Early-Age Behavior of Jointed Plain Concrete Pavement Systems

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ABSTRACT

This paper mainly focuses on the early-age behavior of concrete pavement systems under varying temperature and moisture gradients upon construction. In an effort to better understand the early-age behavior of the jointed plain concrete pavements under varying environmental conditions, a field study has been conducted on instrumented portland cement concrete slabs in Platteville, Wisconsin. The study involves on-site measurements, extensive laboratory testing, and analyses of the concrete pavement systems under temperature and moisture profiles using finite element methodology-based analytical tools. The aim of the study is to summarize the laboratory test results for concrete samples and the analysis of

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the early-age slab deflection data captured with linear variable displacement transducers (LVDTs). In the analytical modeling of the slabs, the ISLAB2000 finite element model has been used. Based on the large number of comprehensive finite element analyses, a good match has been observed with the analytical solutions and field measurements, thus capturing the early-age behavior of concrete pavement systems under temperature and moisture profiles. Such important findings are presented and discussed in the paper in relation to the early behavior of concrete pavement systems.

Key words: early-age behavior—finite element methodology—jointed plain concrete pavements—temperature effects

INTRODUCTION

Climatic factors can affect the performance of portland cement concrete (PