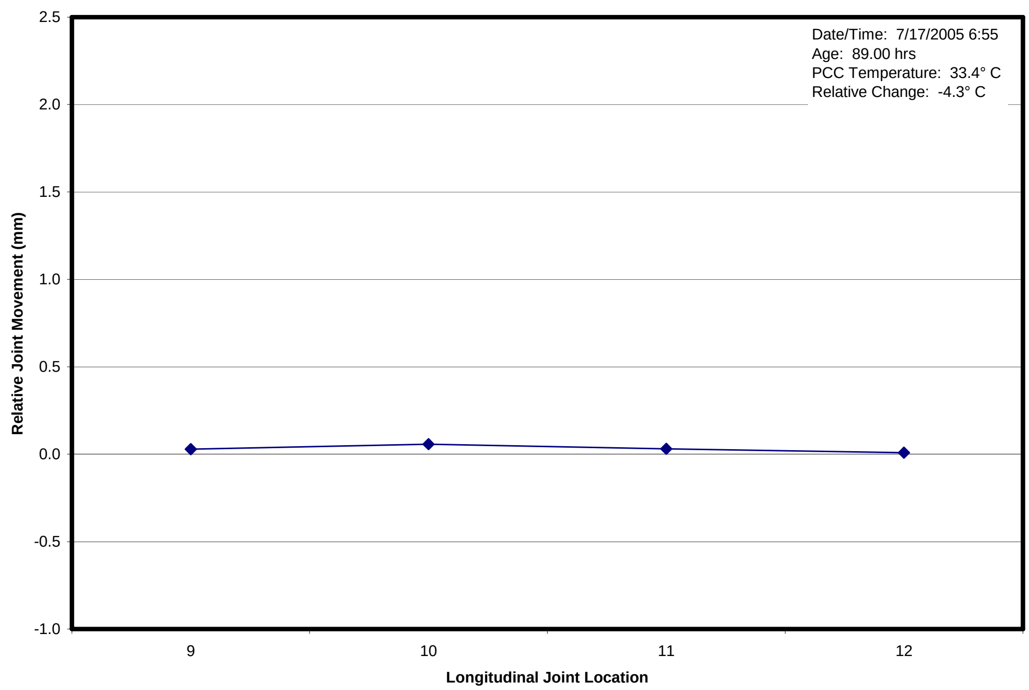


Figure I.20. Longitudinal joint relative opening

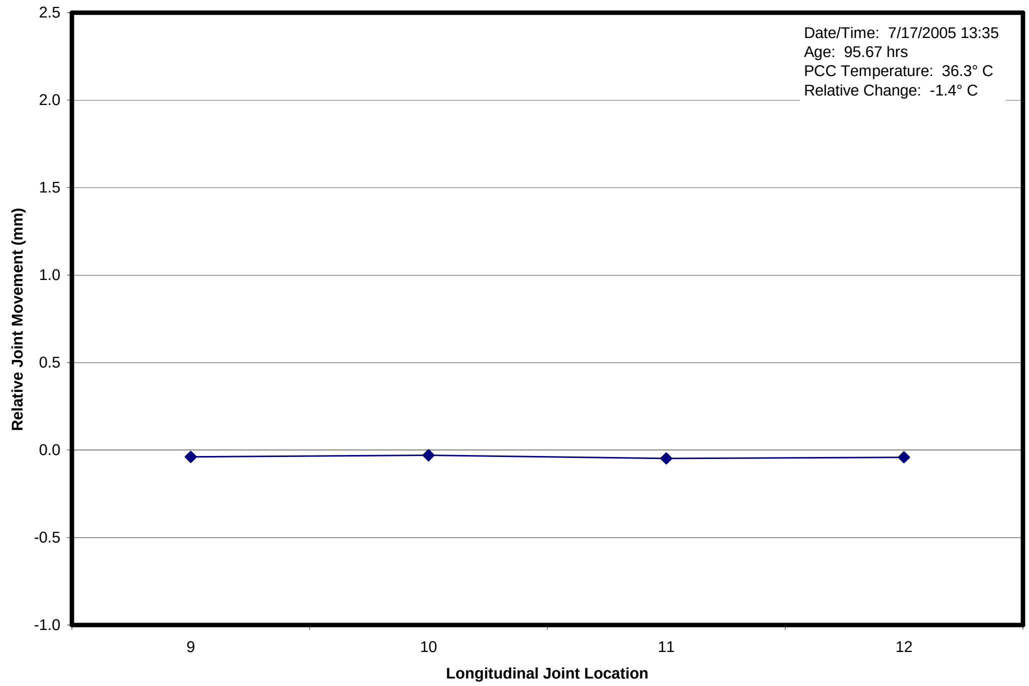


Figure I.21. Longitudinal joint relative opening

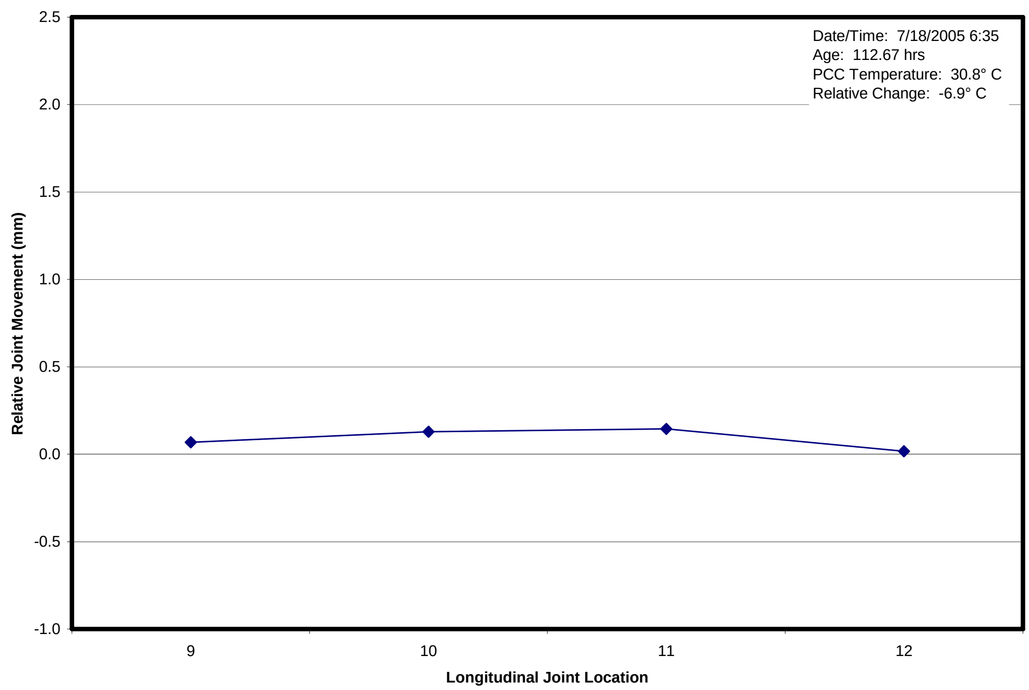


Figure I.22. Longitudinal joint relative opening

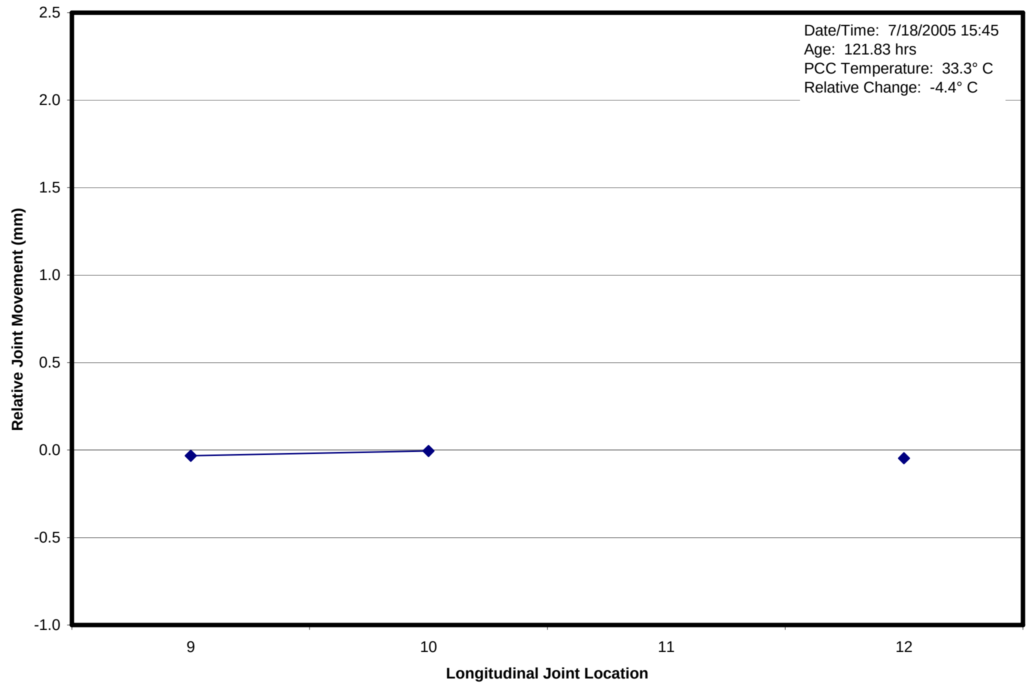


Figure I.23. Longitudinal joint relative opening

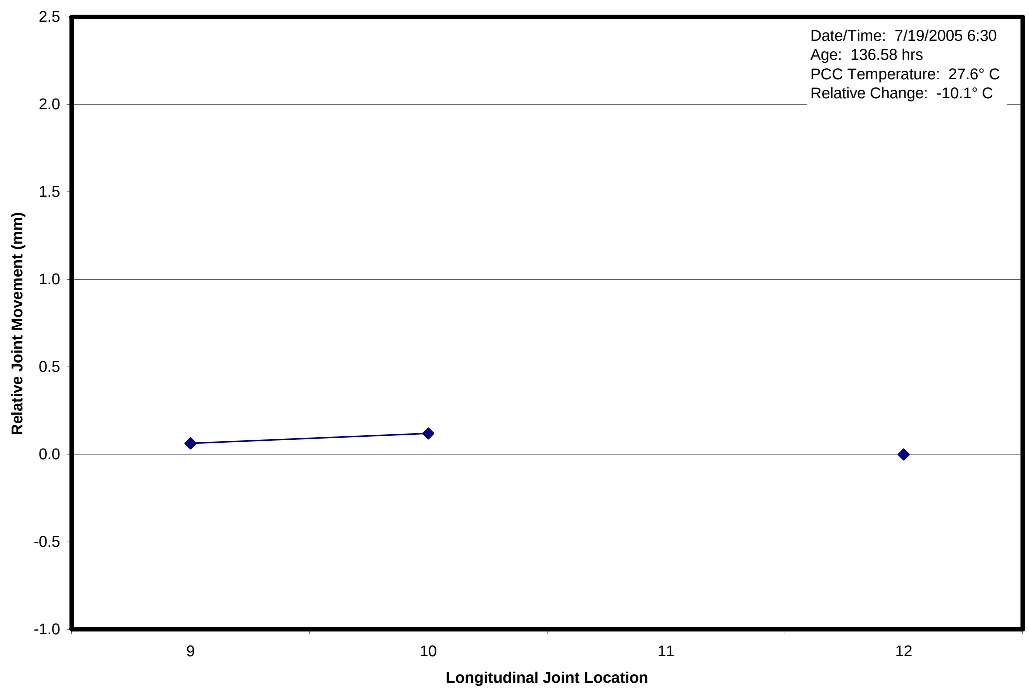


Figure I.24. Longitudinal joint relative opening

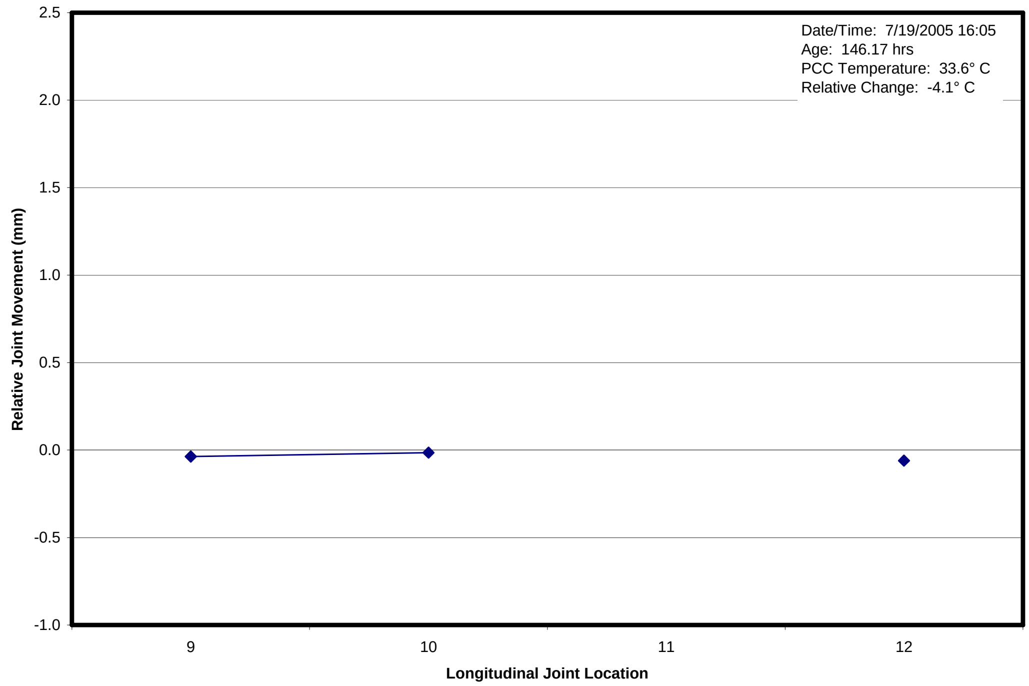


Figure I.25. Longitudinal joint relative opening

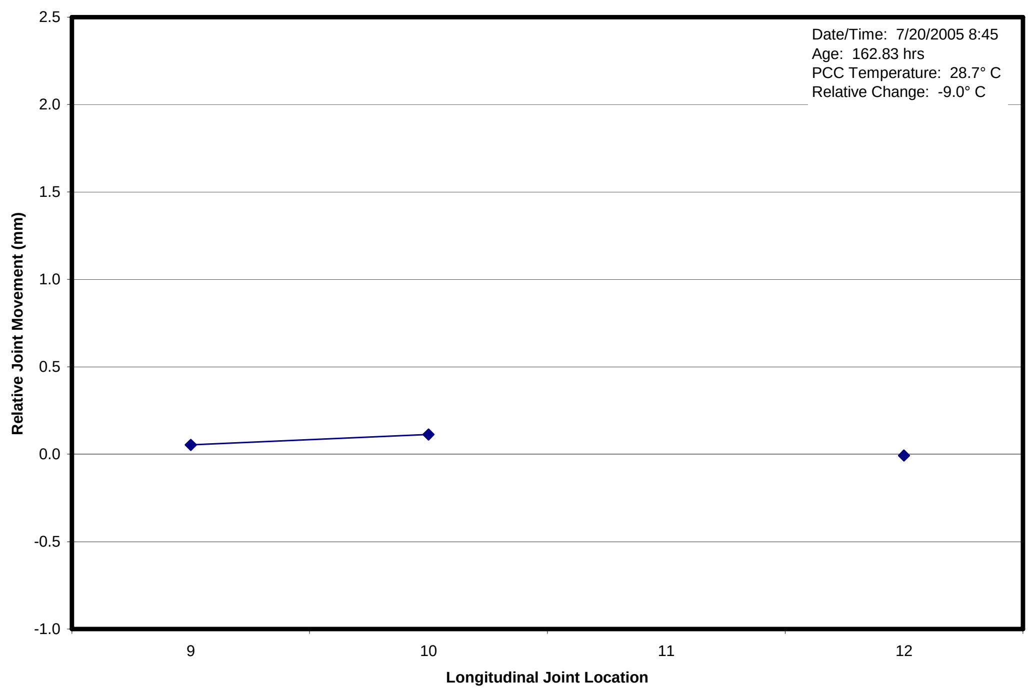


Figure I.26. Longitudinal joint relative opening

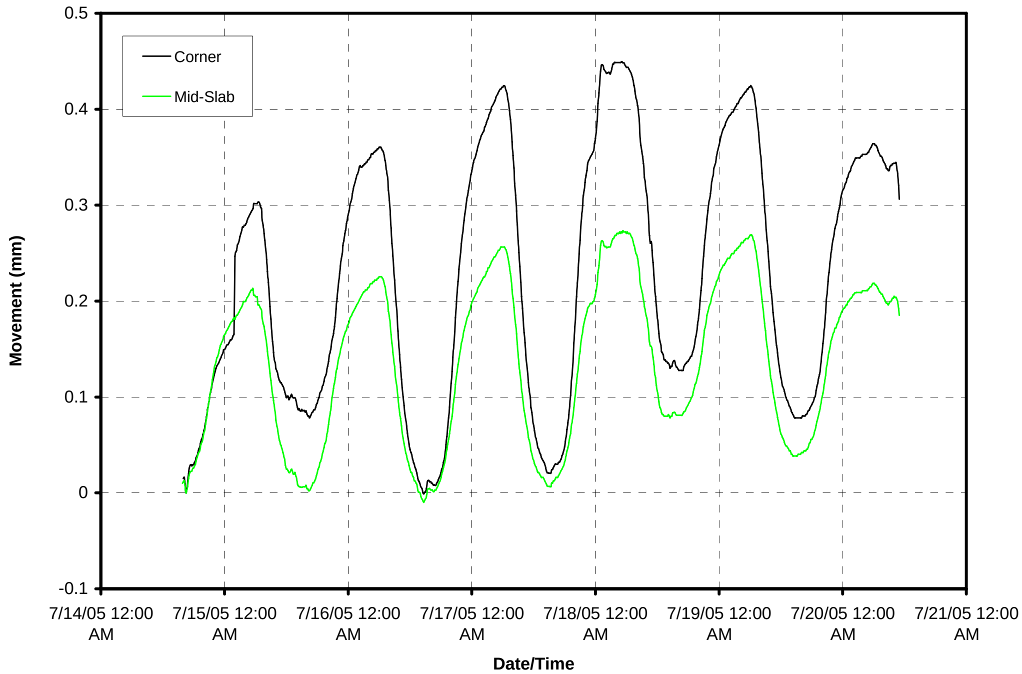


Figure I.27. LVDT record

Table I.1. Level A slab edge profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1011	7/14/2005 10:11	20.25	41.4	29.9	83.1	189.8	3.10
14JL1614	7/14/2005 16:14	26.33	46.1	32.3	95.9	210.7	2.94
15JL0623	7/15/2005 6:23	40.50	37.8	20.4	84.7	183.6	3.14
15JL1430	7/15/2005 14:30	48.58	40.0	32.9	94.5	212.7	2.92
16JL0633	7/16/2005 6:33	64.67	34.7	21.1	94.9	202.1	3.00
16JL1519	7/16/2005 15:19	73.42	39.2	32.8	86.0	196.8	3.04
17JL0643	7/17/2005 6:43	88.83	33.4	21.7	97.7	215.9	2.90
17JL1315	7/17/2005 13:15	95.33	36.0	32.8	90.7	200.9	3.01
18JL0605	7/18/2005 6:05	112.17	31.1	20.0	94.1	199.3	3.02
18JL1458	7/18/2005 14:58	121.08	33.0	27.0	91.3	192.8	3.07
19JL0606	7/19/2005 6:06	136.17	27.7	16.2	96.9	211.1	2.93
19JL1544	7/19/2005 15:44	145.83	33.3	29.4	87.7	194.6	3.06
20JL0743	7/20/2005 7:43	161.83	29.0	23.9	85.7	185.8	3.13

Table I.2. Level A mid-slab profile summary

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1027	7/14/2005 10:27	20.58	41.6	30.3	99.3	150.8	3.42
14JL1623	7/14/2005 16:23	26.50	46.3	32.5	102.5	152.4	3.40
15JL0632	7/15/2005 6:32	40.58	37.8	20.6	98.3	146.8	3.45
15JL1440	7/15/2005 14:40	48.75	40.3	32.6	100.4	149.5	3.43
16JL0641	7/16/2005 6:41	64.75	34.7	21.1	98.3	149.2	3.43
16JL1528	7/16/2005 15:28	73.58	39.2	32.8	96.2	136.9	3.54
17JL0650	7/17/2005 6:50	88.92	33.4	21.7	102.5	169.3	3.26
17JL1324	7/17/2005 13:24	95.50	36.2	32.8	96.5	142.8	3.49
18JL0617	7/18/2005 6:17	112.33	30.8	20.0	103.6	150.7	3.42
18JL1506	7/18/2005 15:06	121.17	33.0	27.0	105.6	157.0	3.36
19JL0613	7/19/2005 6:13	136.33	27.7	16.2	104.2	152.5	3.40
19JL1555	7/19/2005 15:55	146.00	33.3	29.4	96.8	135.8	3.55
20JL0751	7/20/2005 7:51	161.92	29.0	23.9	98.2	137.0	3.54

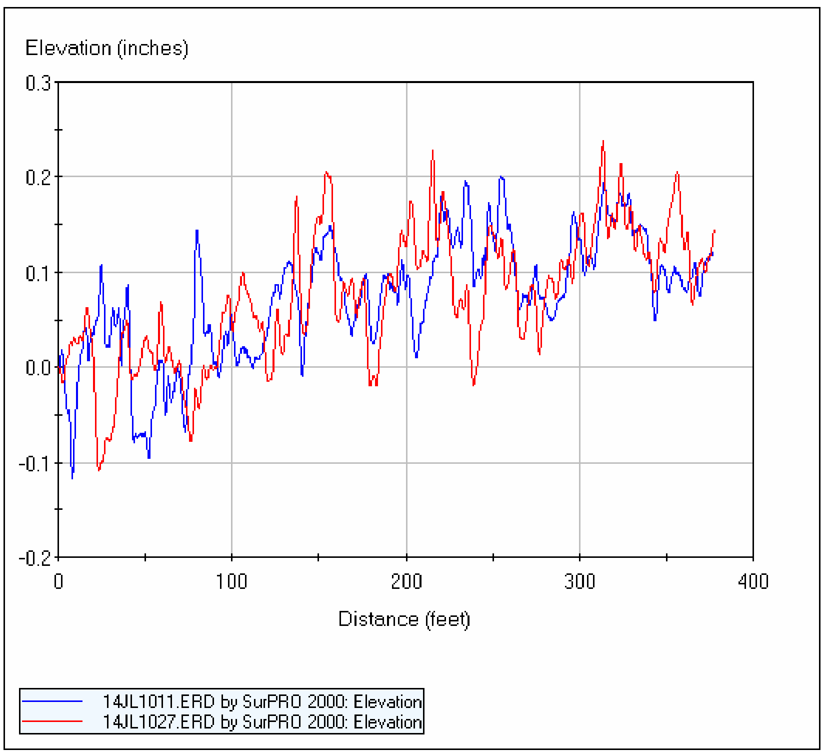


Figure I.28. Level A profile – July 14, 2005 morning

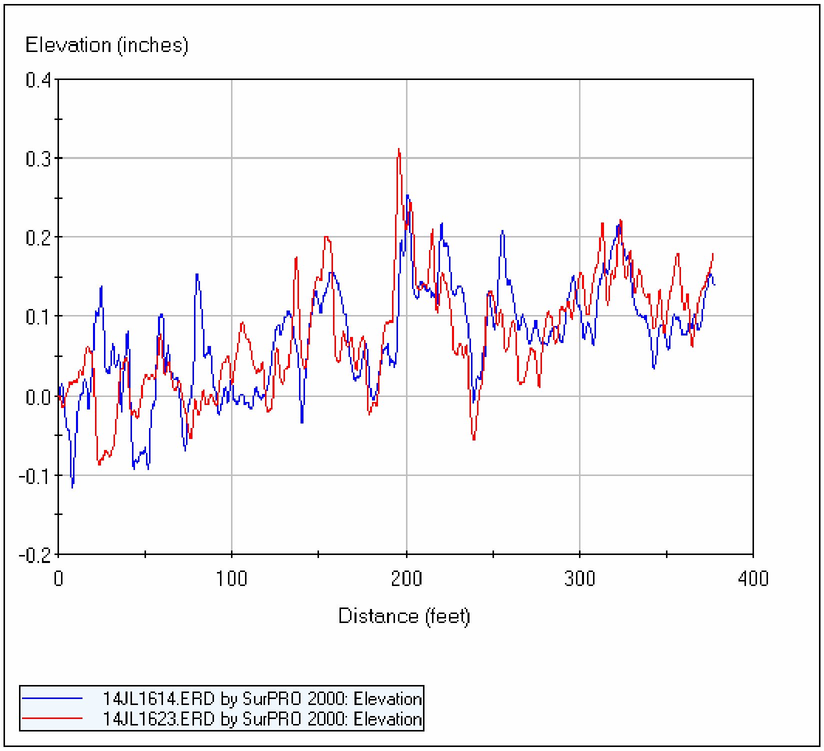


Figure I.29. Level A profile – July 14, 2005 afternoon

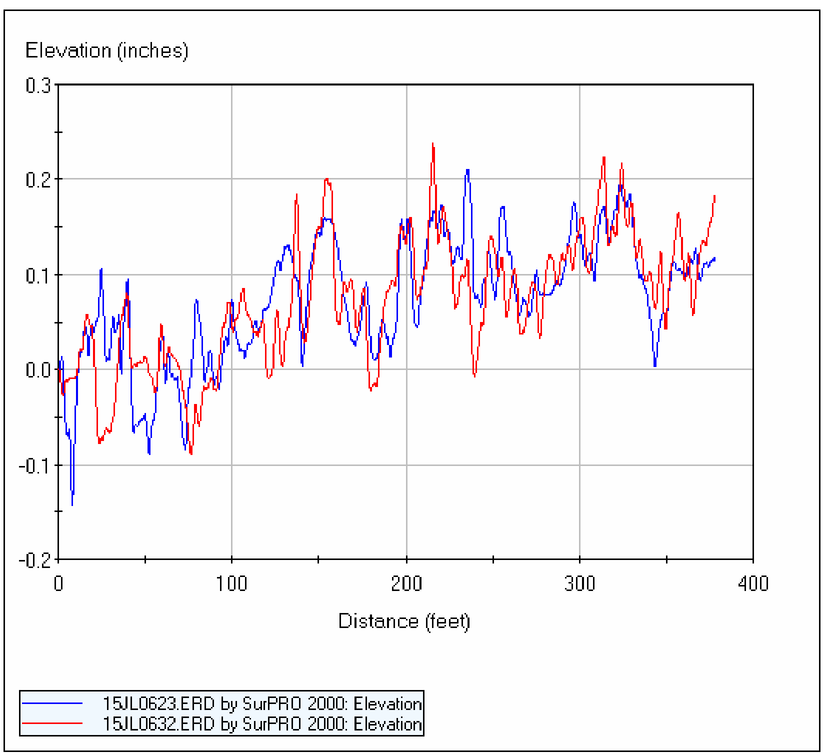


Figure I.30. Level A profile – July 15, 2005 morning

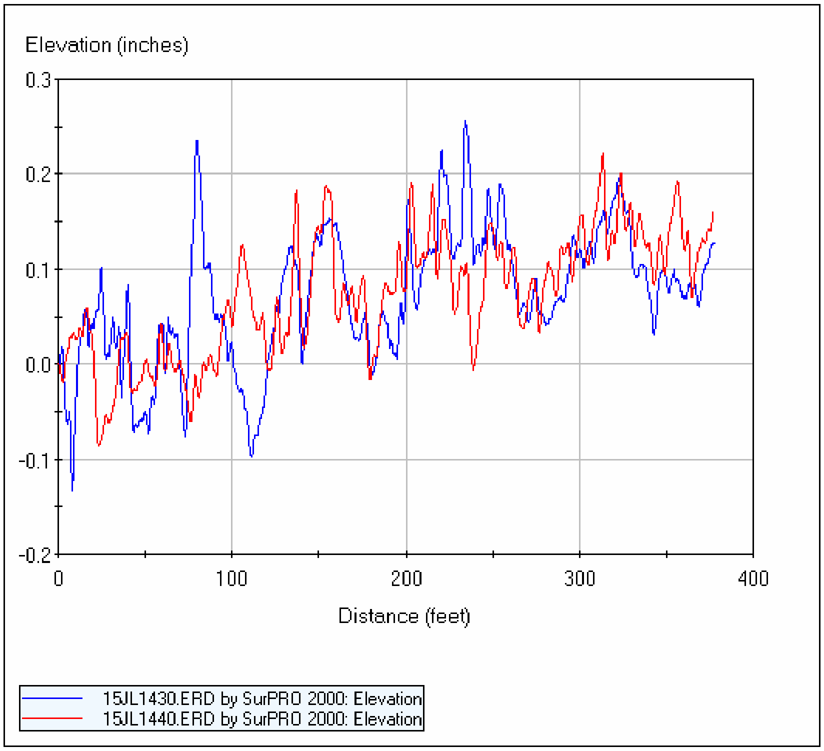


Figure I.31. Level A profile – July 15, 2005 afternoon

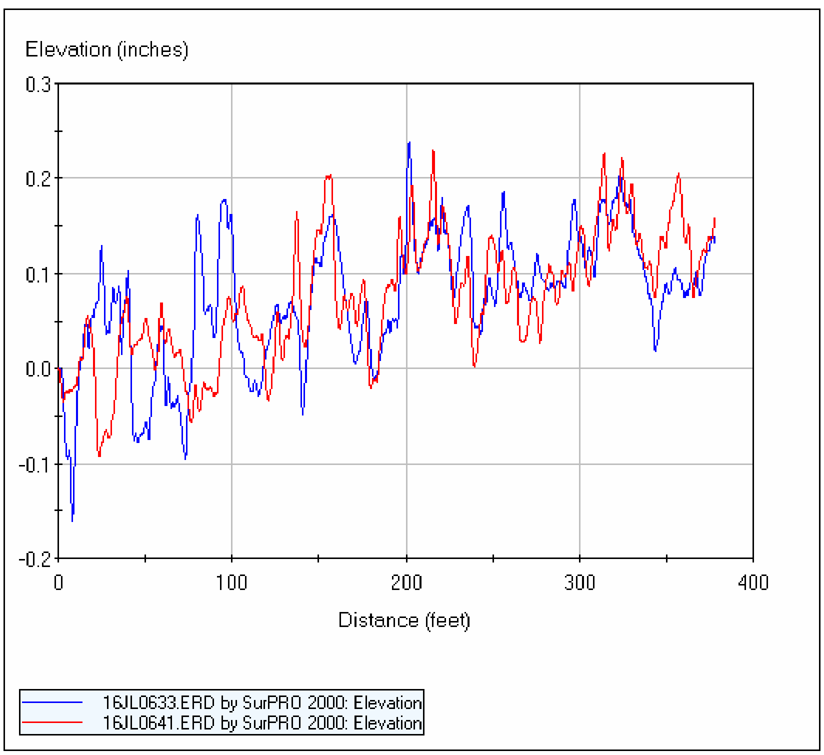


Figure I.32. Level A profile – July 16, 2005 morning

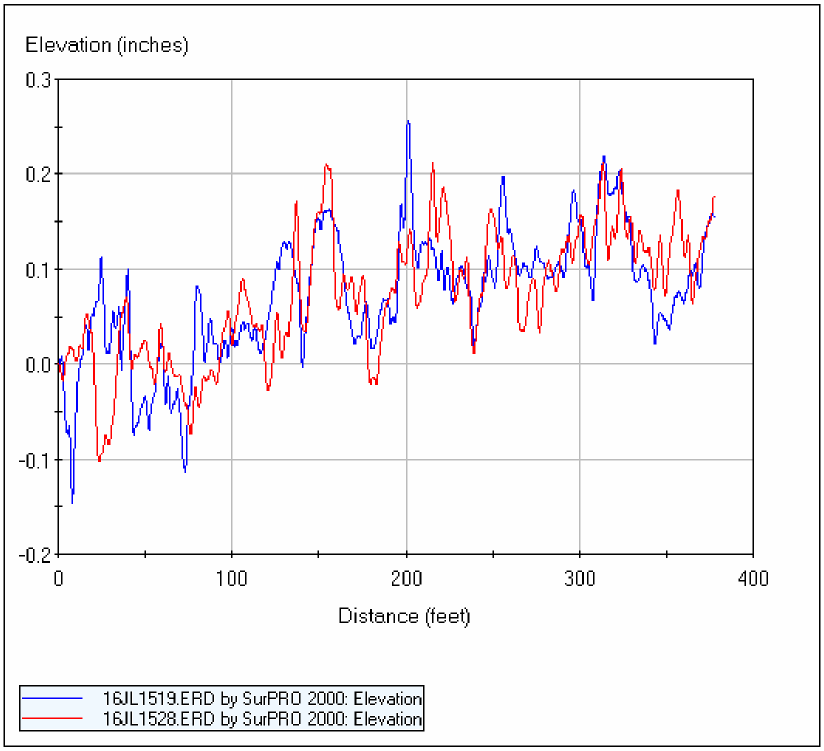


Figure I.33. Level A profile – July 16, 2005 afternoon

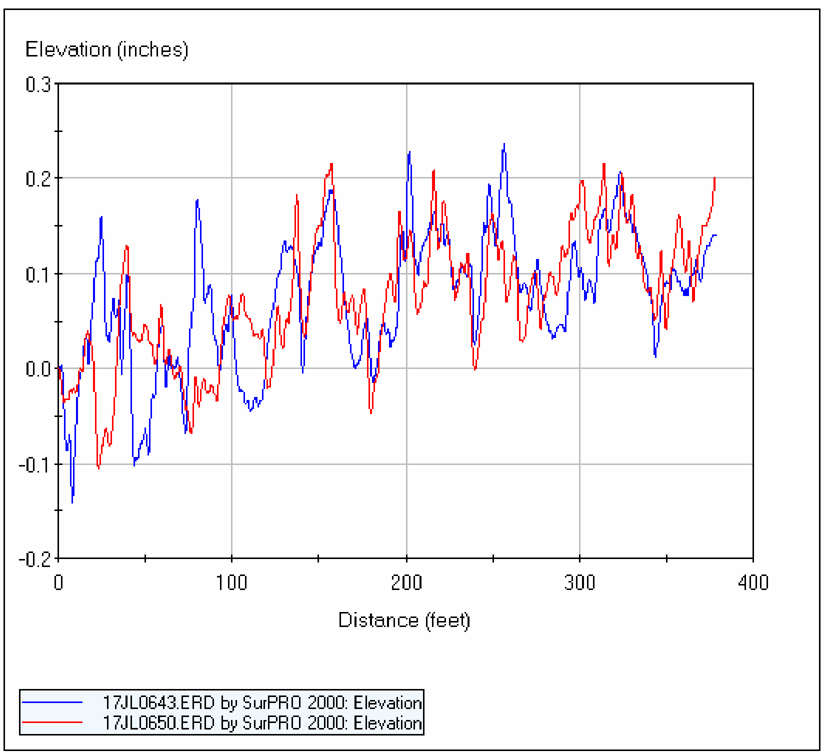


Figure I.34. Level A profile – July 17, 2005 morning

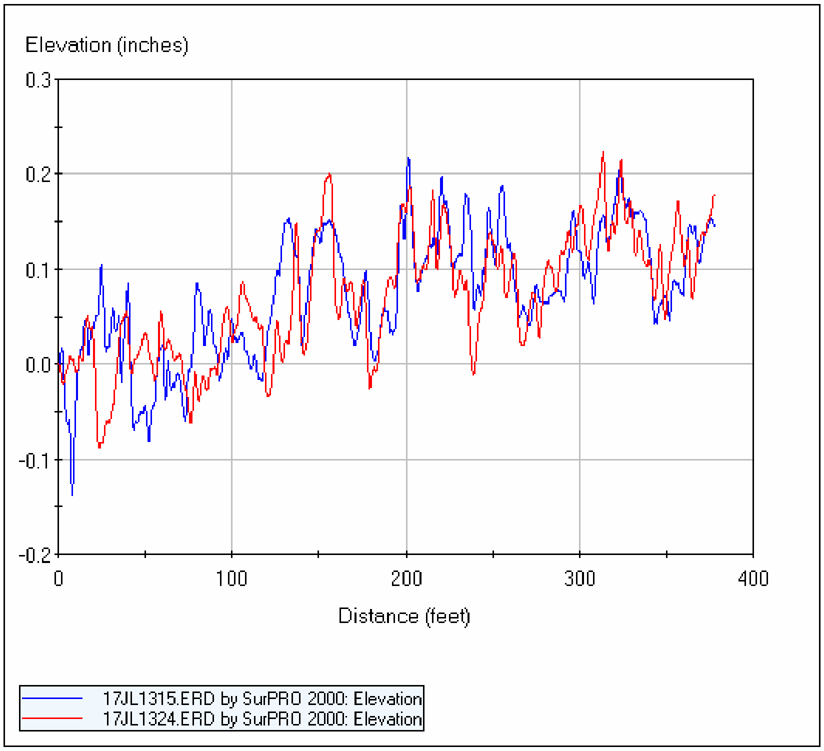


Figure I.35. Level A profile – July 17, 2005 afternoon

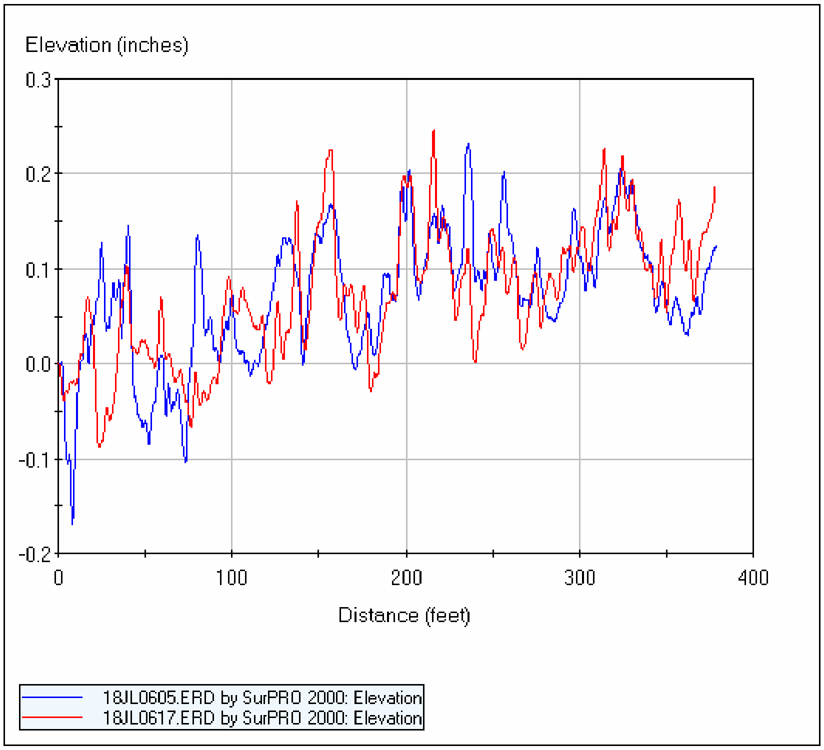


Figure I.36. Level A profile – July 18, 2005 morning

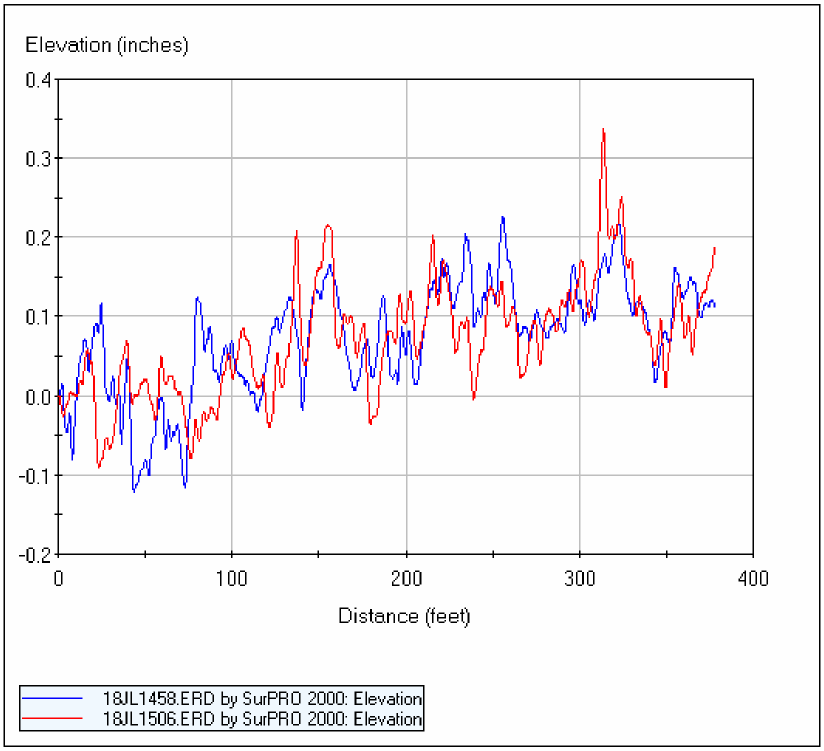


Figure I.37. Level A profile – July 18, 2005 afternoon

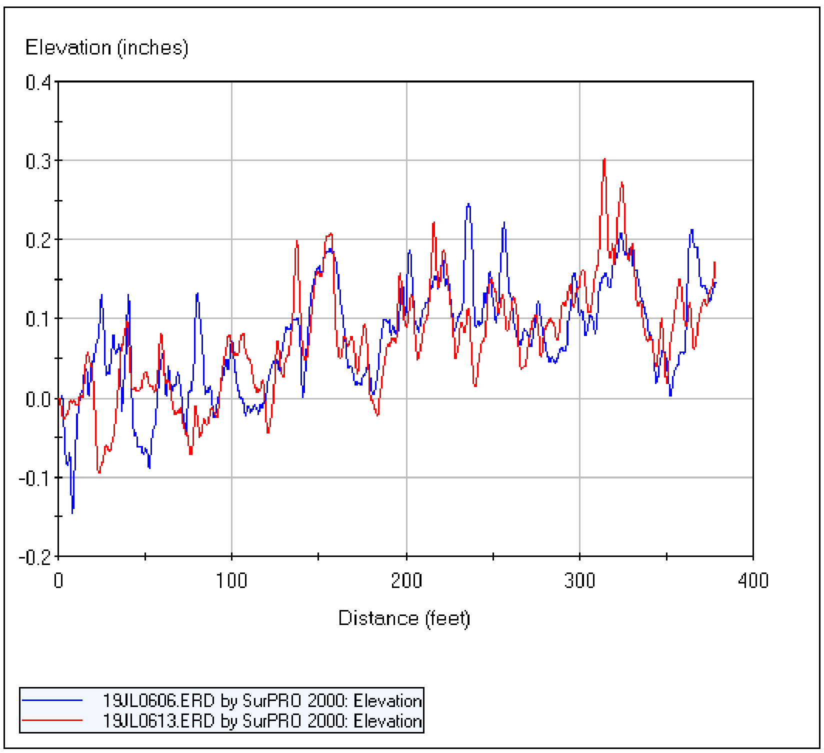


Figure I.38. Level A profile – July 19, 2005 morning

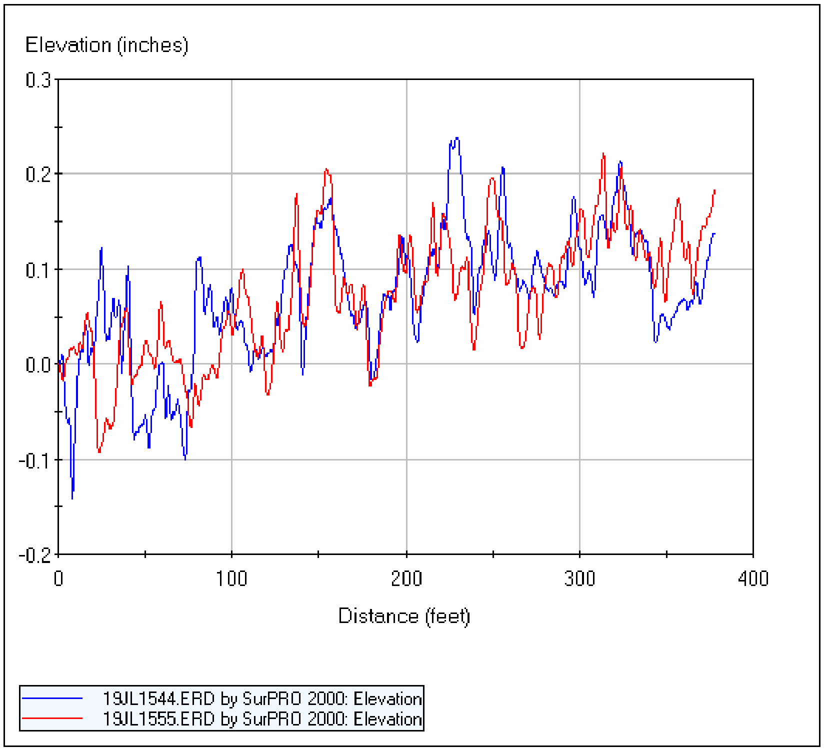


Figure I.39. Level A profile – July 19, 2005 afternoon

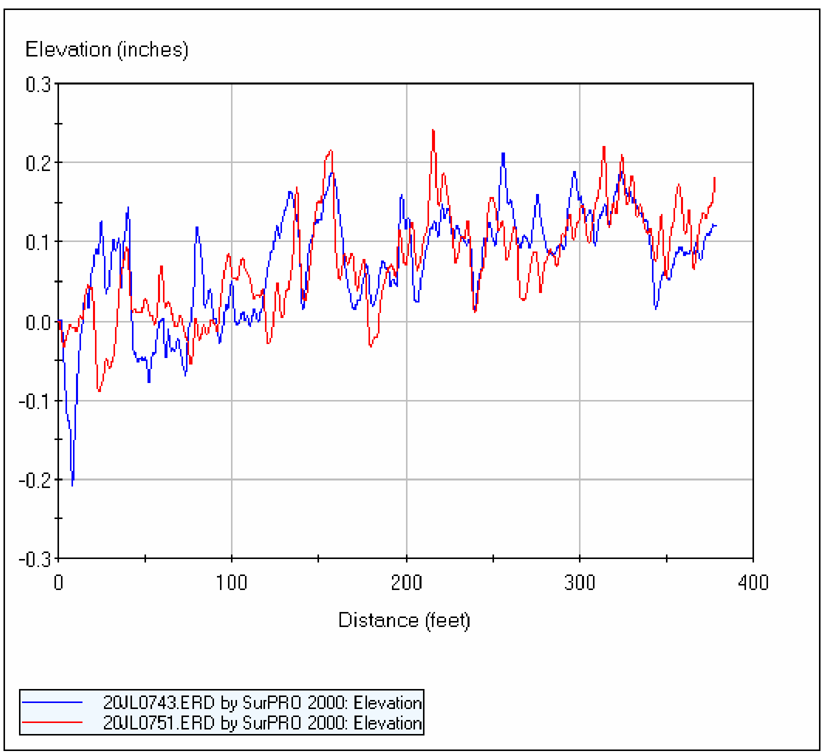


Figure I.40. Level A profile – July 20, 2005 morning

Table I.3. Level B profile summary (2 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1040	7/14/2005 10:40	20.75	41.7	30.4	118.1	222.5	2.85
14JL1634	7/14/2005 16:34	26.67	46.3	32.8	118.8	242.3	2.71
15JL0646	7/15/2005 6:46	40.83	37.7	21.3	125.7	224.3	2.84
15JL1449	7/15/2005 14:49	48.92	40.3	32.6	120.4	241.1	2.72
16JL0650	7/16/2005 6:50	64.92	34.7	21.1	121.5	245.3	2.69
16JL1537	7/16/2005 15:37	73.67	39.2	32.8	120.7	237.7	2.74
17JL0658	7/17/2005 6:58	89.08	33.4	21.7	118.3	233.4	2.77
17JL1333	7/17/2005 13:33	95.67	36.3	32.8	117.8	228.1	2.81
18JL0627	7/18/2005 6:27	112.50	30.8	20.0	116.6	239.7	2.73
18JL1514	7/18/2005 15:14	121.33	33.1	27.0	121.8	238.3	2.74
19JL0621	7/19/2005 6:21	136.42	27.6	16.2	116.4	233.2	2.77
19JL1604	7/19/2005 16:04	146.17	33.6	29.4	115.7	216.0	2.90
20JL0801	7/20/2005 8:01	162.08	28.9	23.9	116.4	219.1	2.88

Table I.4. Level B profile summary (3 ft. from free edge)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1641	7/14/2005 16:41	26.75	46.3	32.6	106.0	187.4	3.12
15JL0658	7/15/2005 6:58	41.08	37.5	21.7	106.4	178.9	3.18
15JL1507	7/15/2005 15:07	49.17	40.4	32.4	101.1	173.9	3.22
16JL0657	7/16/2005 6:57	65.08	34.4	21.1	107.0	188.9	3.10
16JL1551	7/16/2005 15:51	73.92	39.6	32.8	104.0	186.4	3.12
17JL0705	7/17/2005 7:05	89.17	33.3	21.7	102.5	171.5	3.24
17JL1340	7/17/2005 13:40	95.75	36.4	32.8	100.9	168.8	3.27
18JL0635	7/18/2005 6:35	112.67	30.8	20.0	101.2	168.2	3.27
19JL0628	7/19/2005 6:28	136.58	27.6	16.2	107.5	174.7	3.22
19JL1613	7/19/2005 16:13	146.33	33.7	29.4	98.9	161.2	3.33
20JL0816	7/20/2005 8:16	162.33	28.8	23.9	106.4	174.2	3.22

Table I.5. Level B profile summary (3 ft. from longitudinal joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1706	7/14/2005 17:06	27.17	46.4	32.4	107.5	167.9	3.27
15JL0716	7/15/2005 7:16	41.33	37.3	22.4	104.4	167.5	3.28
15JL1526	7/15/2005 15:26	49.50	40.8	33.0	103.2	167.3	3.28
16JL0712	7/16/2005 7:12	65.25	34.4	21.1	108.3	176.6	3.20
16JL1607	7/16/2005 16:07	74.17	39.6	32.8	103.5	157	3.36
17JL0720	7/17/2005 7:20	89.42	33.3	21.7	106.3	167.2	3.28
17JL1356	7/17/2005 13:56	96.00	36.7	32.8	103.9	159.6	3.34
18JL0652	7/18/2005 6:52	112.92	30.4	20.0	105.8	157.5	3.36
18JL1539	7/18/2005 15:39	121.75	33.3	27.0	97.9	148.0	3.44
19JL0644	7/19/2005 6:44	136.83	27.4	16.2	102.1	154.8	3.38
19JL1629	7/19/2005 16:29	146.58	33.9	29.4	99.3	146.9	3.45
20JL0831	7/20/2005 8:31	162.58	28.7	23.9	102.8	151.1	3.41

Table I.6. Level B profile summary (1 ft. from longitudinal joint)

File Name	Date/Time	Age (hrs)	Avg. Pavement Temperature (°C)	Ambient Temperature (°C)	IRI (in/mi)	PTRN (in/mi)	RN
14JL1657	7/14/2005 16:57	27.00	46.3	32.4	95.0	186.7	3.12
15JL0708	7/15/2005 7:08	41.25	37.3	22.4	87.2	155.2	3.38
15JL1518	7/15/2005 15:18	49.42	40.7	32.6	89.5	168.4	3.27
16JL1558	7/16/2005 15:58	74.08	39.6	32.8	88.9	172.2	3.24
17JL0712	7/17/2005 7:12	89.25	33.3	21.7	88.0	163.6	3.31
17JL1349	7/17/2005 13:49	95.92	36.6	32.8	86.0	165.5	3.29
18JL0644	7/18/2005 6:44	112.83	30.7	20.0	87.5	158.2	3.35
18JL1531	7/18/2005 15:31	121.58	33.2	27.0	84.3	152.6	3.40
19JL0637	7/19/2005 6:37	136.67	27.5	16.2	92.7	164.7	3.30
19JL1620	7/19/2005 16:20	146.42	33.8	29.4	84.0	153.9	3.39
20JL0824	7/20/2005 8:24	162.50	28.7	23.9	87.4	159.3	3.34

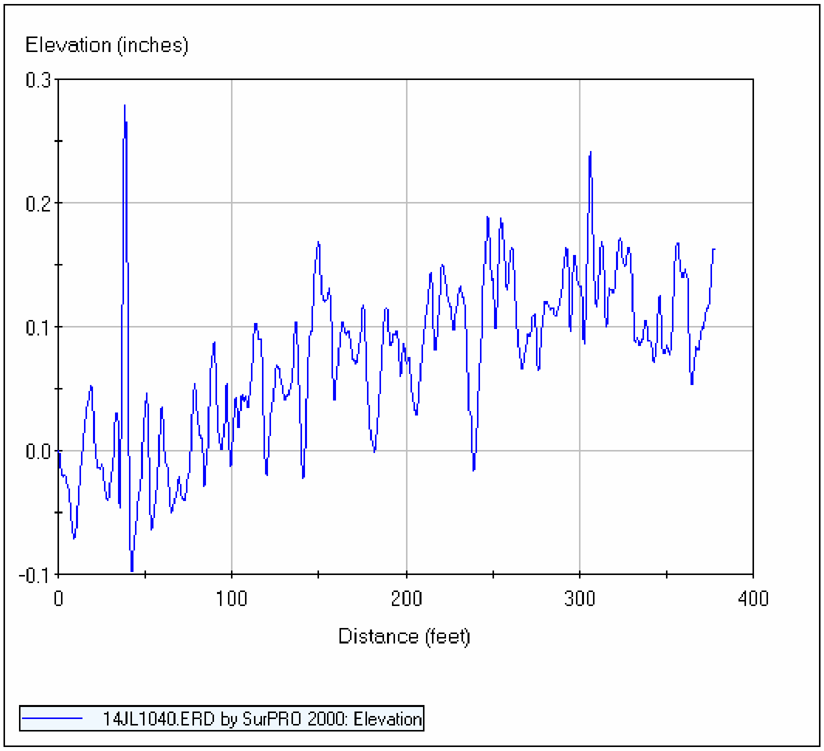


Figure I.41. Level B profile – 2 ft. from free edge only – July 14, 2005 morning

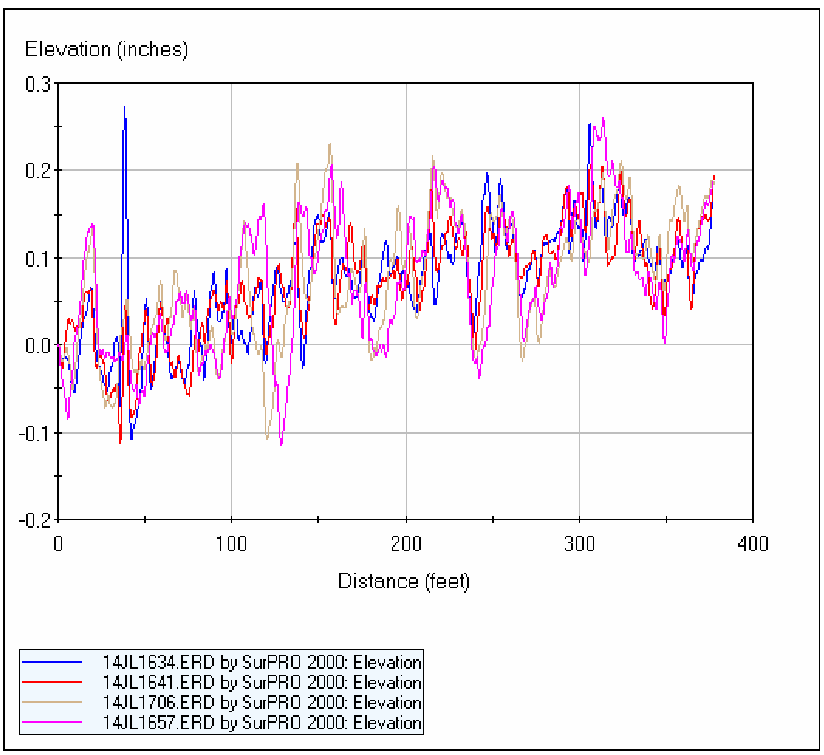


Figure I.42. Level B Profile – July 14, 2005 afternoon

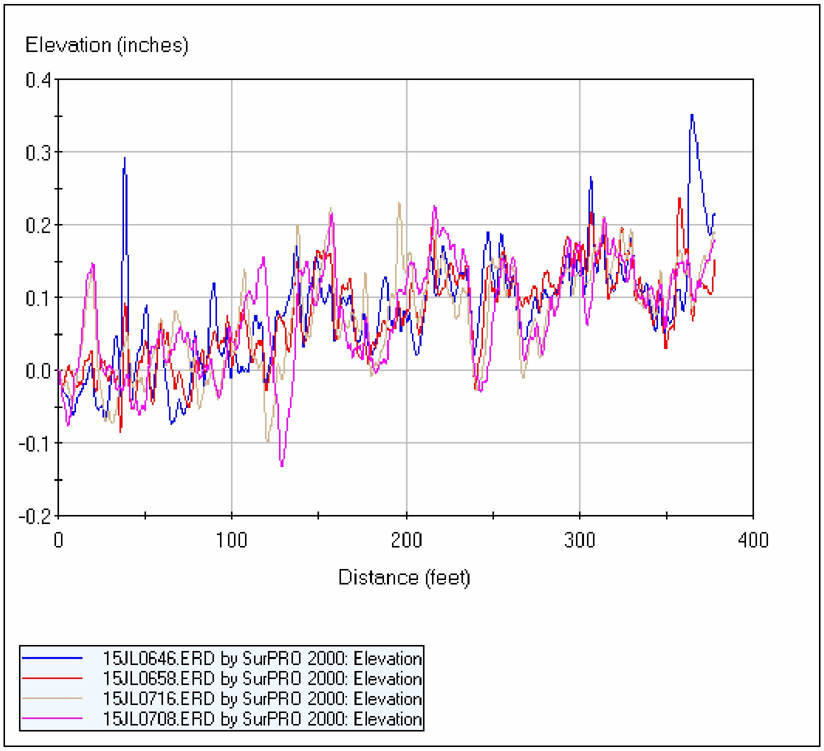


Figure I.43. Level B profile – July 15, 2005 morning

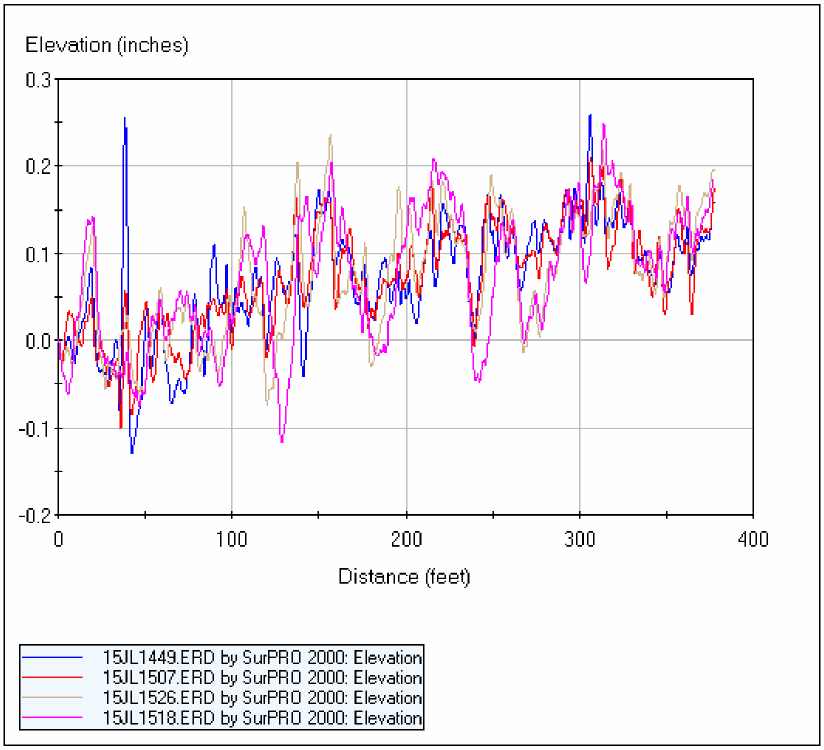


Figure I.44. Level B profile – July 15, 2005 afternoon

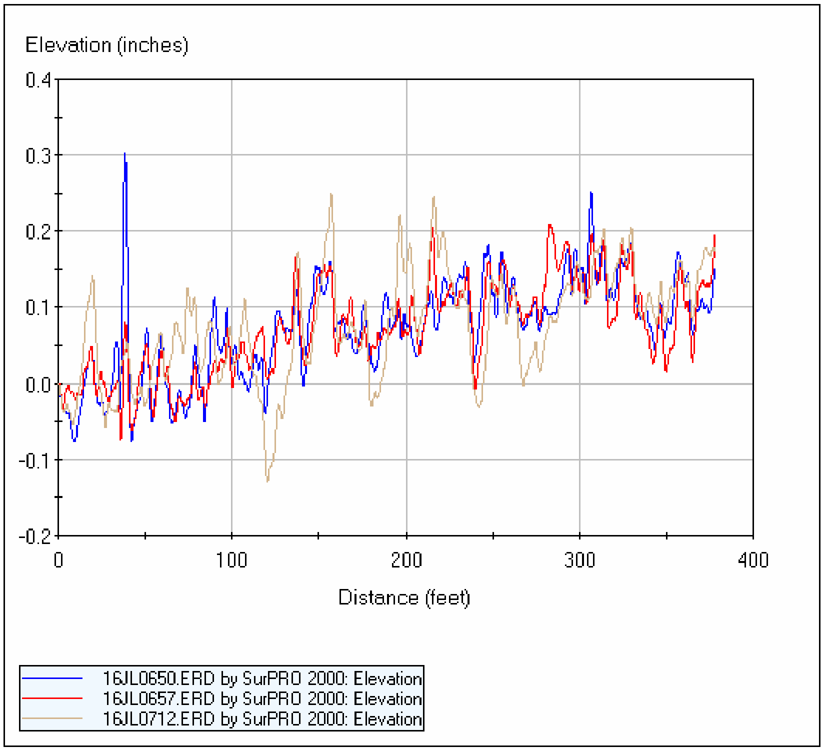


Figure I.45. Level B profile – July 16, 2005 morning

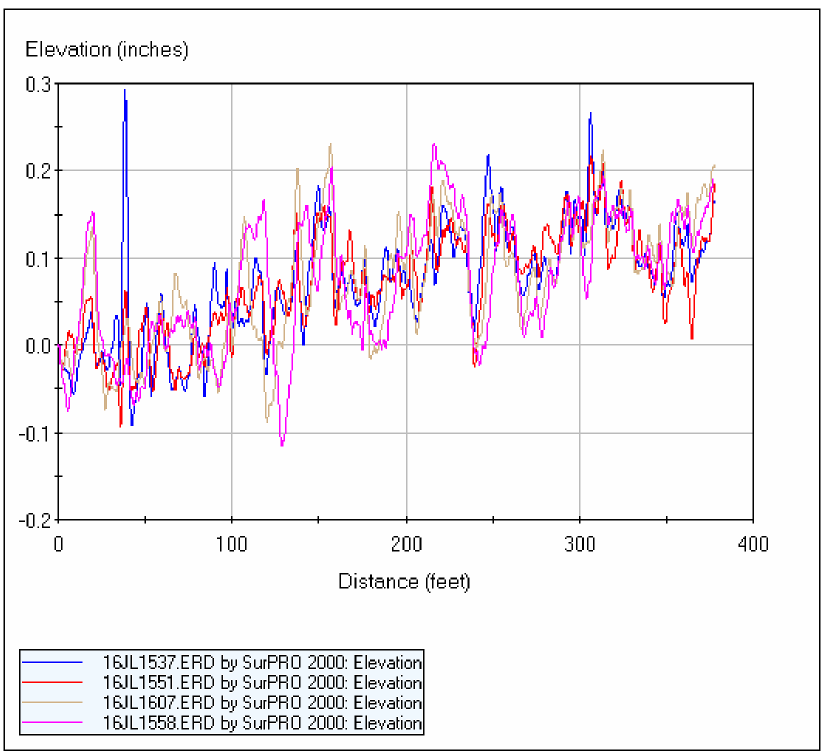


Figure I.46. Level B profile – July 16, 2005 afternoon

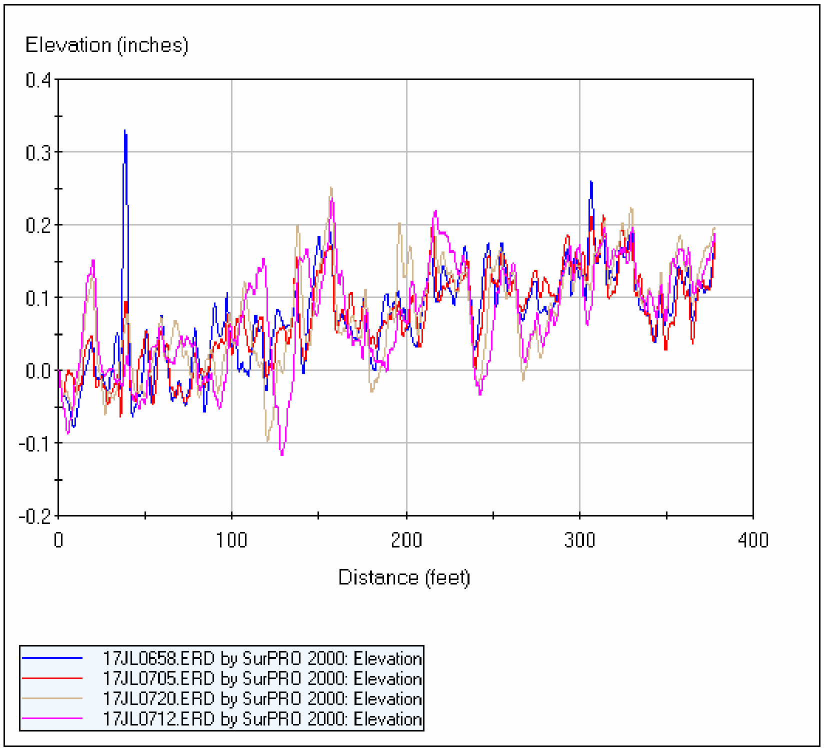


Figure I.47. Level B profile – July 17, 2005 morning

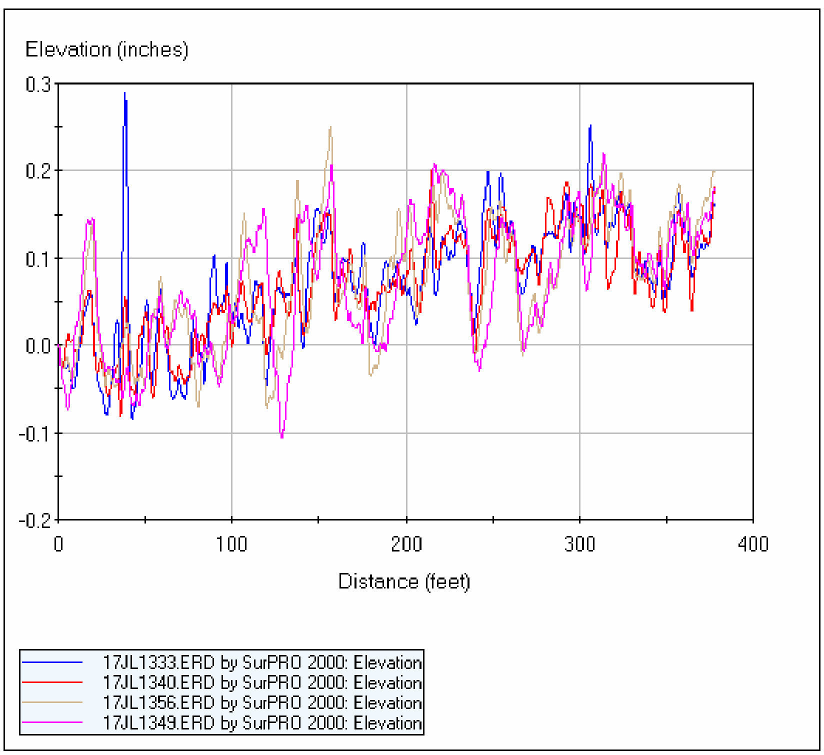


Figure I.48. Level B profile – July 17, 2005 afternoon

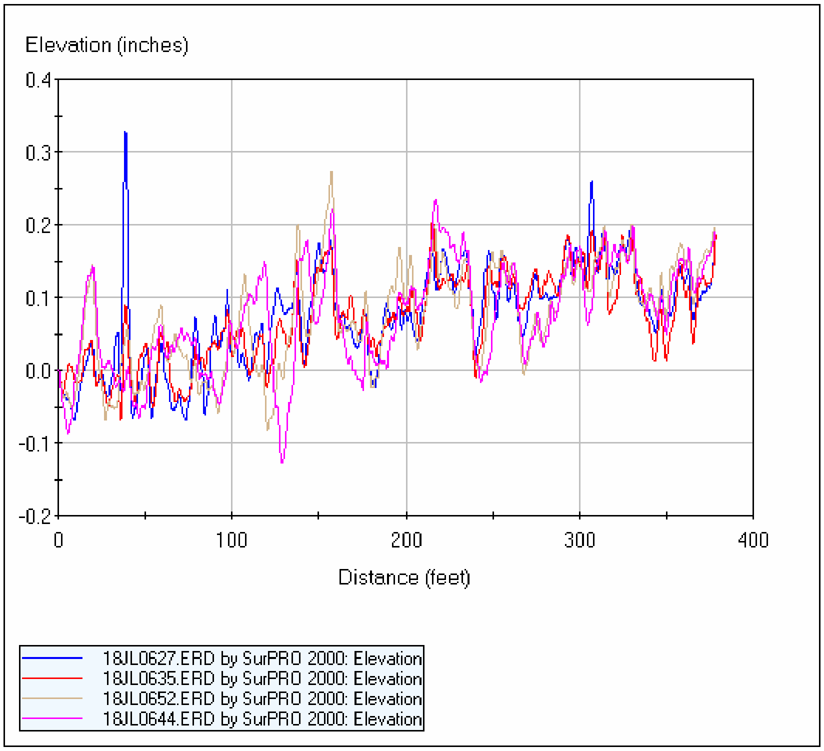


Figure I.49. Level B profile – July 18, 2005 morning

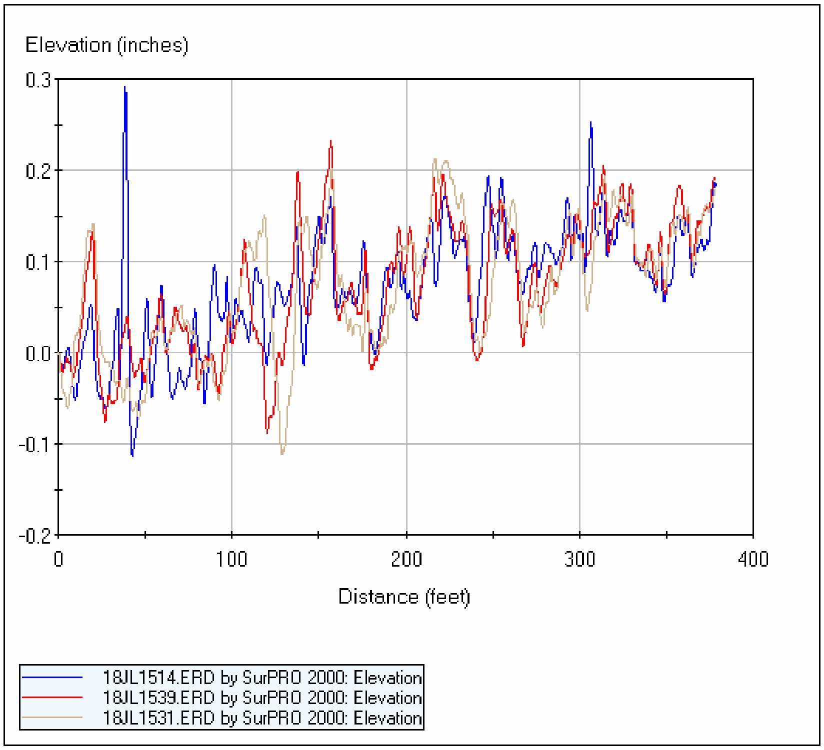


Figure I.50. Level B profile – July 18, 2005 afternoon

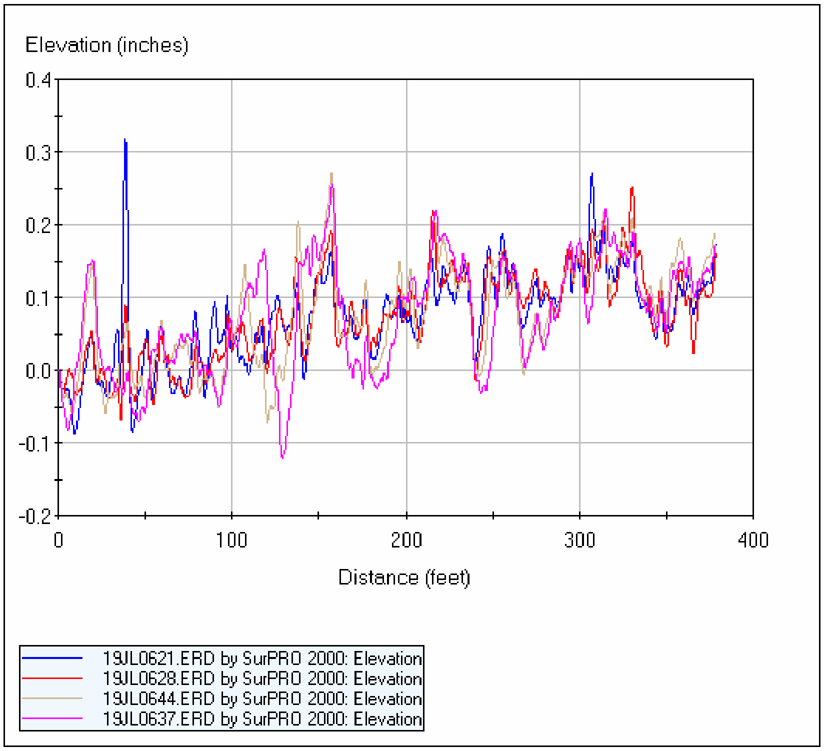


Figure I.51. Level B profile – July 19, 2005 morning

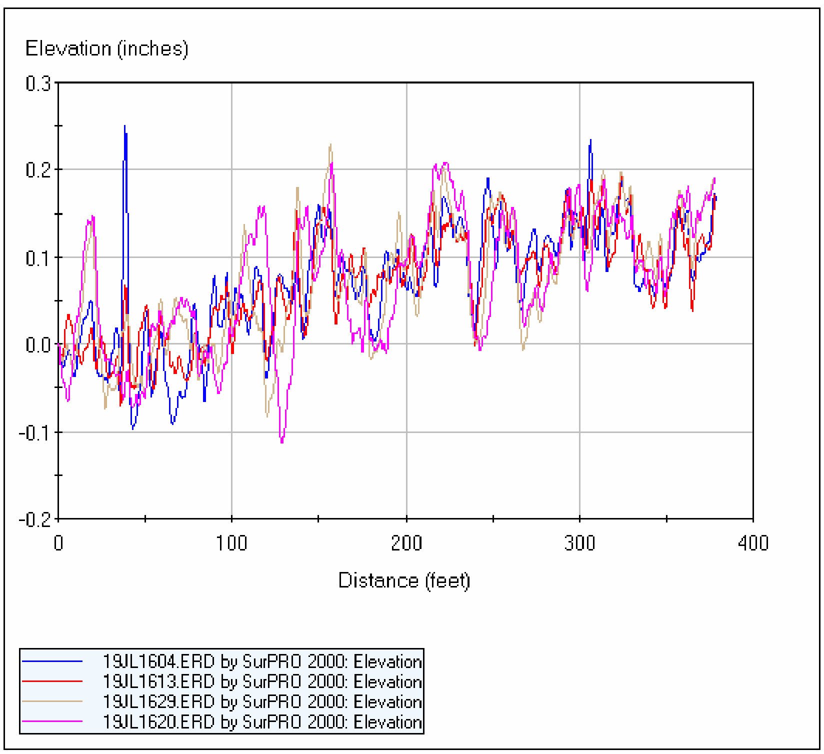


Figure I.52. Level B profile – July 19, 2005 afternoon

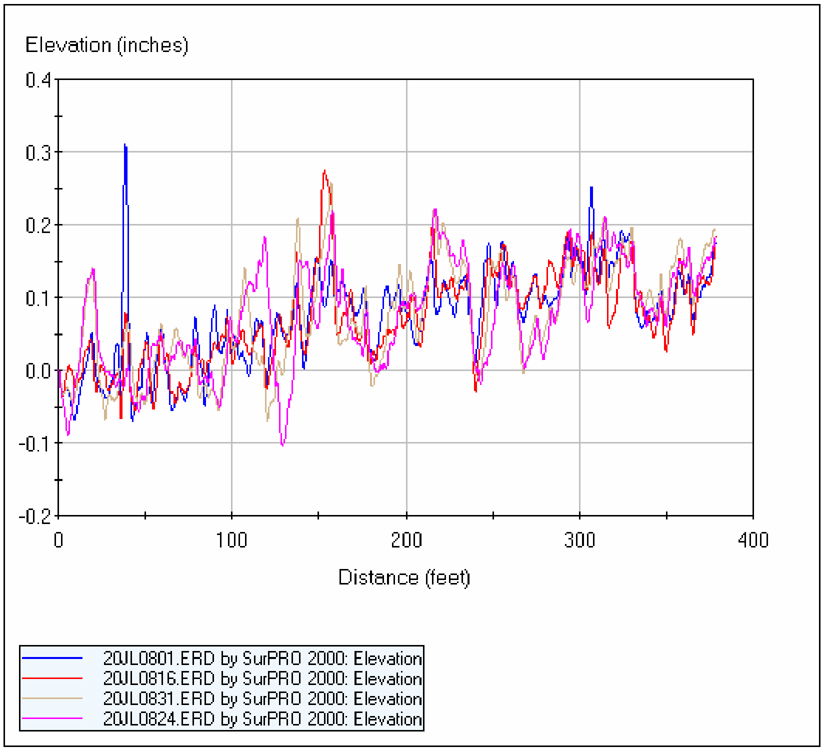


Figure I.53. Level B profile – July 20, morning

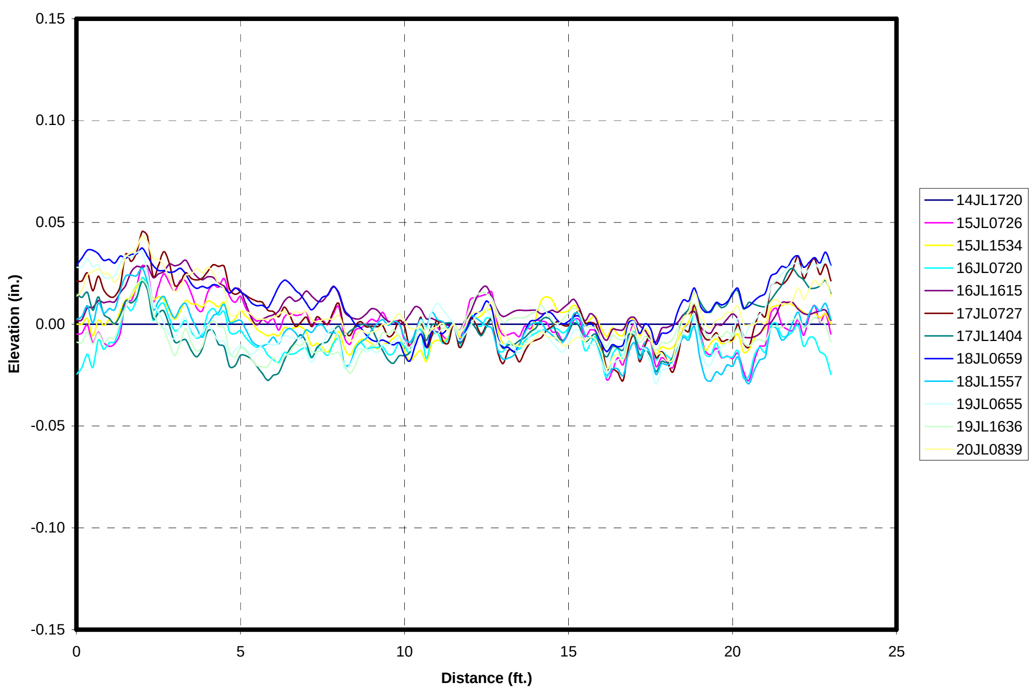


Figure I.54. Level C profiles path 1 – slab 9

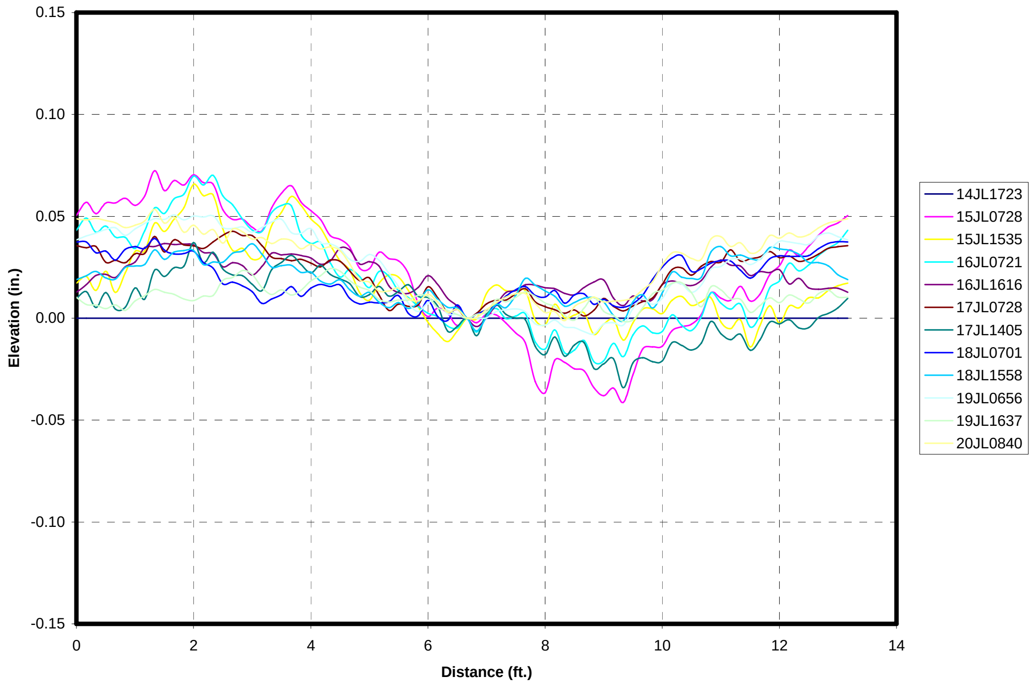


Figure I.55. Level C profiles path 2 – slab 9

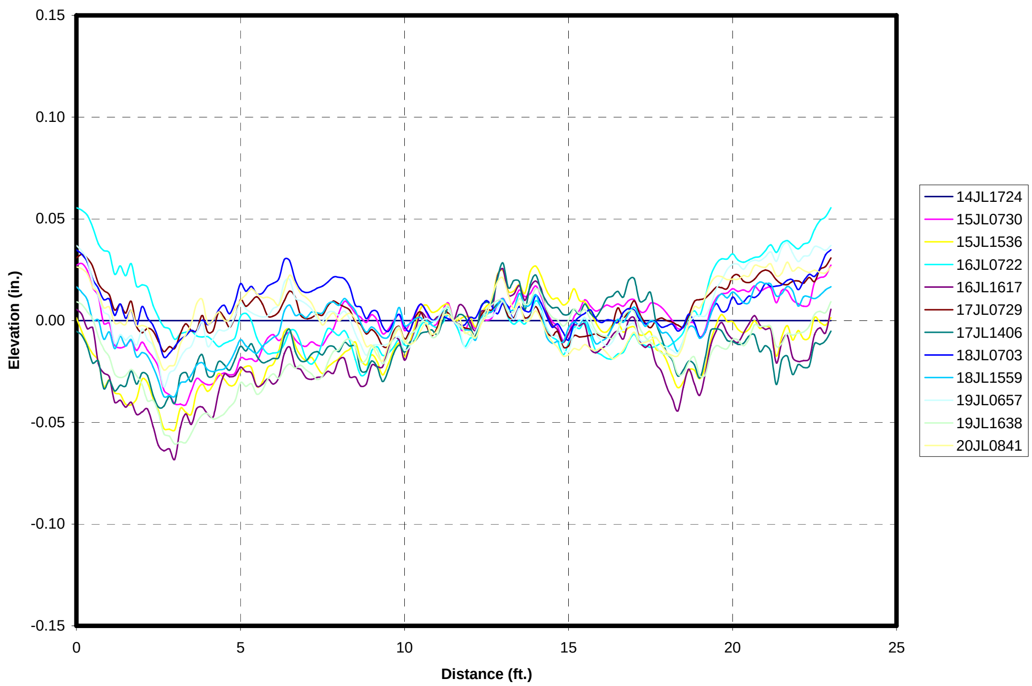


Figure I.56. Level C profiles path 3 – slab 9

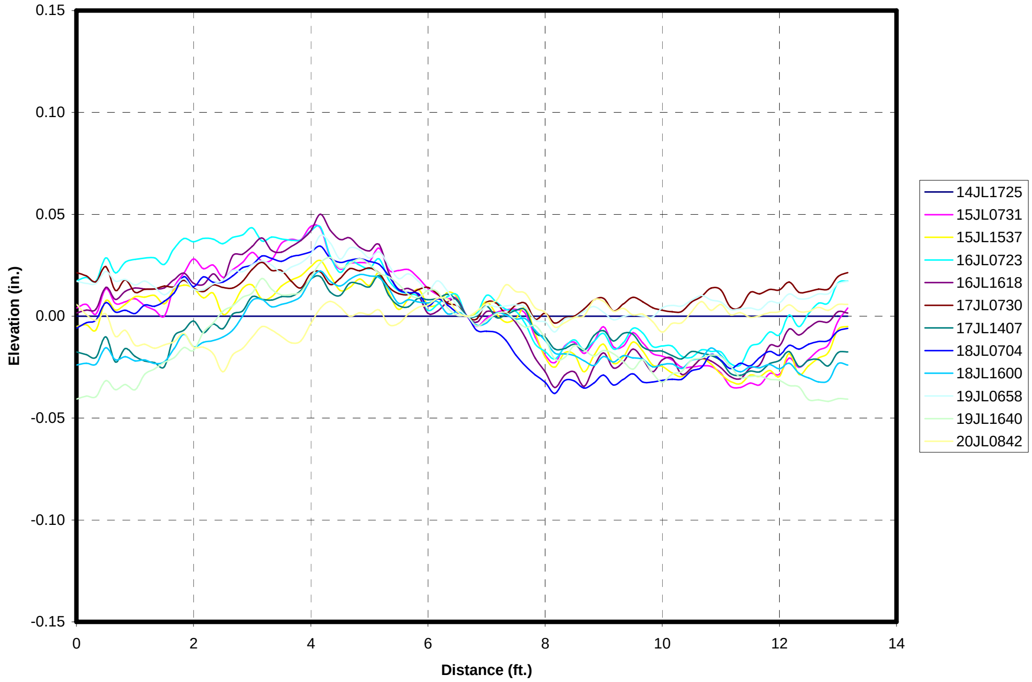


Figure I.57. Level C profiles path 4 – slab 9

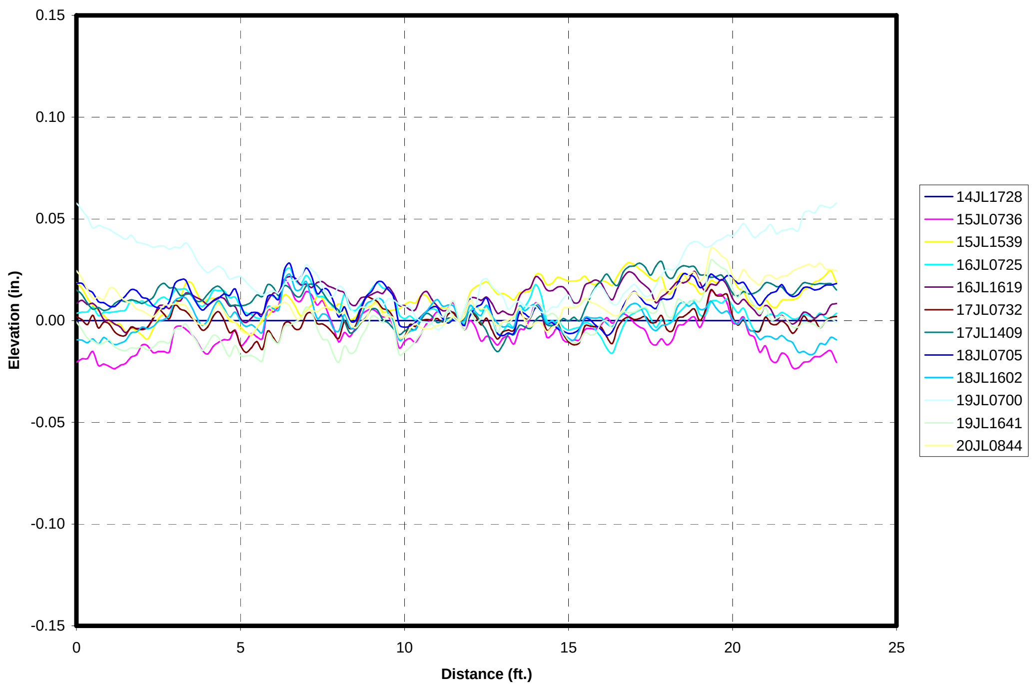


Figure I.58. Level C profiles path 1 – slab 10

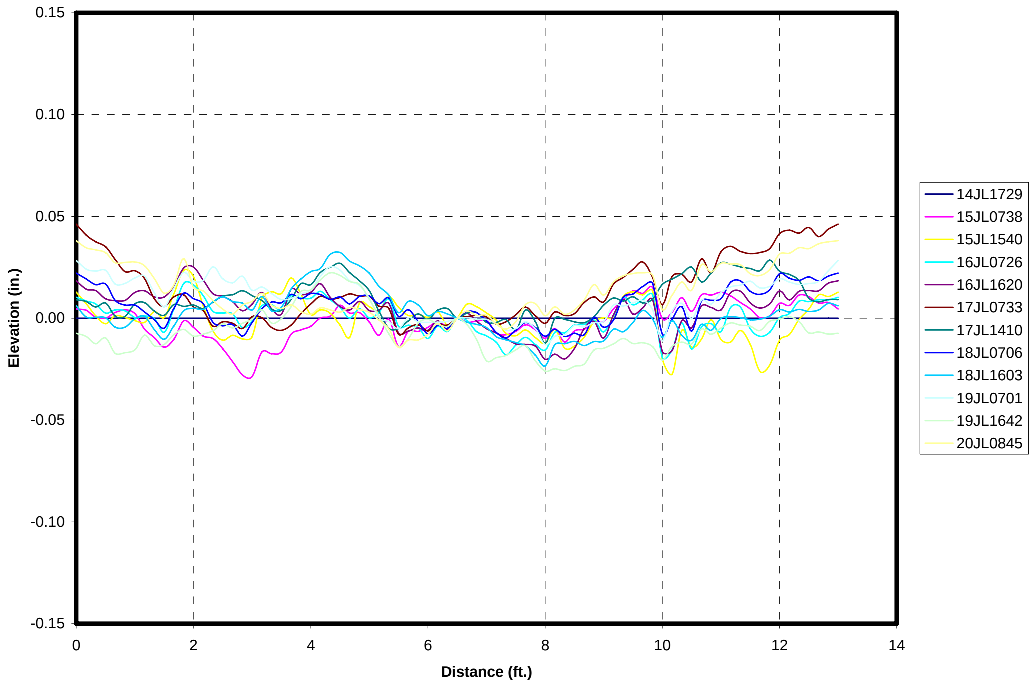


Figure I.59. Level C profiles path 2 – slab 10

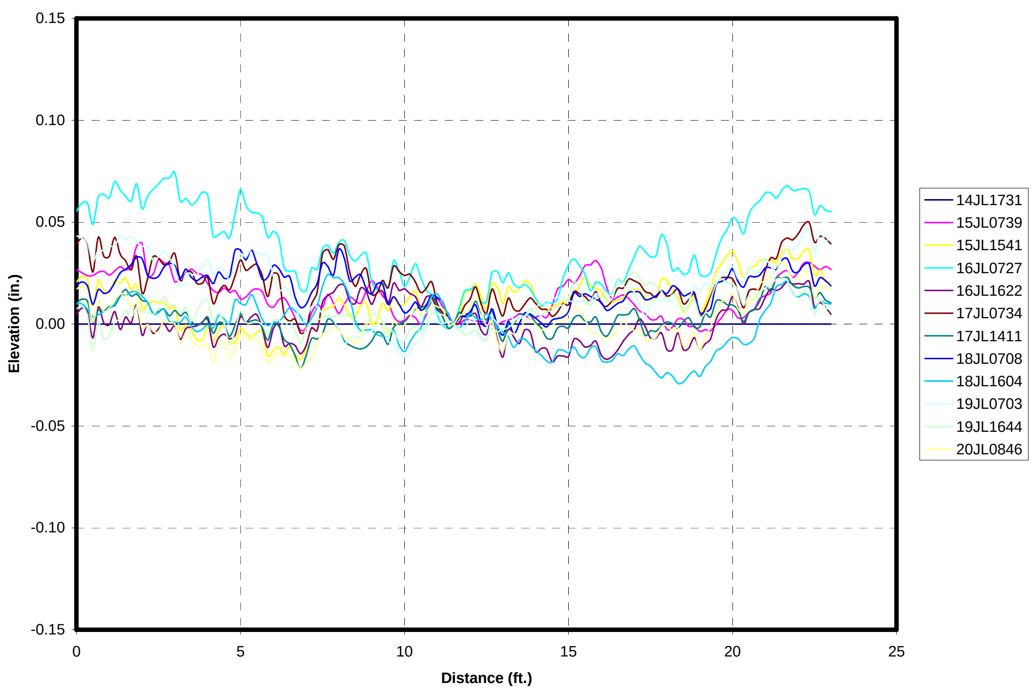


Figure I.60. Level C profiles path 3 – slab 10

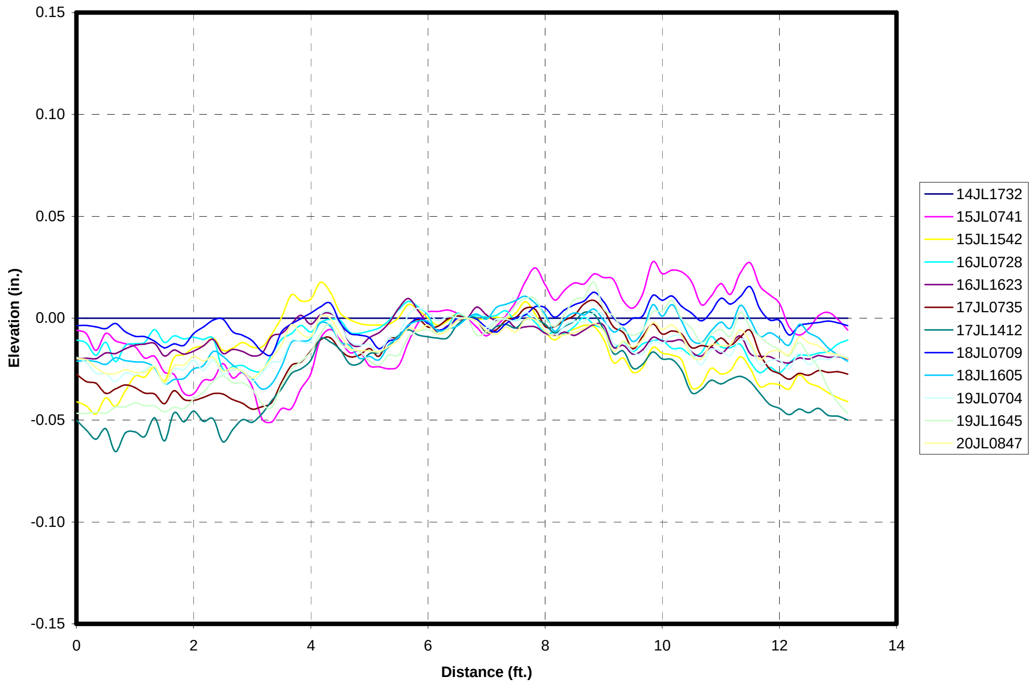


Figure I.61. Level C profiles path 4 – slab 10

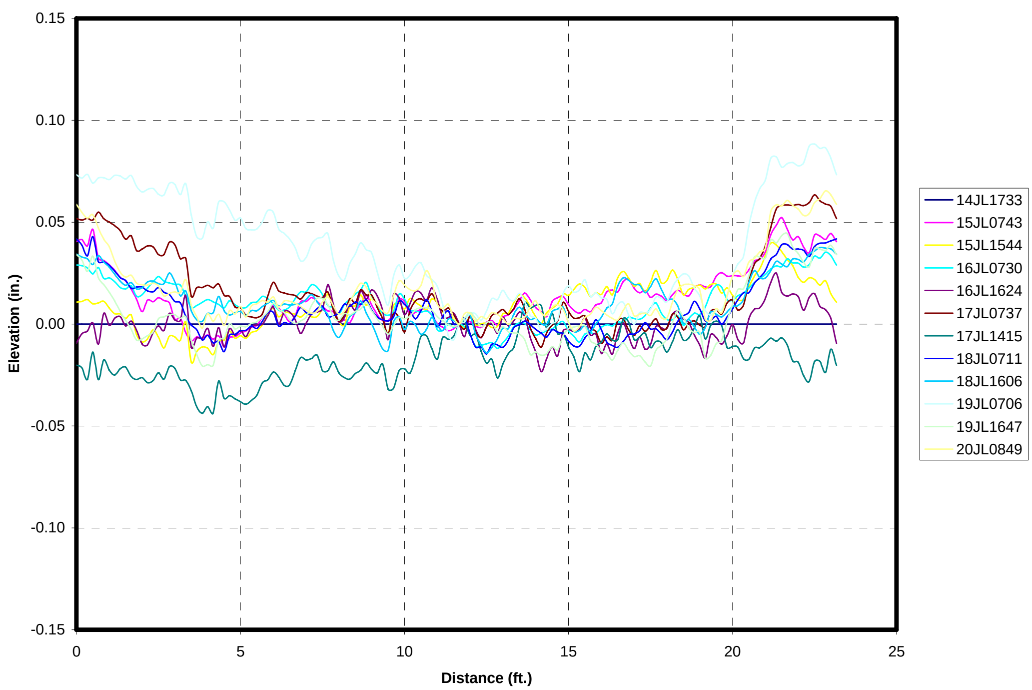


Figure I.62. Level C profiles path 1 – slab 11

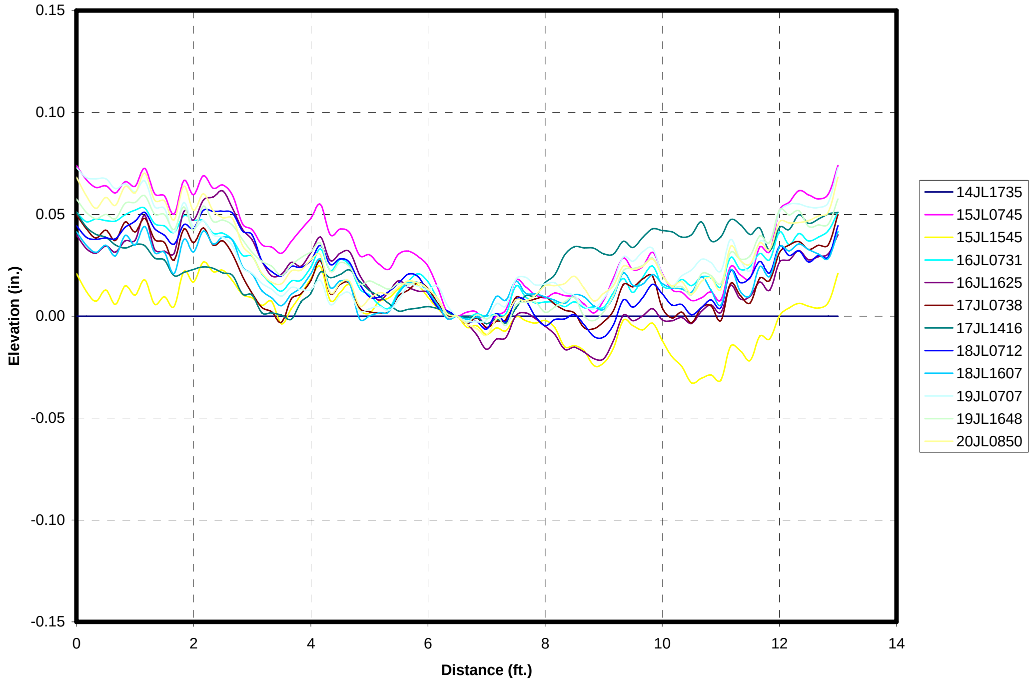


Figure I.63. Level C profiles path 2 – slab 11

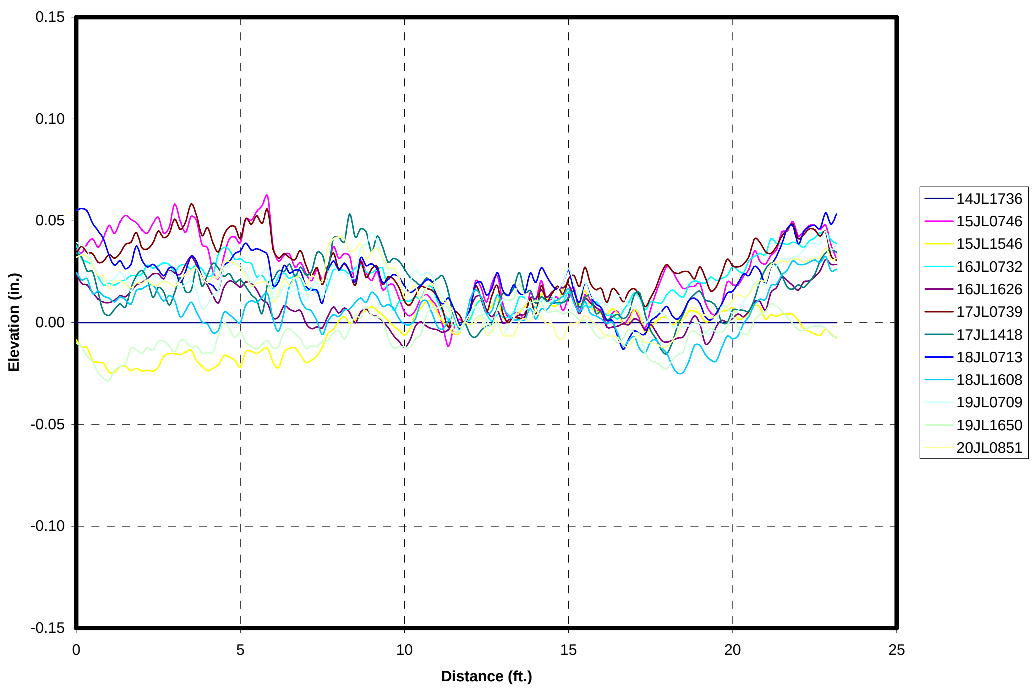


Figure I.64. Level C profiles path 3 – slab 11

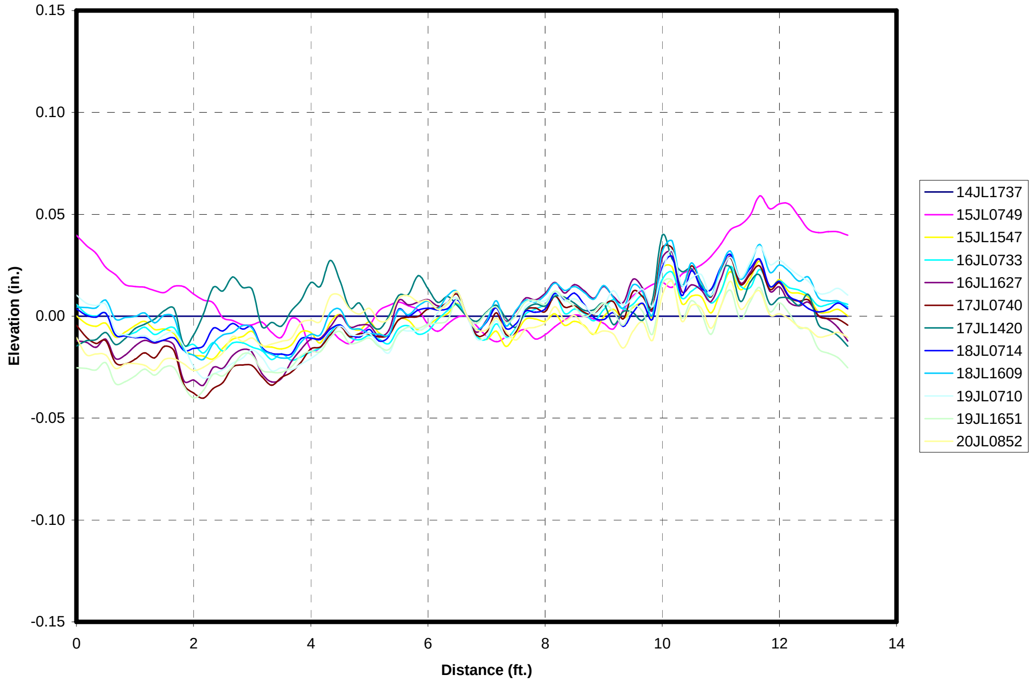


Figure I.65. Level C profiles path 4 – slab 11

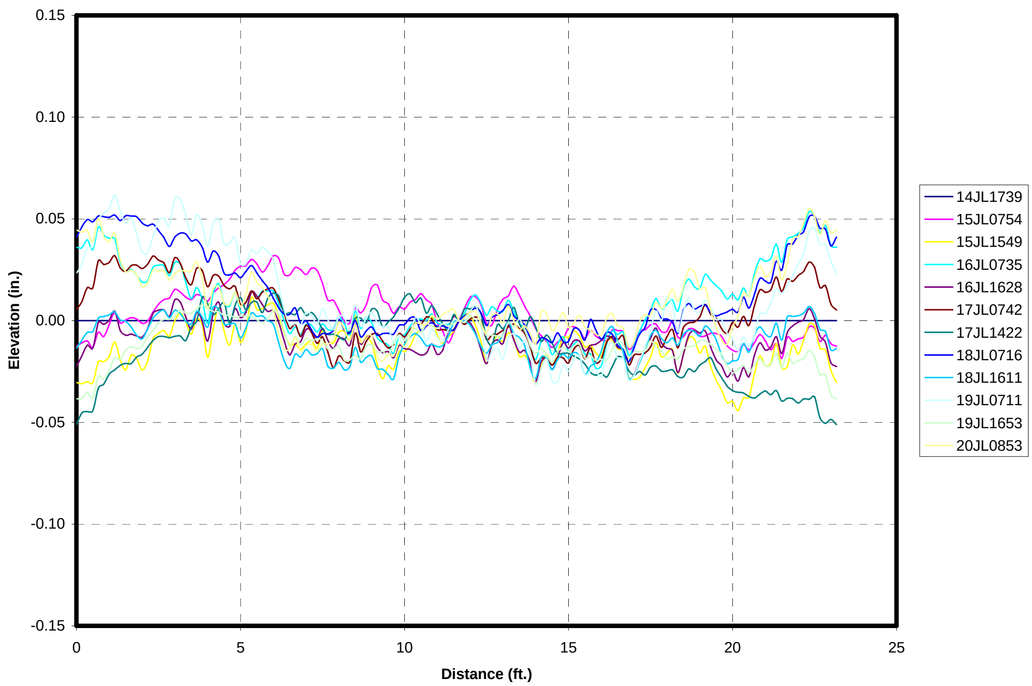


Figure I.66. Level C profiles path 1 – slab 12

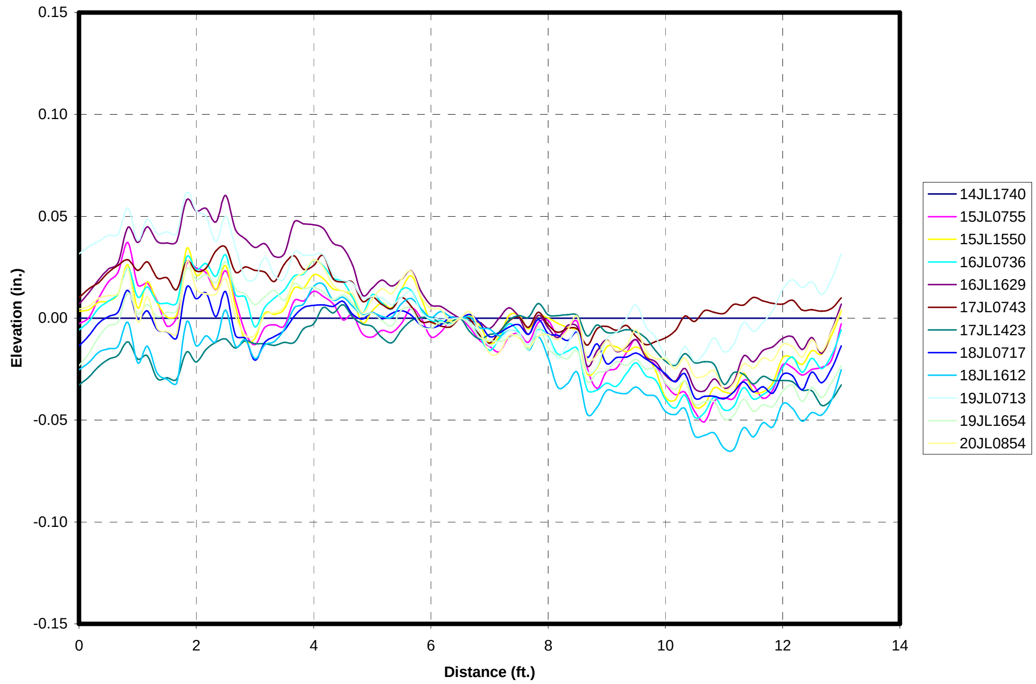


Figure I.67. Level C profiles path 2 – slab 12

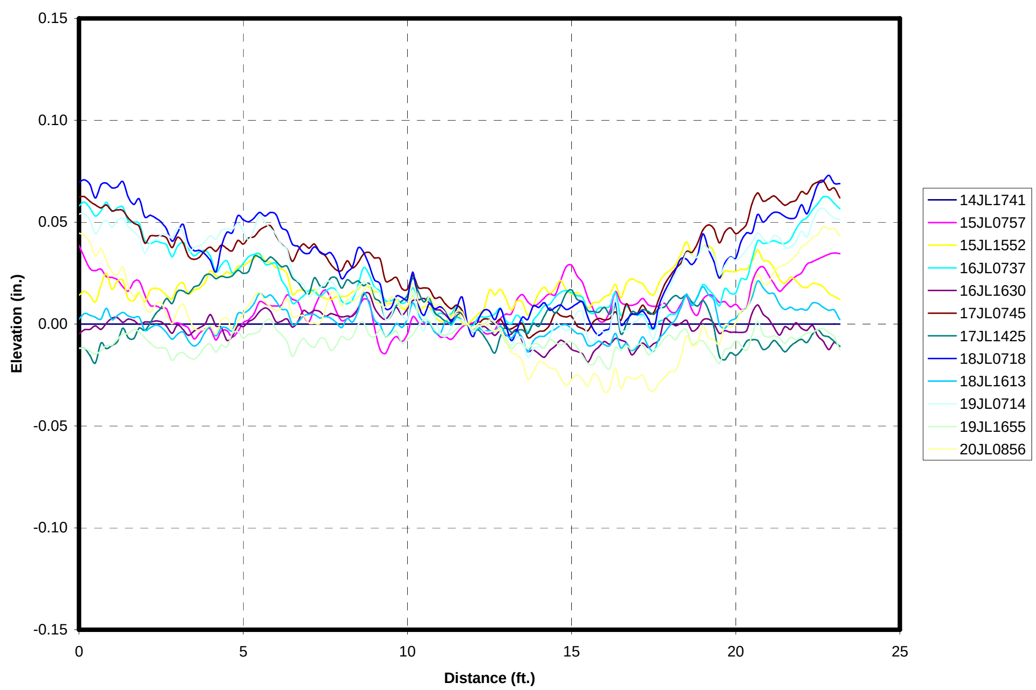


Figure I.68. Level C profiles path 3 – slab 12

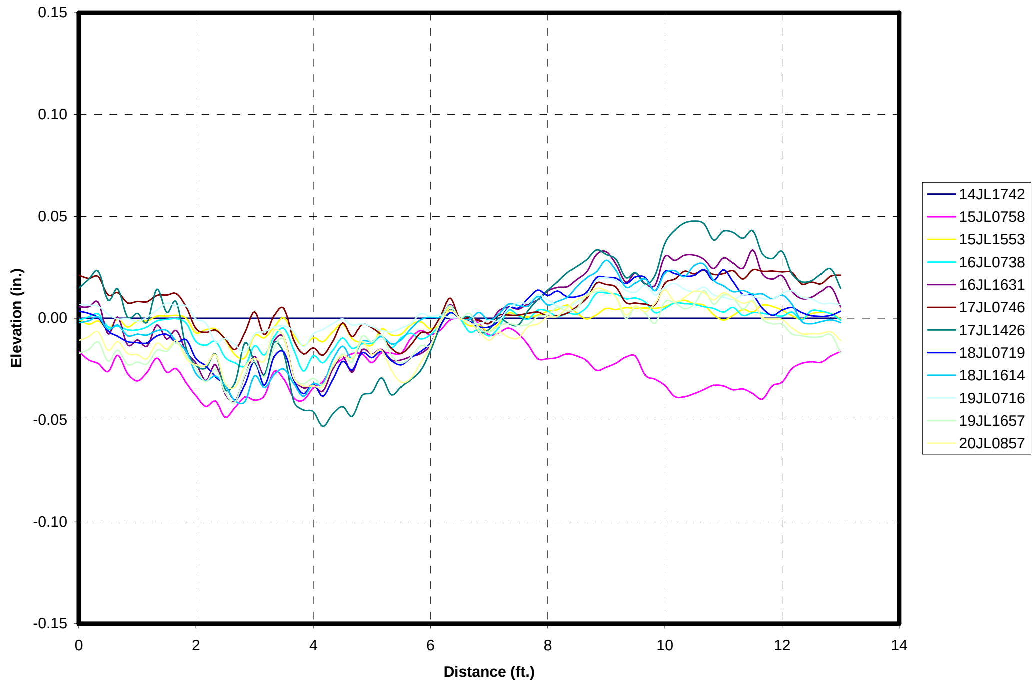


Figure I.69. Level C profiles path 4 – slab 12

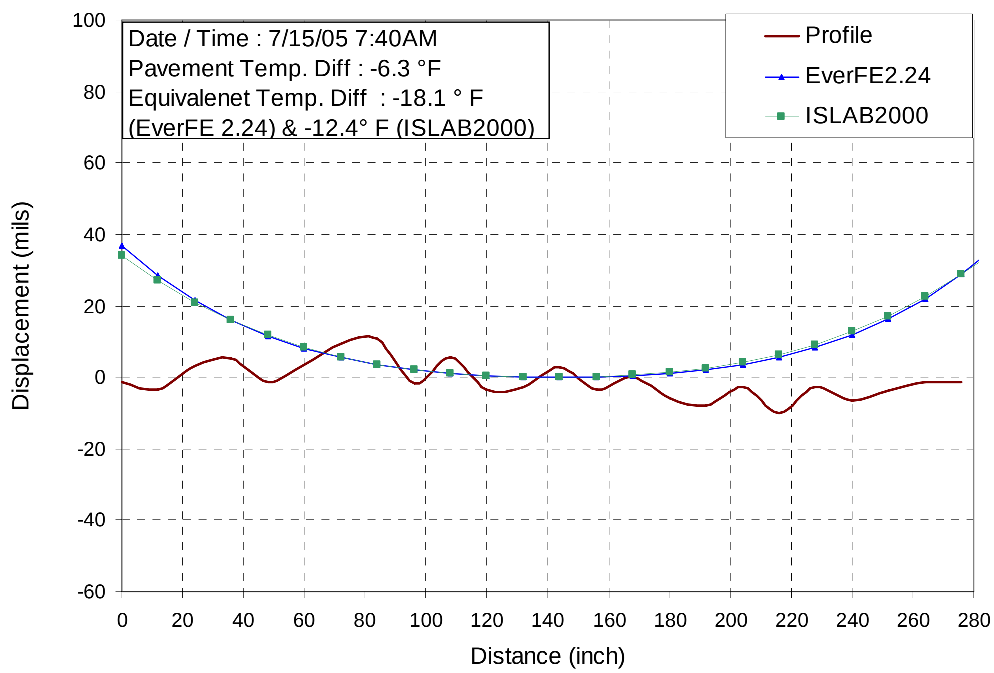


Figure I.70. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 15 morning

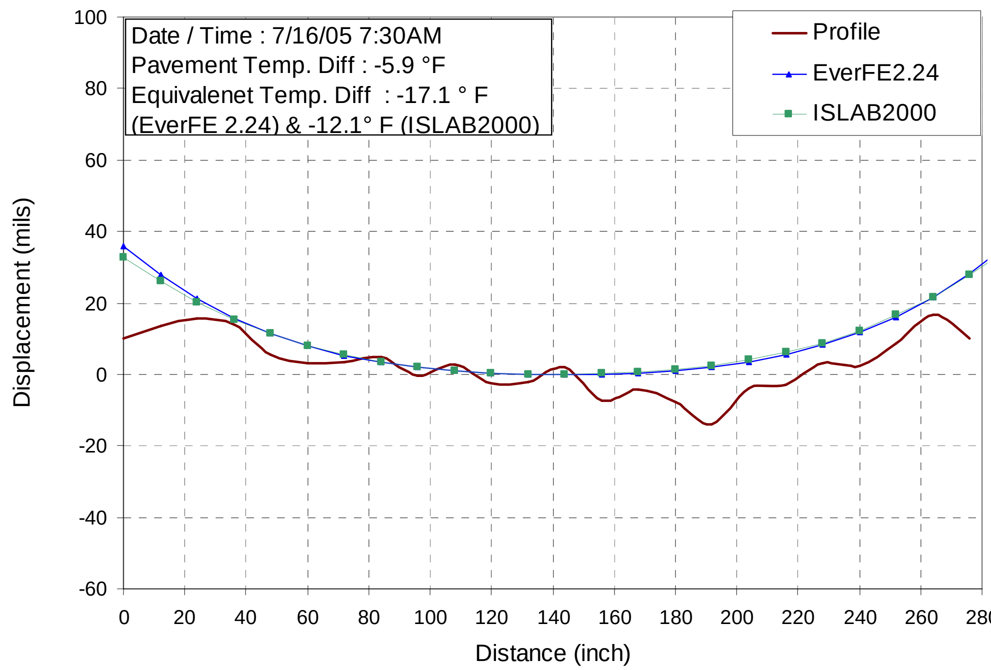


Figure I.71. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 16 morning

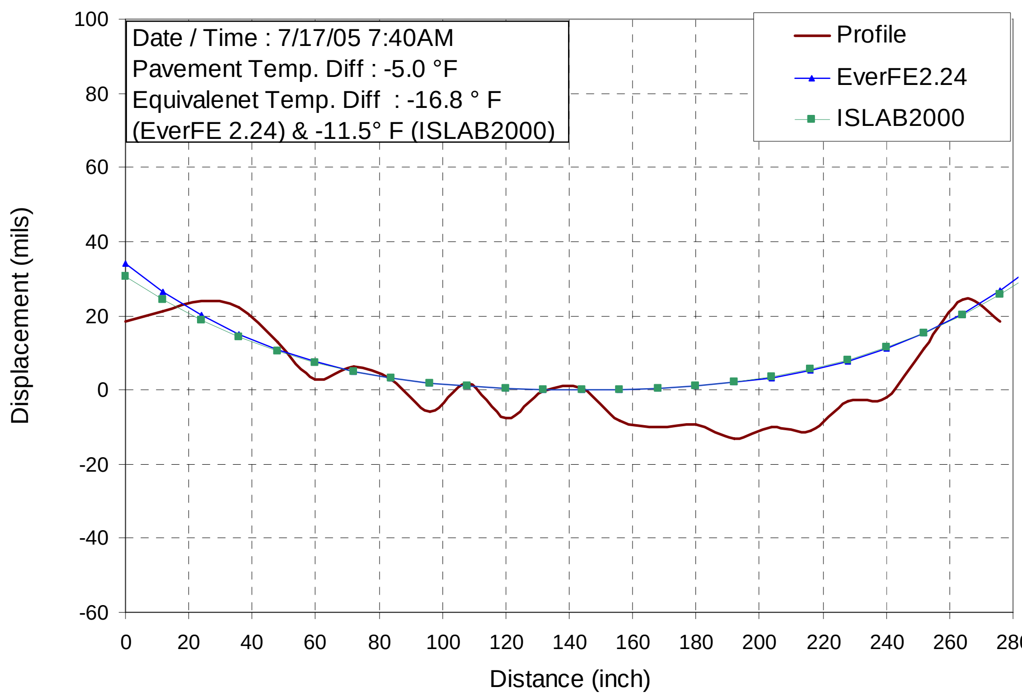


Figure I.72. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 17 morning

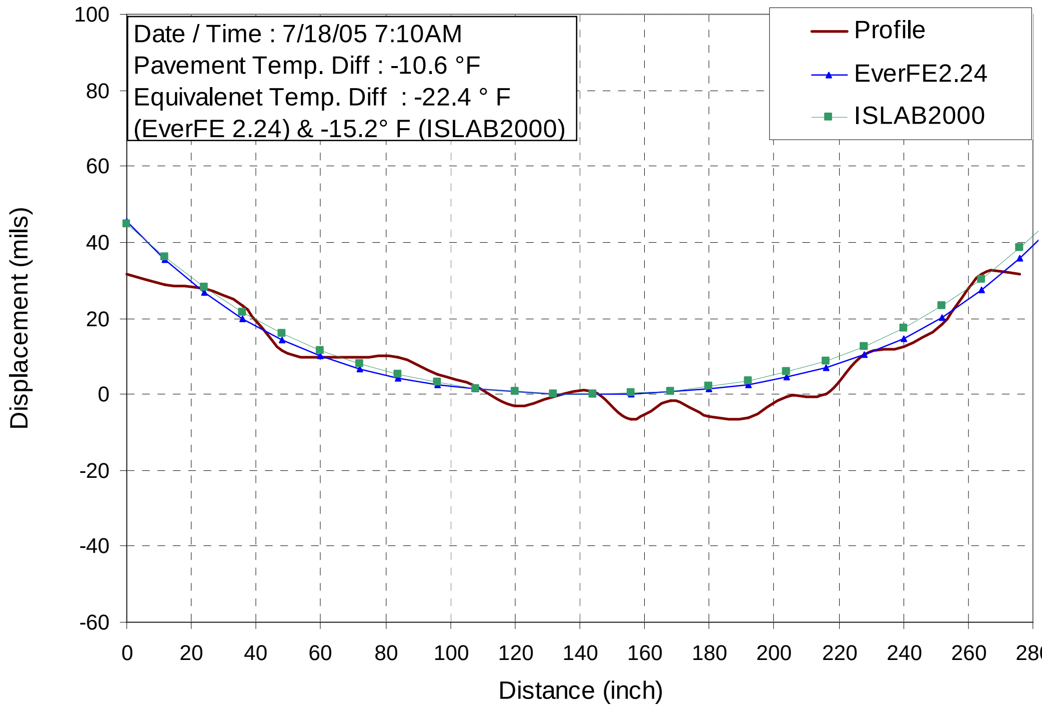


Figure I.73. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 18 morning

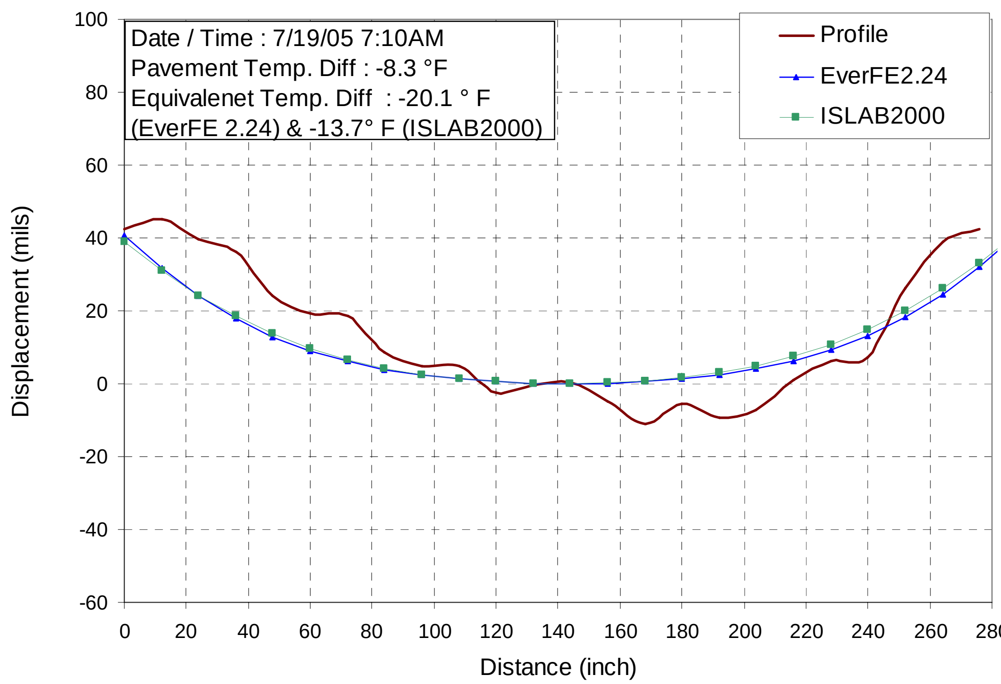


Figure I.74. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 19 morning

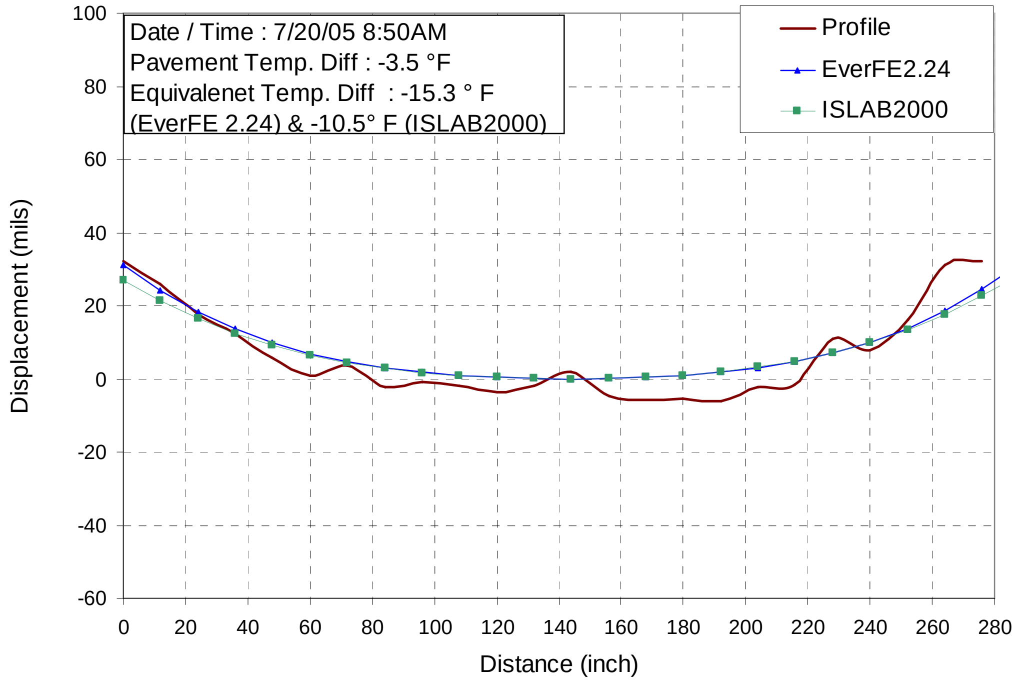


Figure I.75. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 20 morning

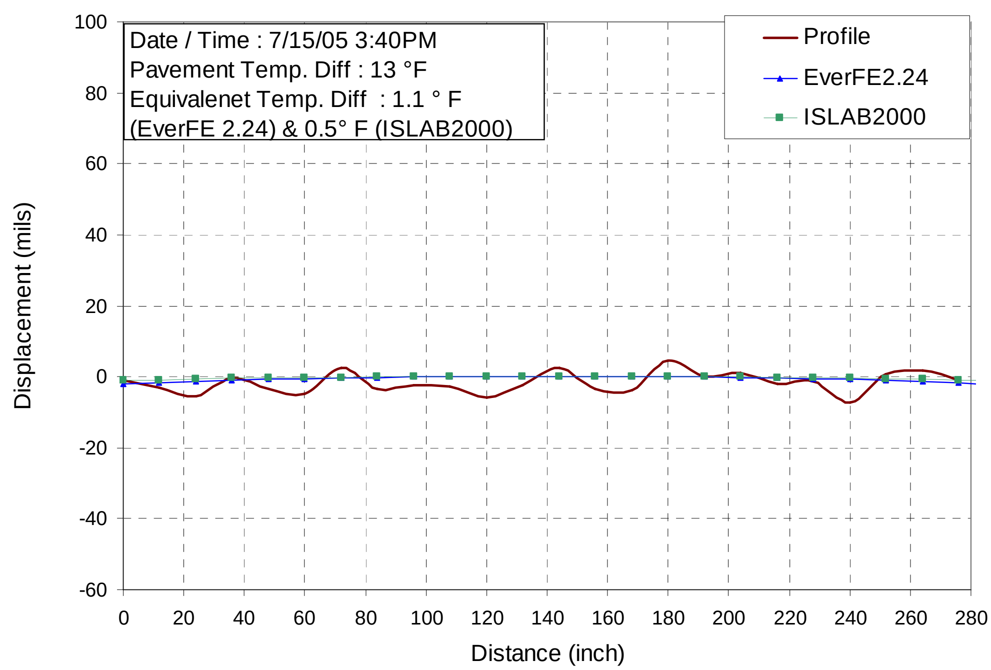


Figure I.76. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 15 afternoon

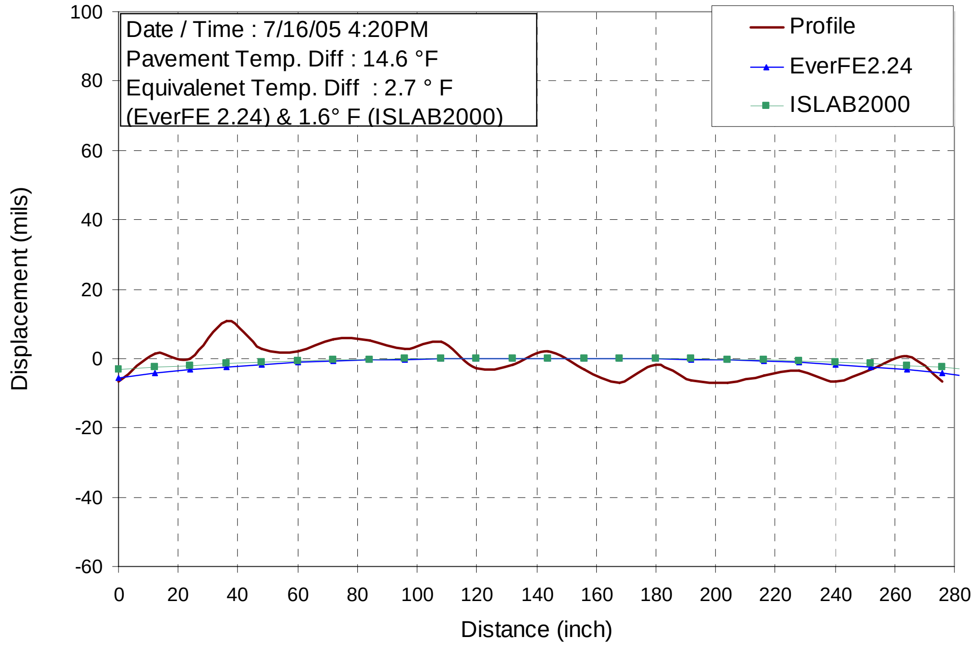


Figure I.77. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 16 afternoon

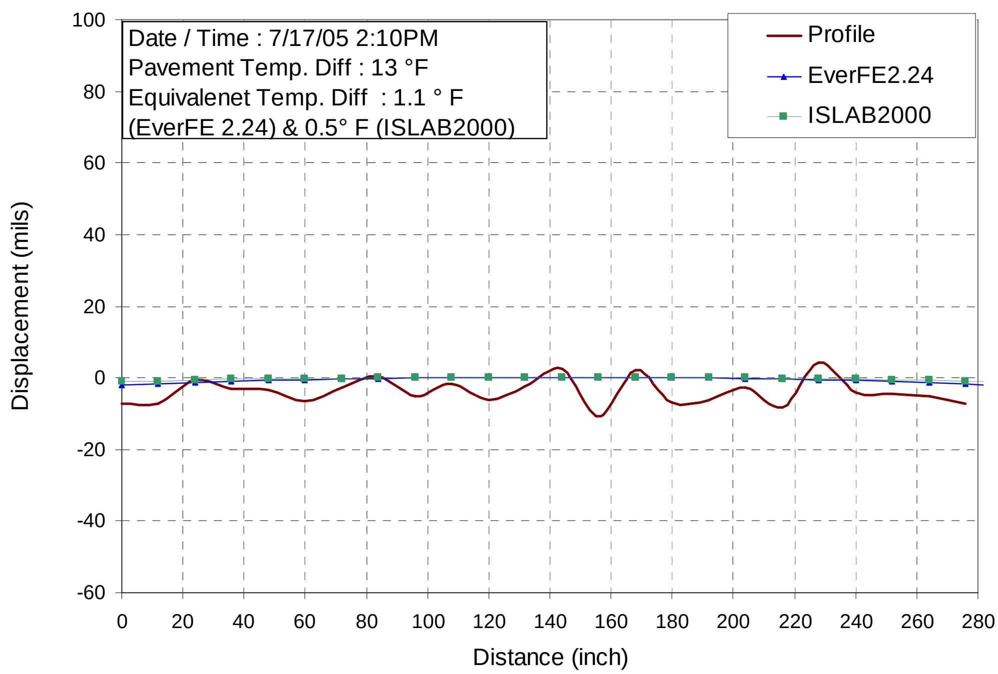


Figure I.78. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 17 afternoon

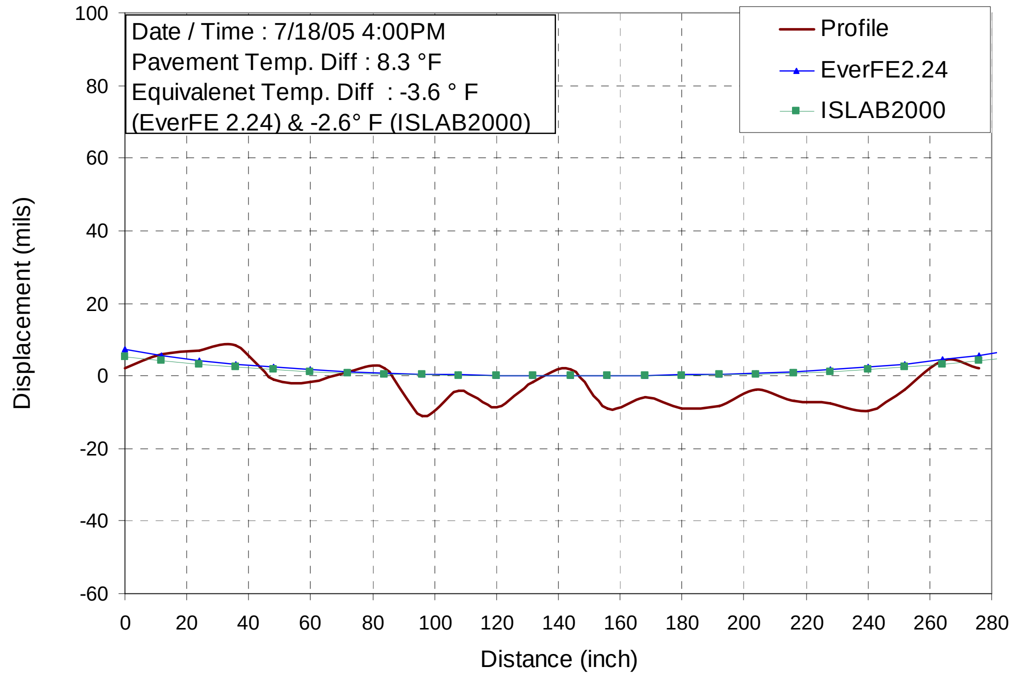


Figure I.79. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 18 afternoon

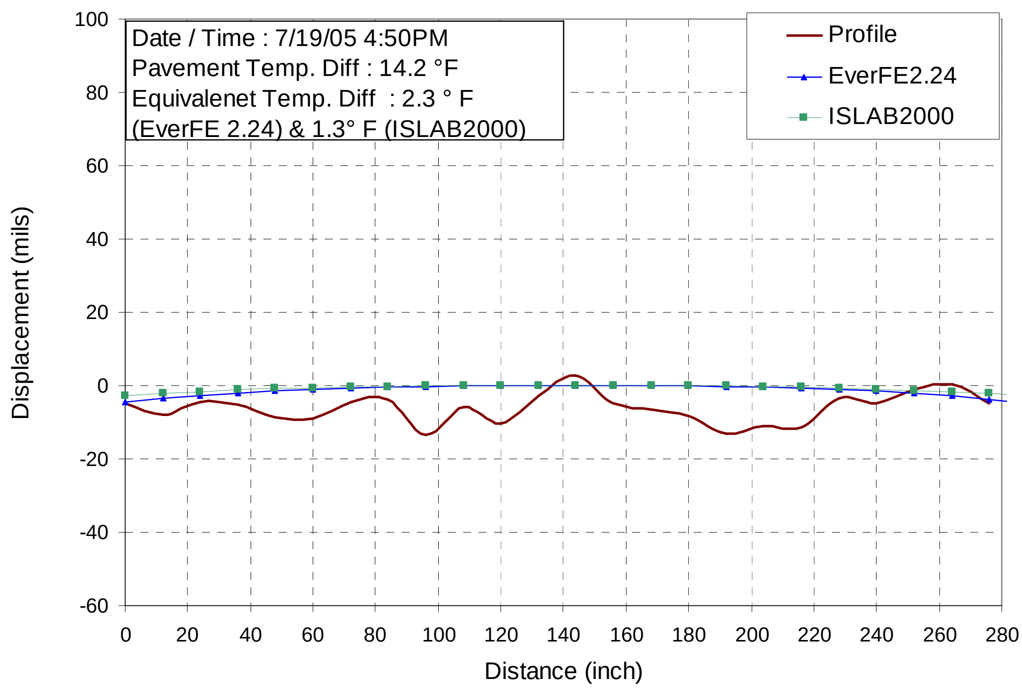


Figure I.80. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 1 (diagonal direction) – July 19 afternoon

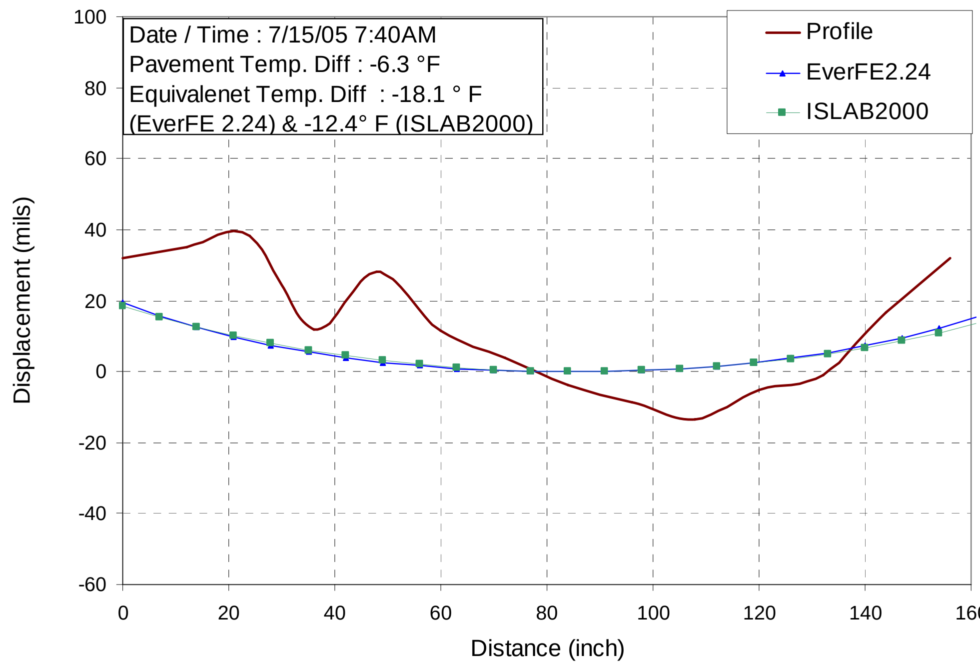


Figure I.81. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 15 morning

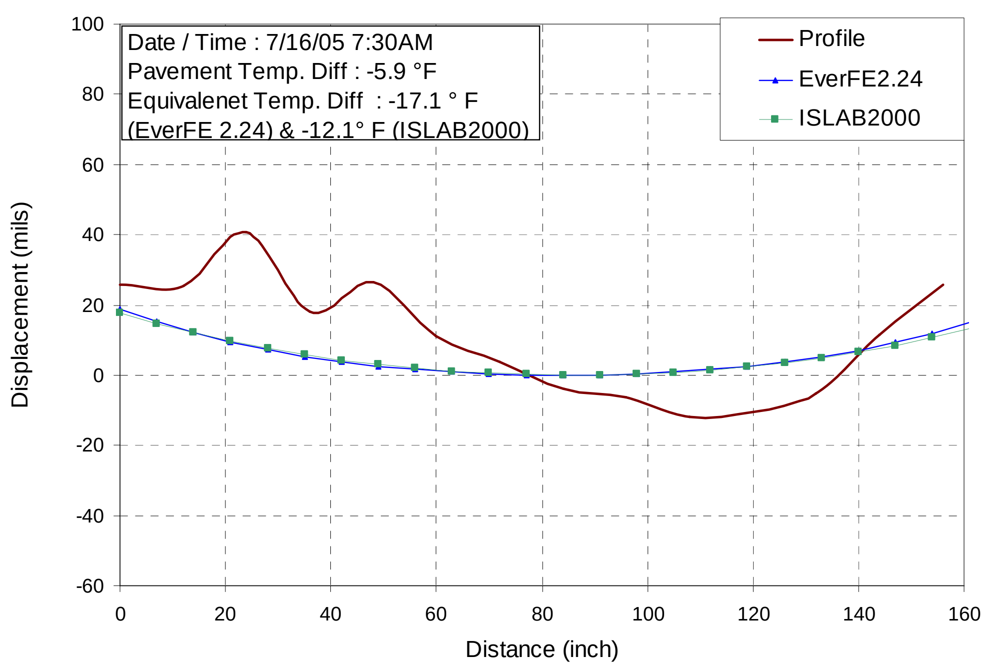


Figure I.82. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 16 morning

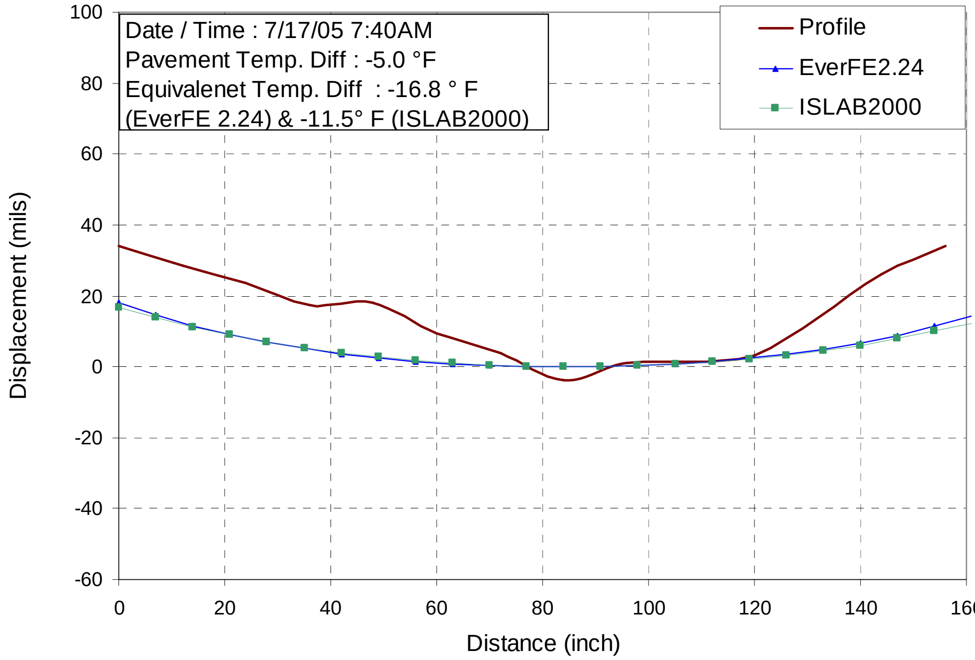


Figure I.83. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 17 morning

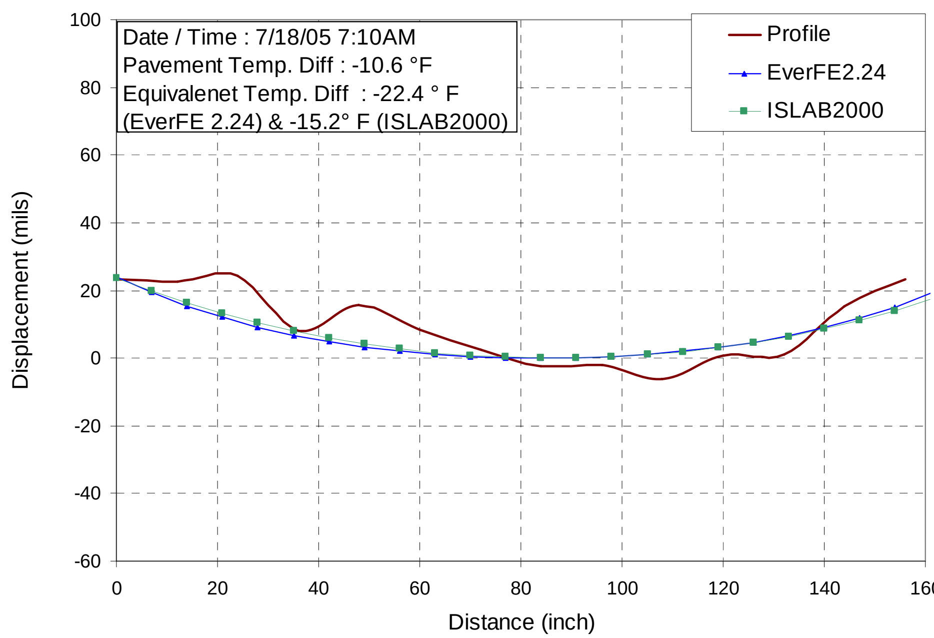


Figure I.84. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 18 morning

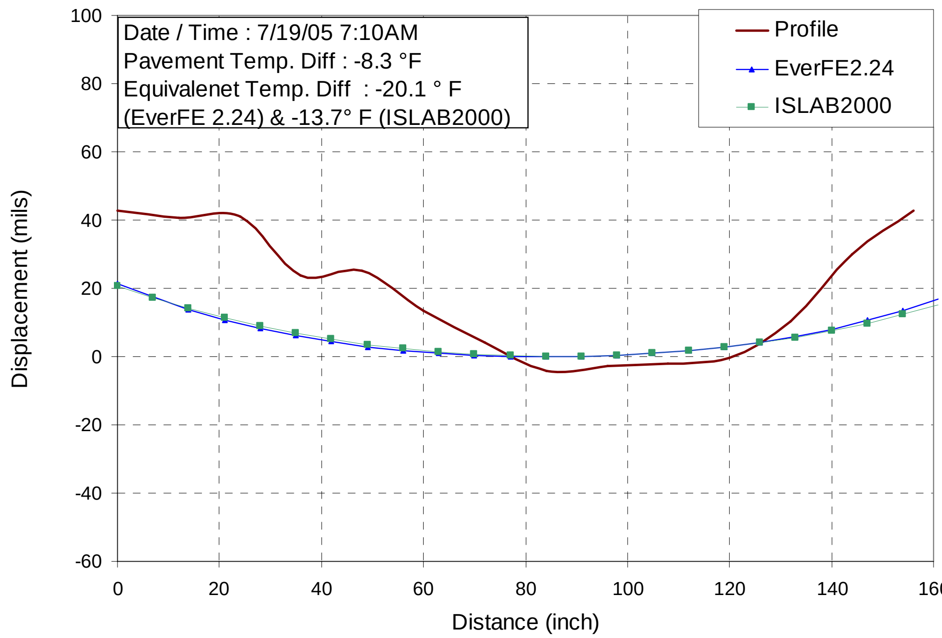


Figure I.85. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 19 morning

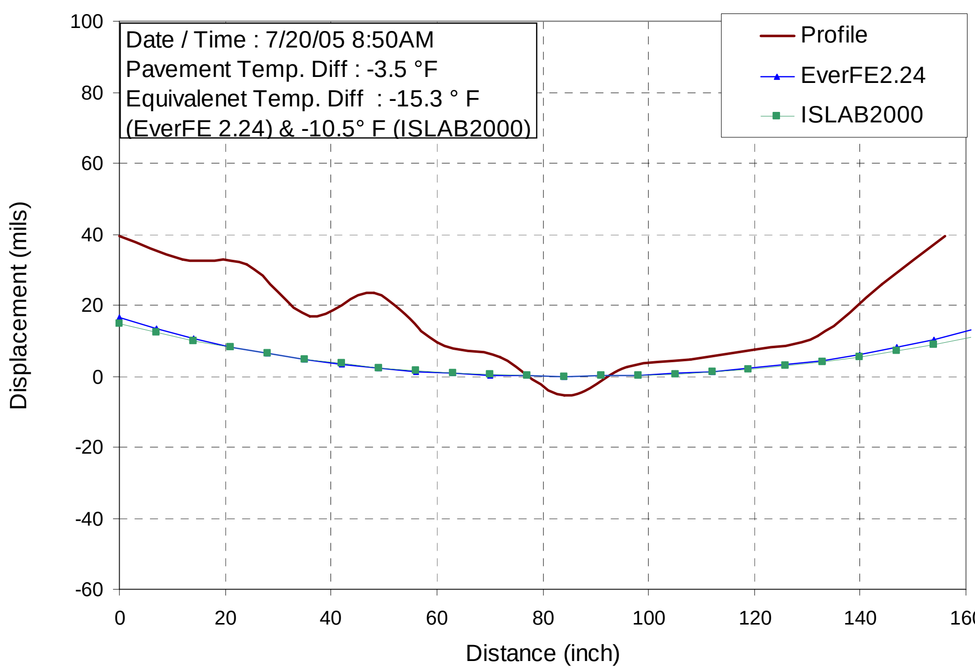


Figure I.86. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 20 morning

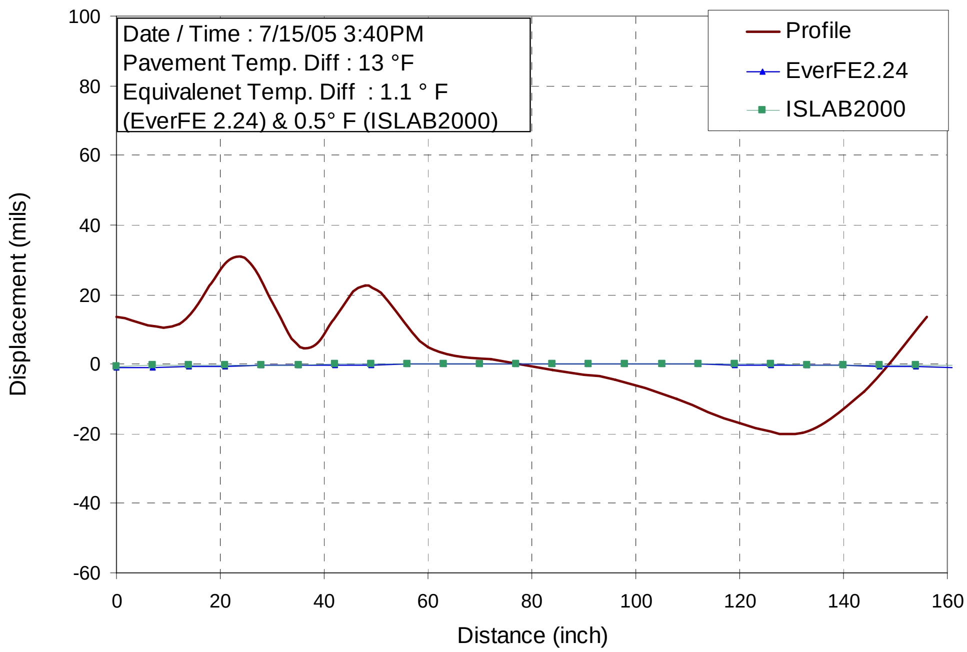


Figure I.87. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 15 afternoon

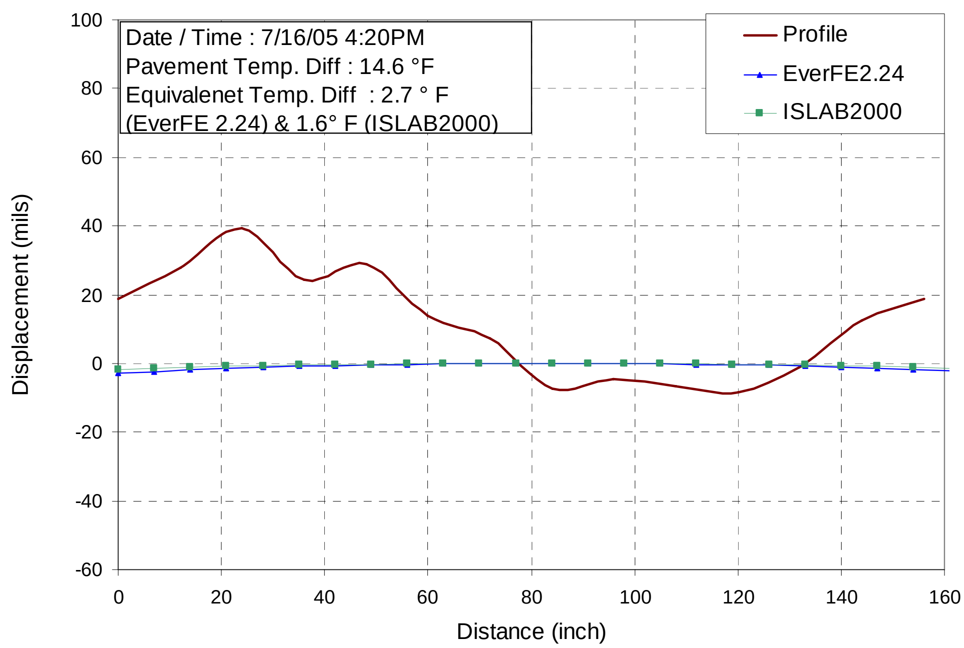


Figure I.88. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 16 afternoon

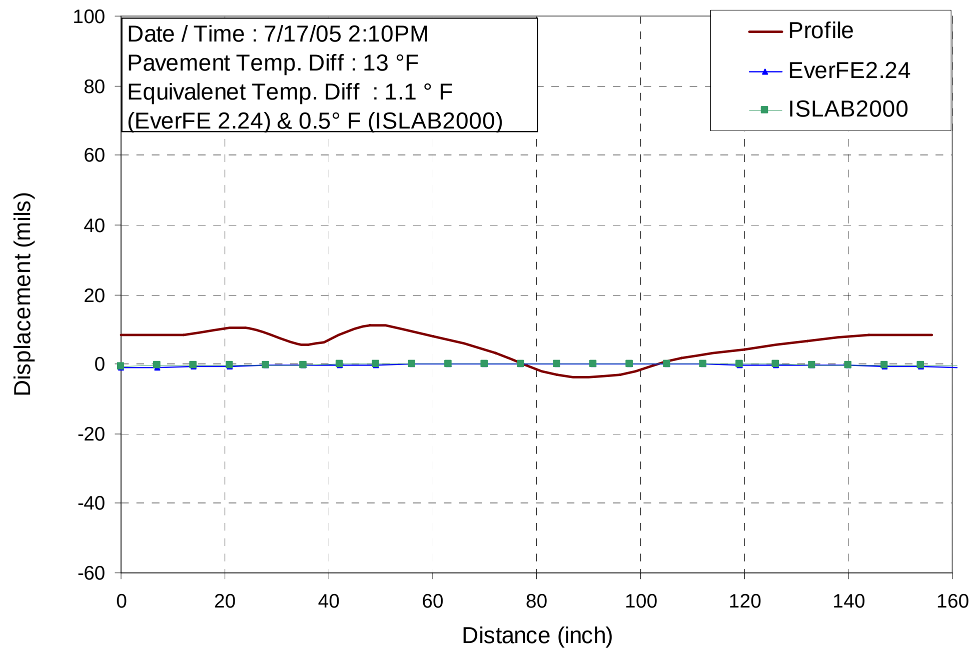


Figure I.89. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 17 afternoon

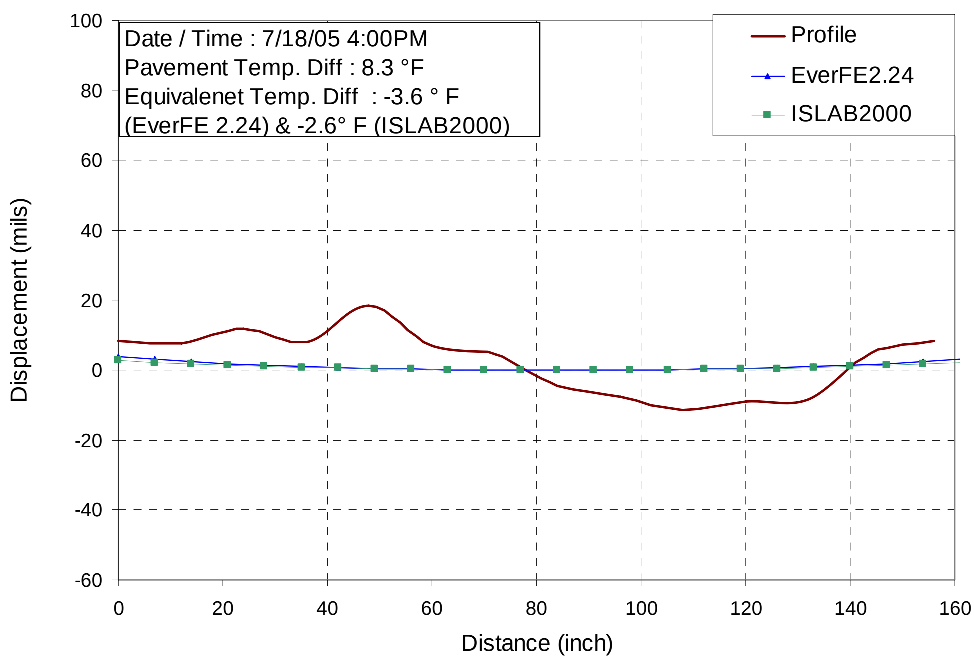


Figure I.90. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 18 afternoon

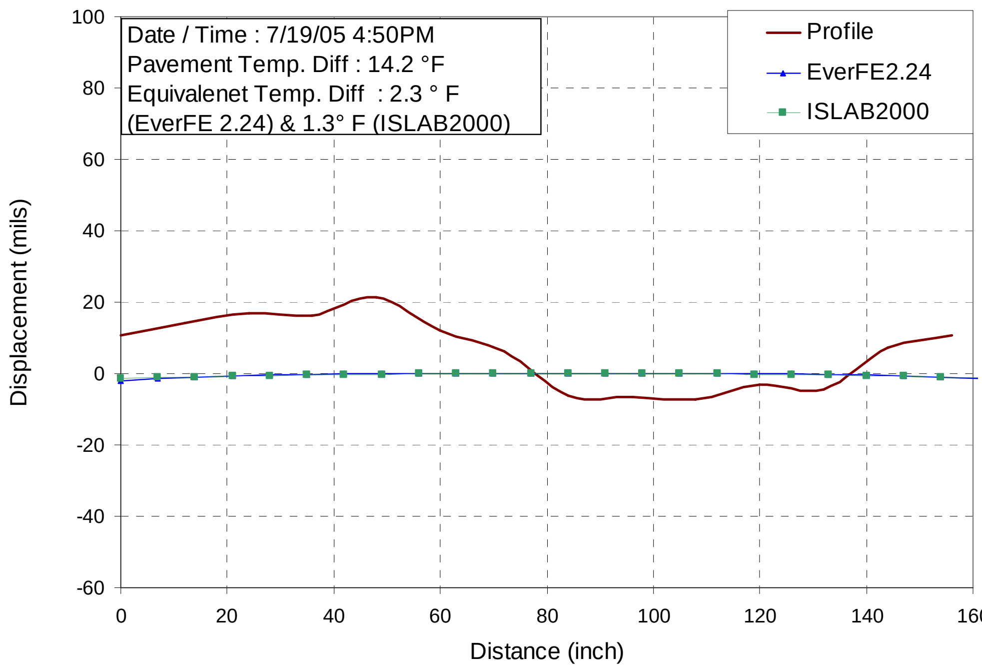


Figure I.91. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 2 (transverse direction) – July 19 afternoon

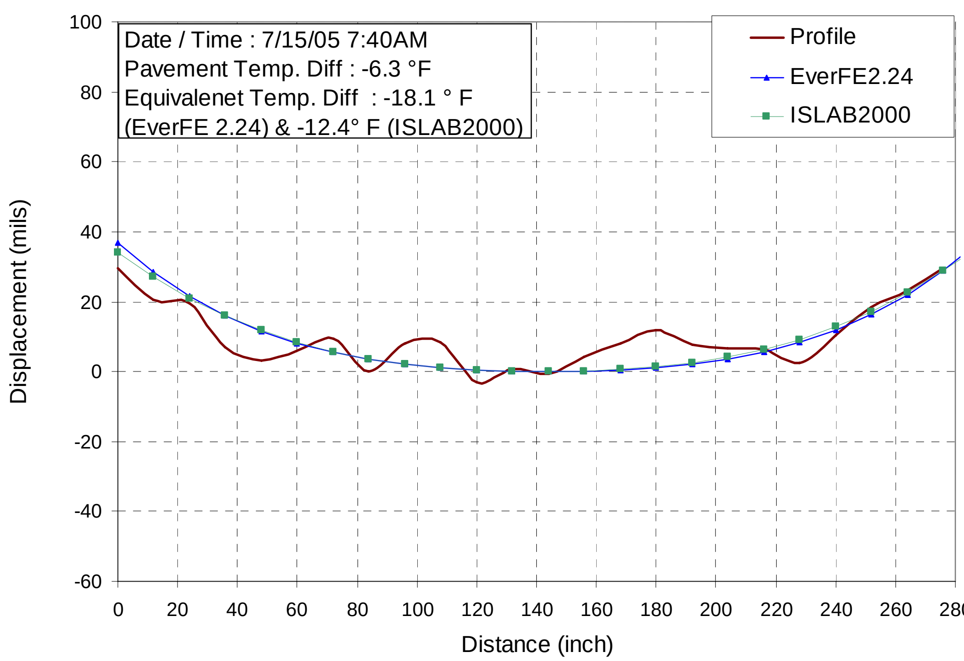


Figure I.92. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 15 morning

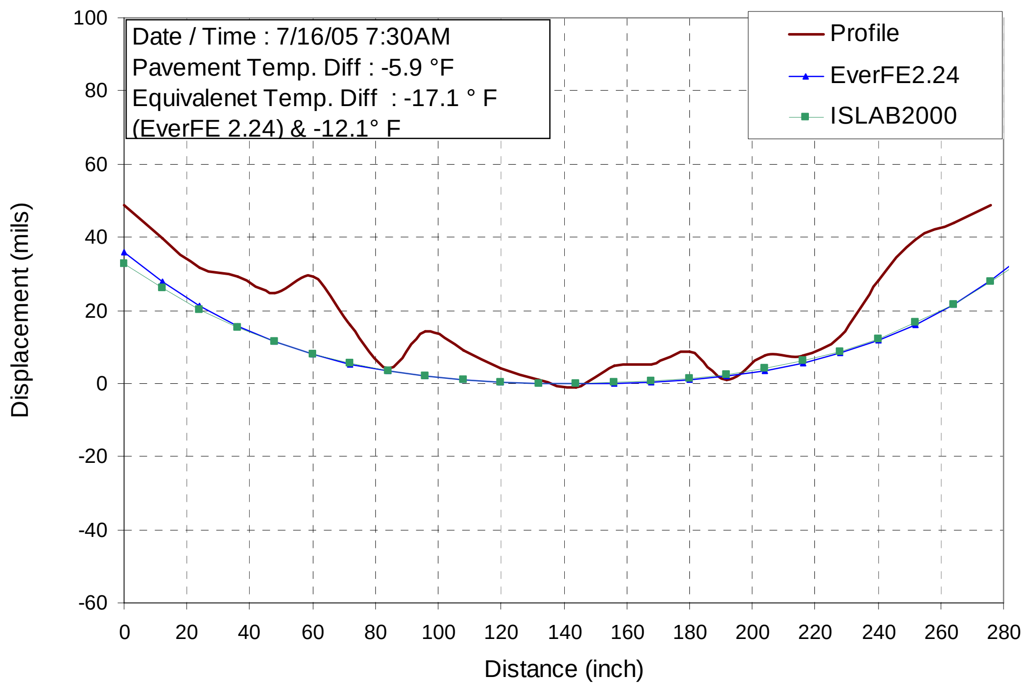


Figure I.93. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 16 morning

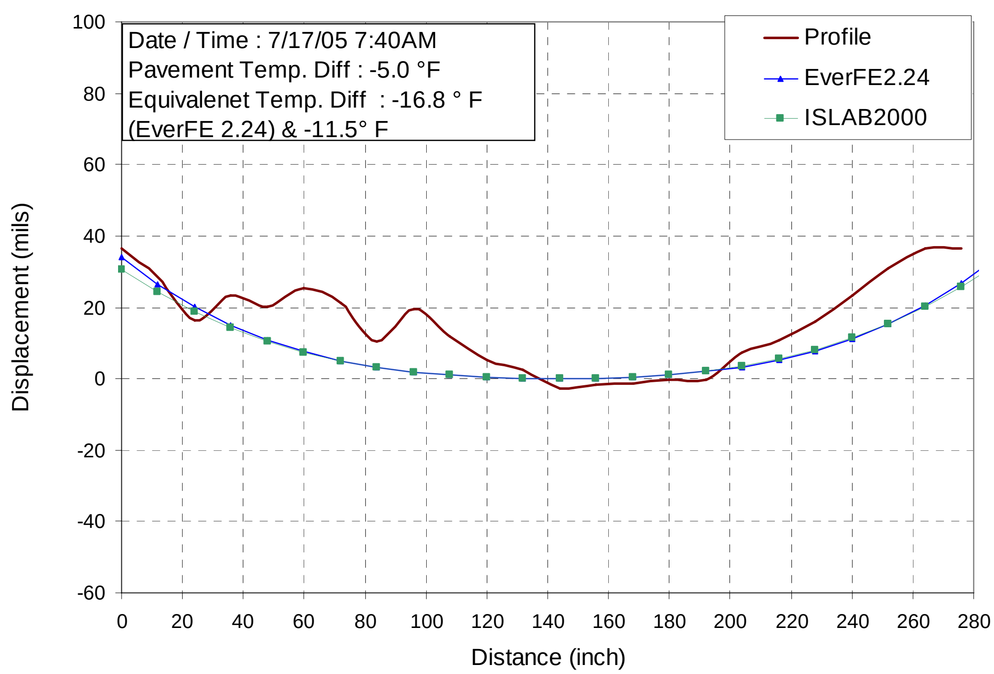


Figure I.94. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 17 morning

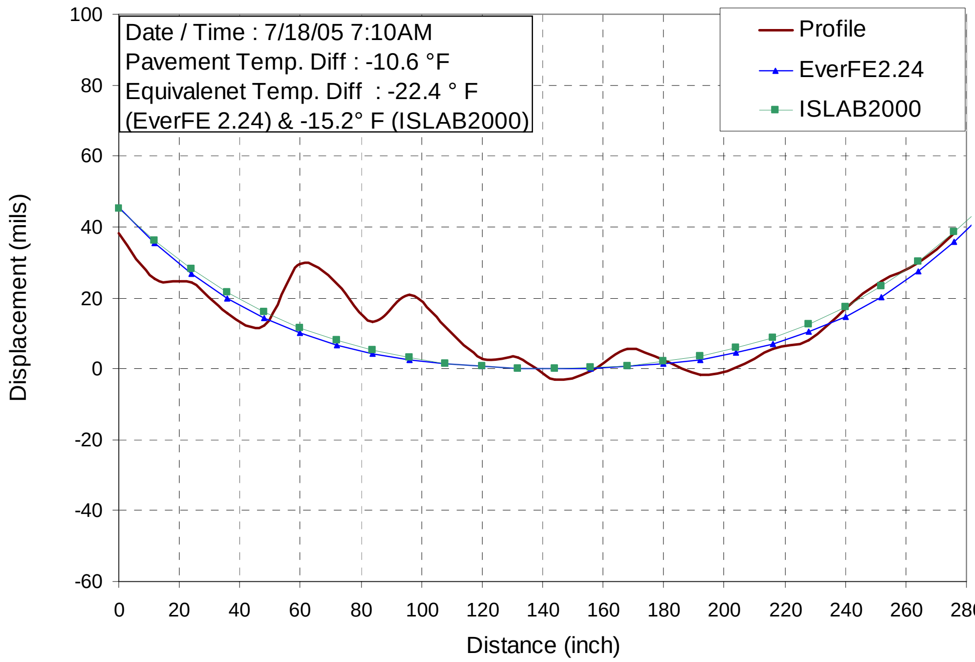


Figure I.95. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 18 morning

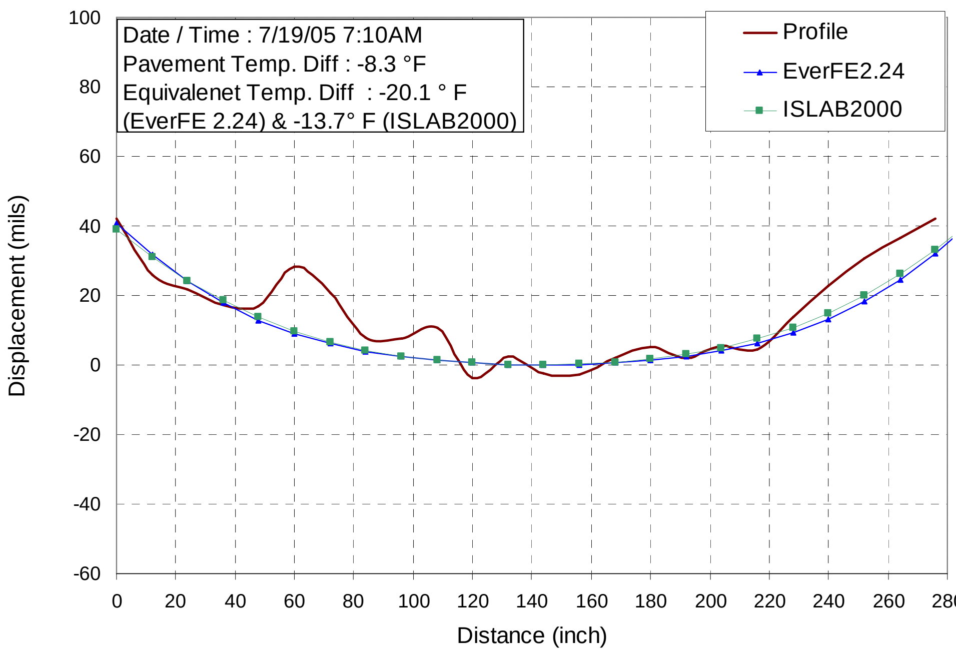


Figure I.96. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 19 morning

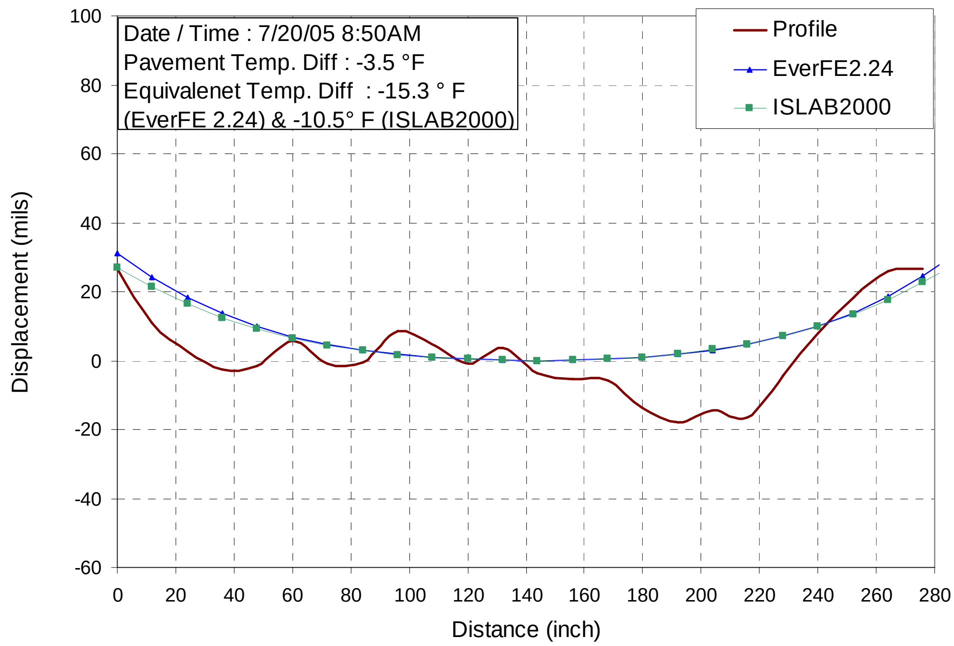


Figure I.97. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 20 morning

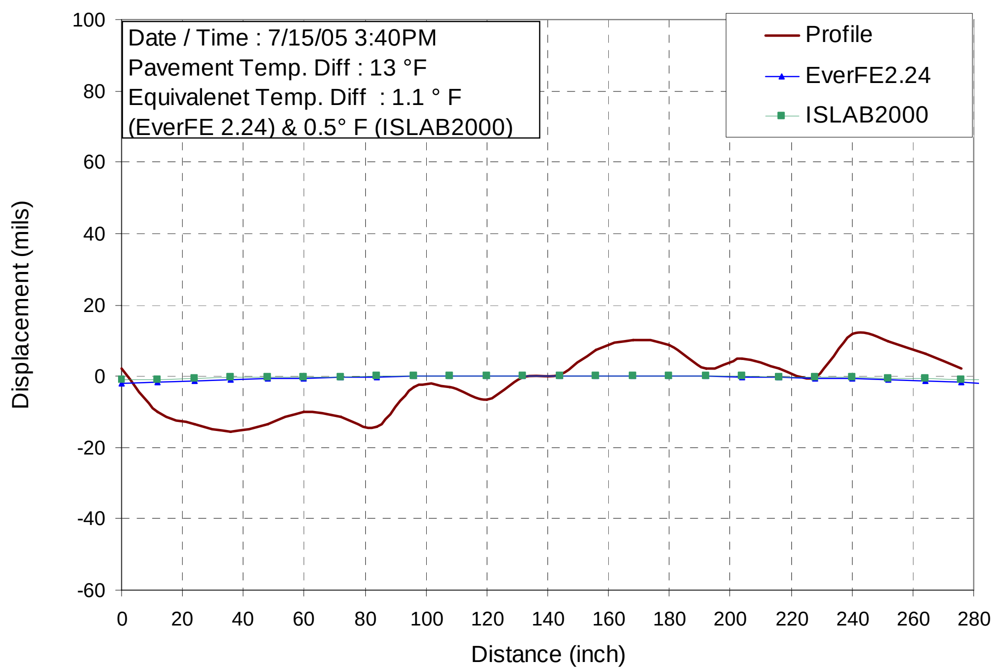


Figure I.98. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 15 afternoon

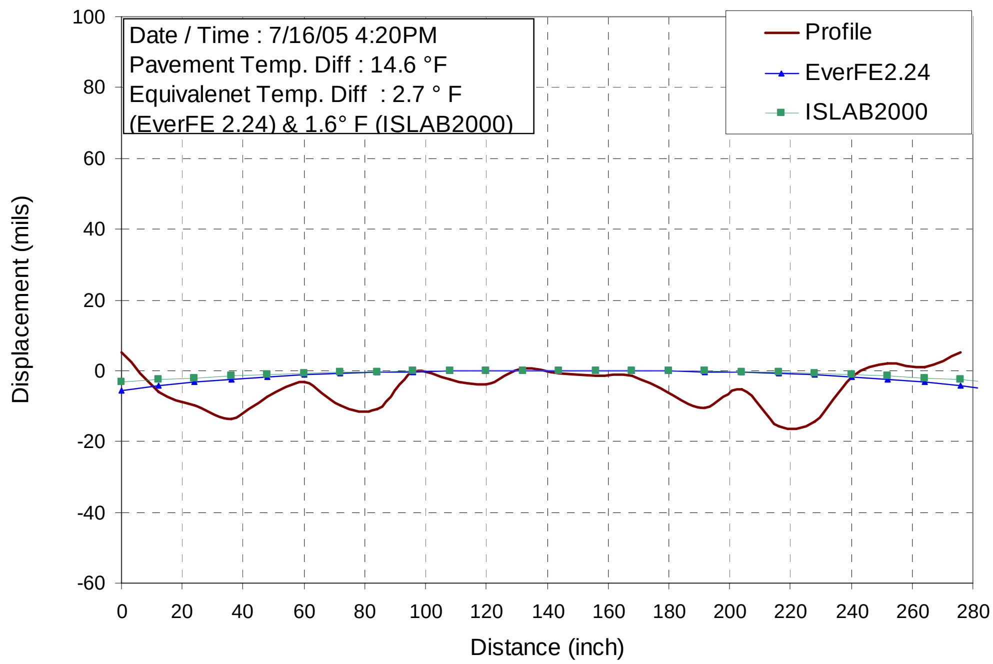


Figure I.99. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 16 afternoon

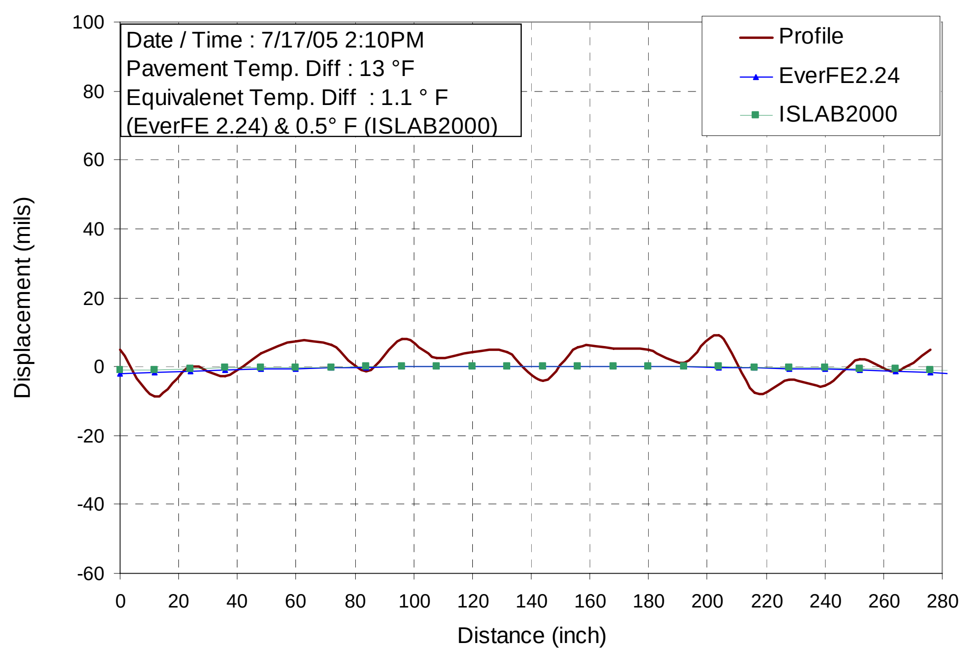


Figure I.100. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 17 afternoon

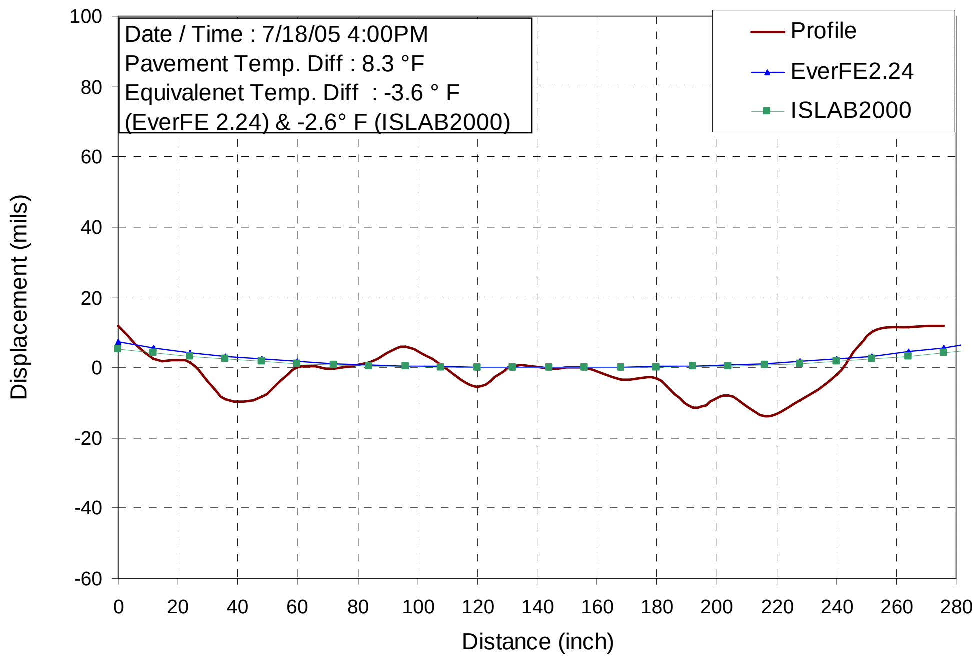


Figure I.101. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 18 afternoon

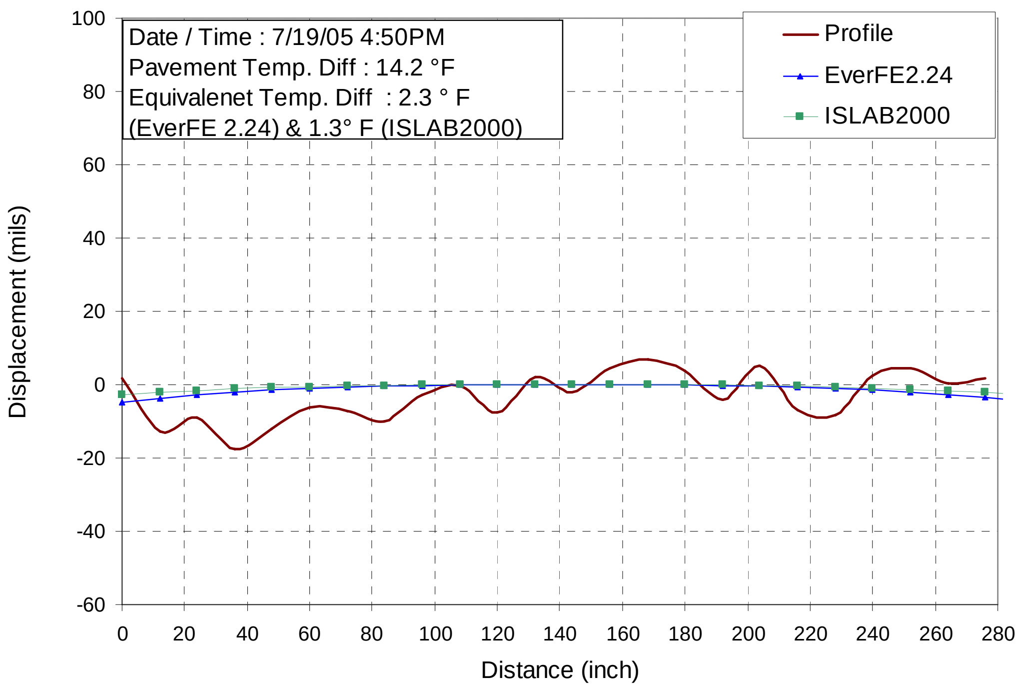


Figure I.102. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 3 (diagonal direction) – July 19 afternoon

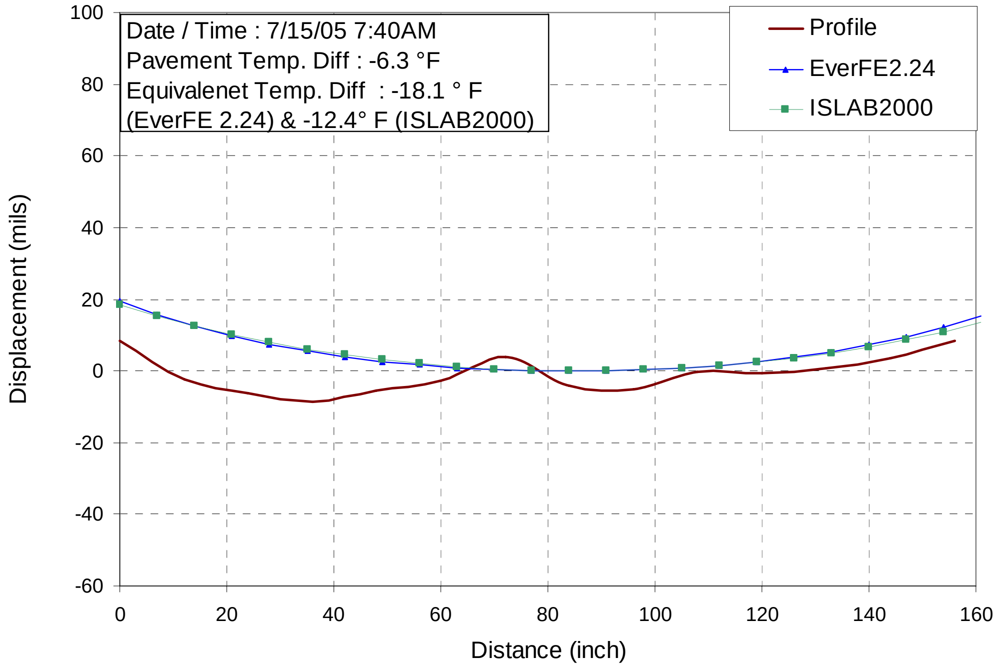


Figure I.103. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 15 morning

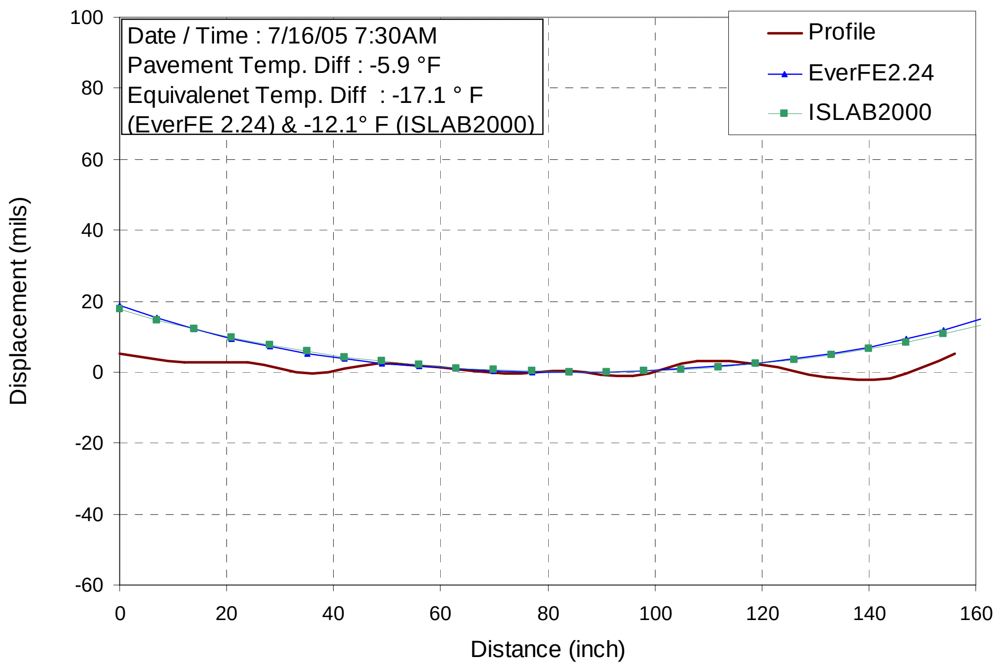


Figure I.104. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 16 morning

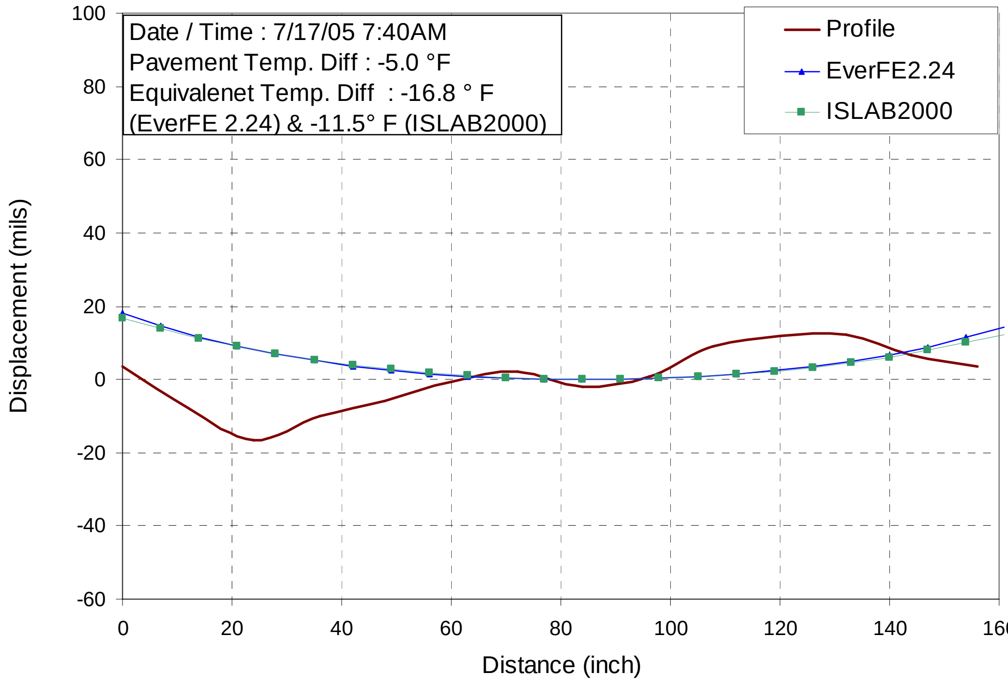


Figure I.105. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 17 morning

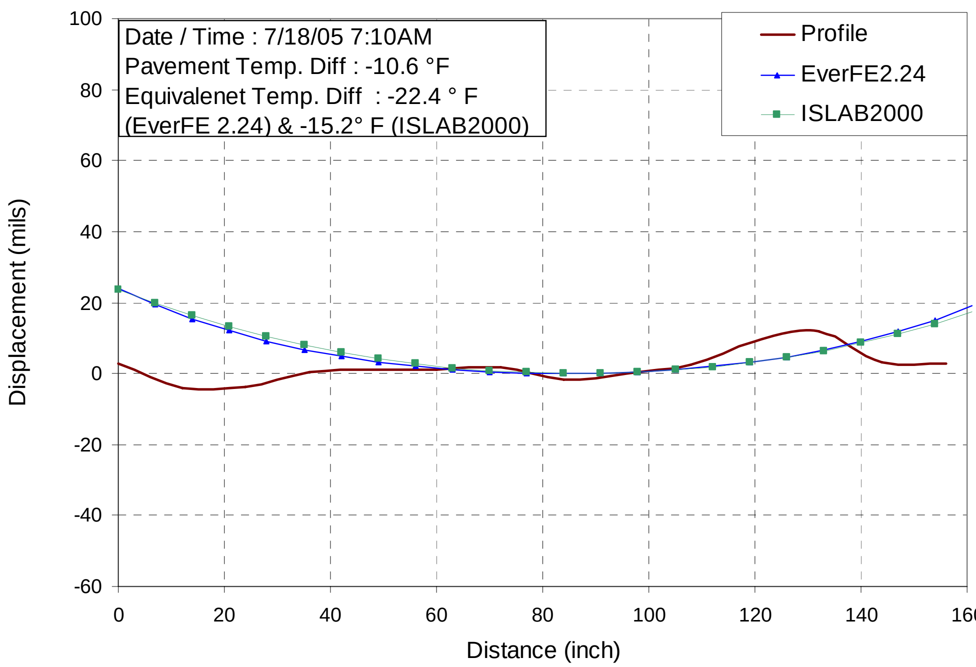


Figure I.106. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 18 morning

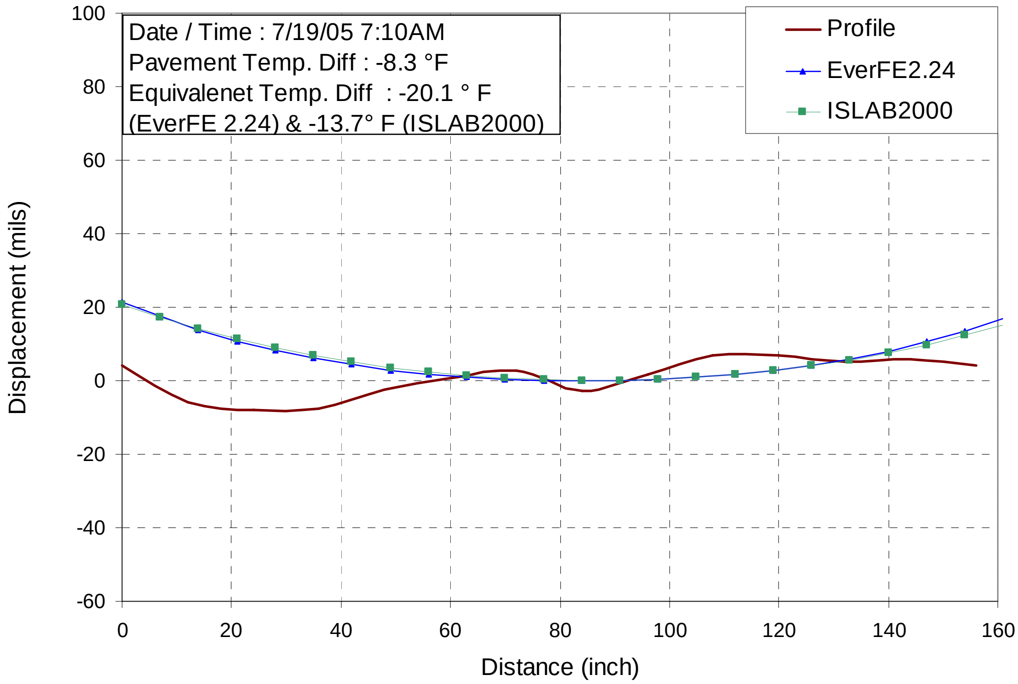


Figure I.107. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 19 morning

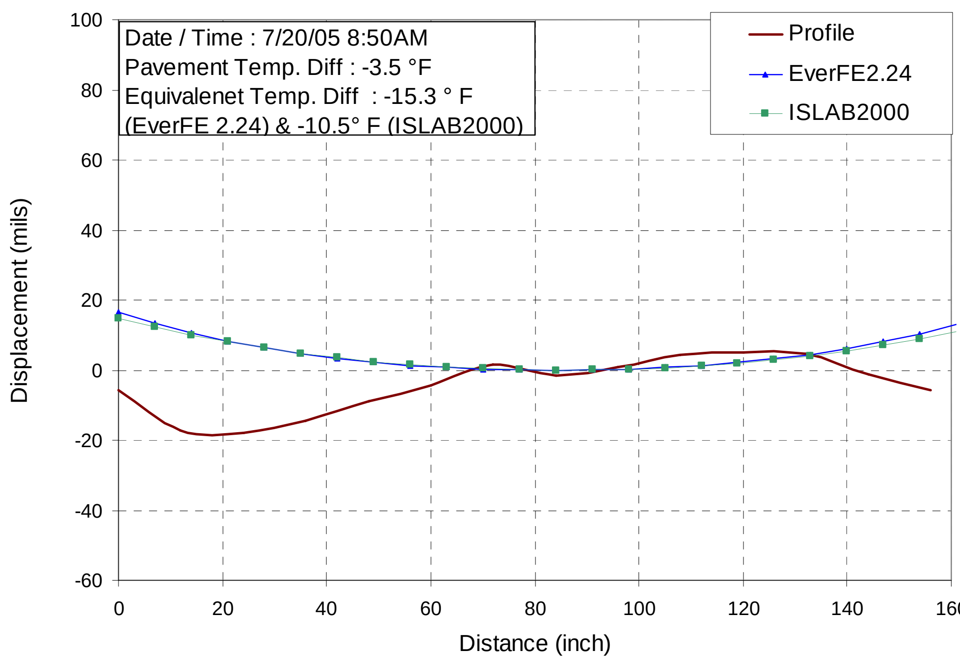


Figure I.108. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 20 morning

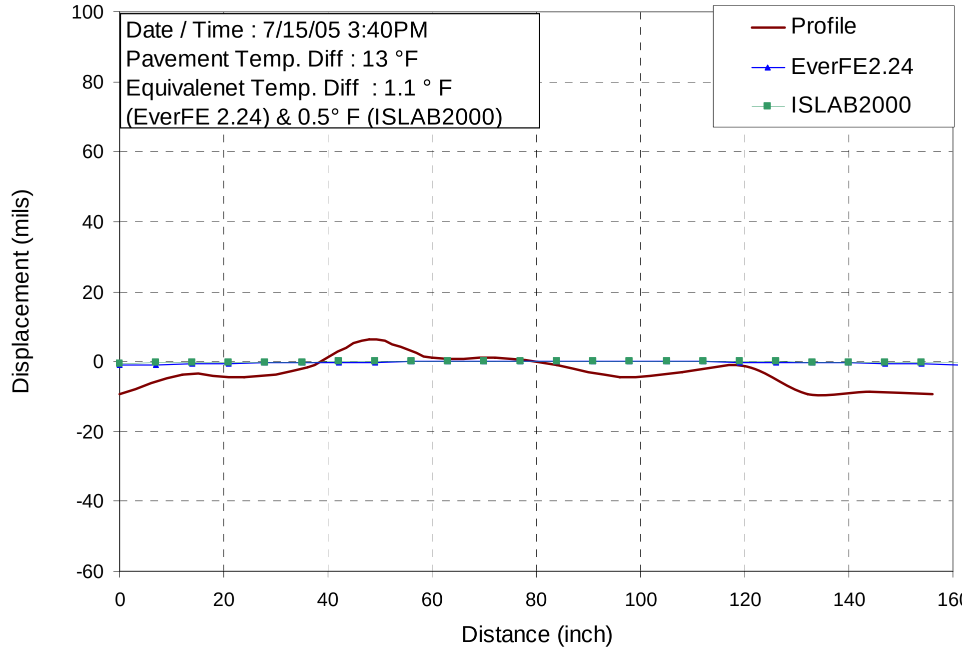


Figure I.109. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 15 afternoon

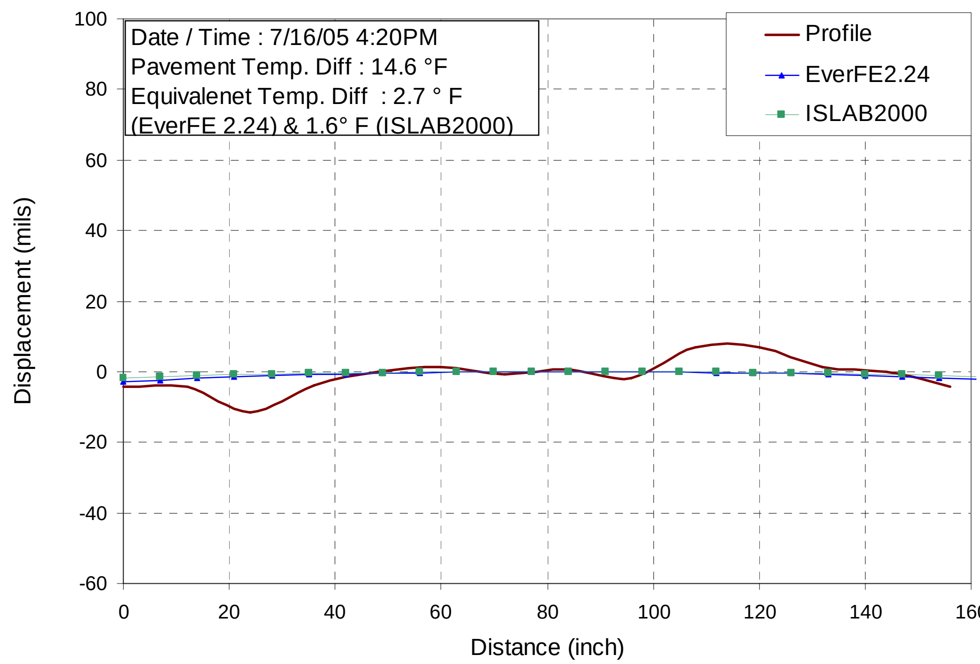


Figure I.110. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 16 afternoon

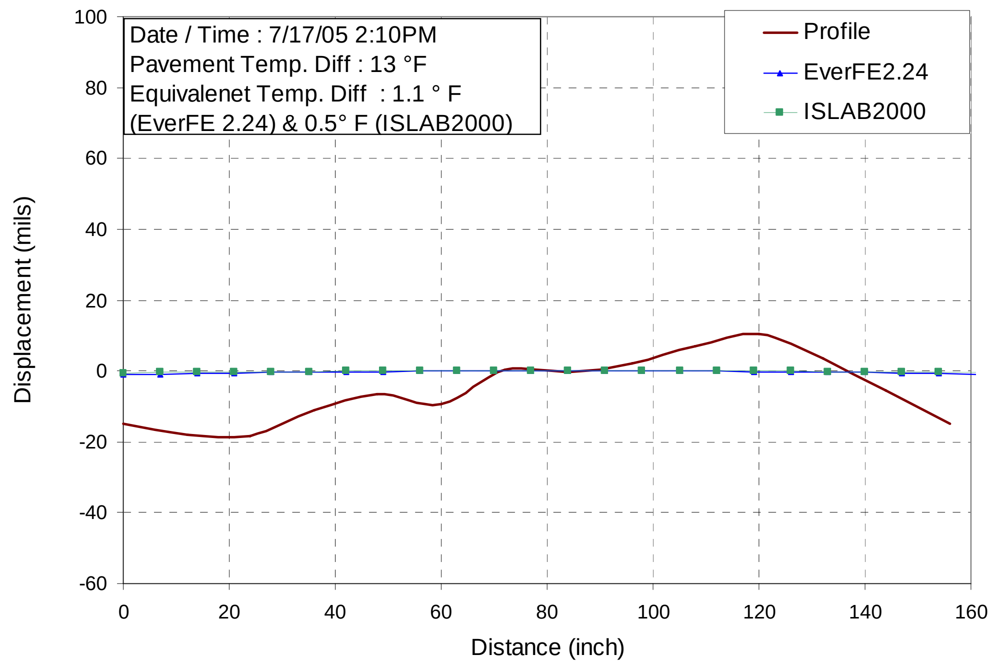


Figure I.111. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 17 afternoon

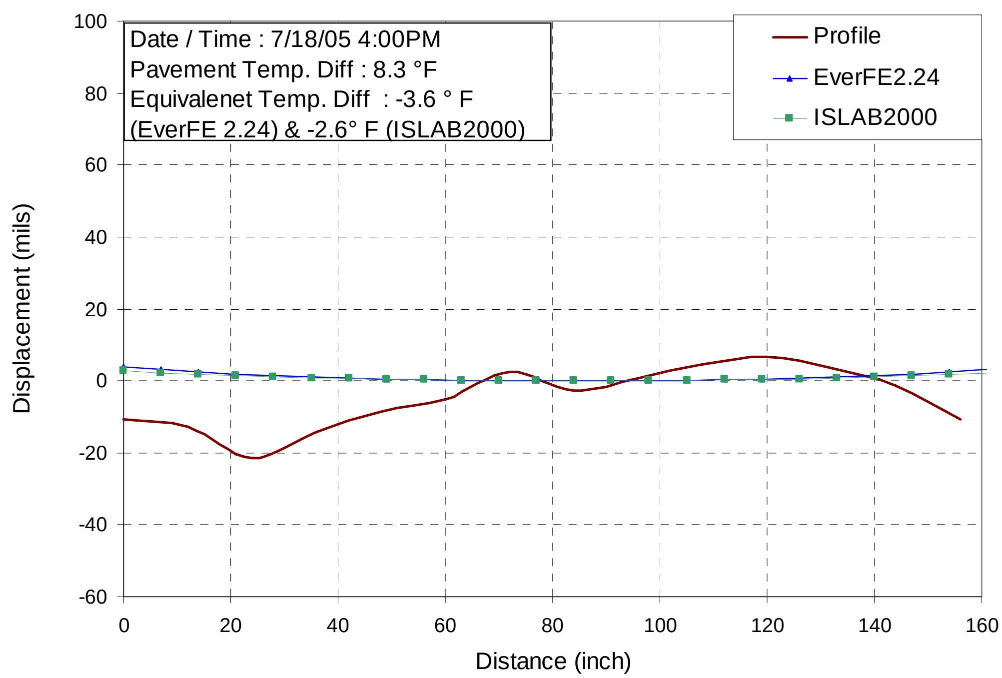


Figure I.112. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 18 afternoon

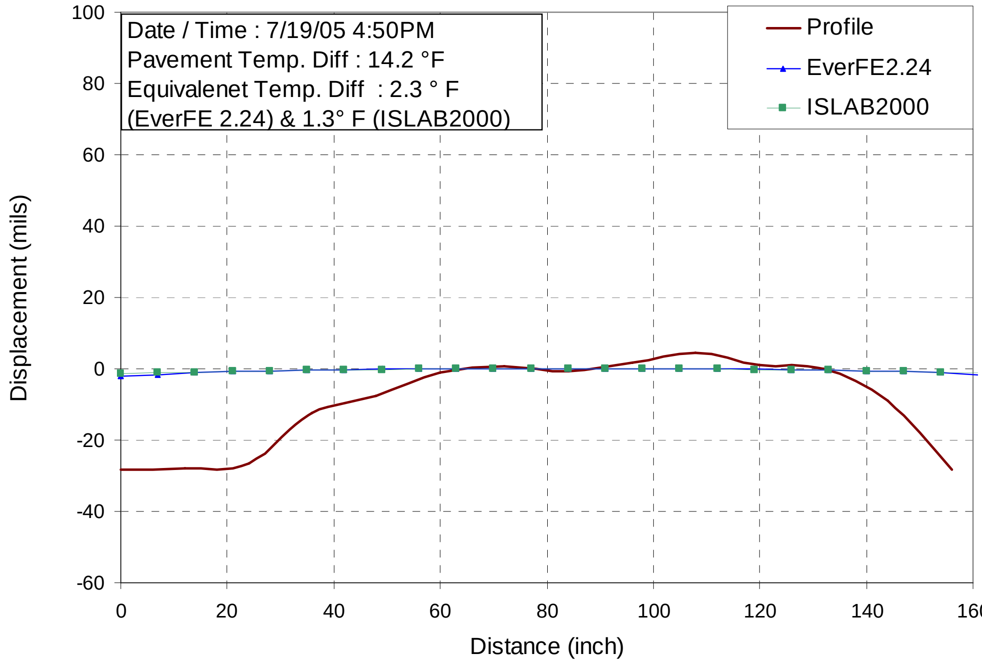


Figure I.113. Comparison of slab curvature behavior between measured and FE-simulated level C profiles path 4 (transverse direction) – July 19 afternoon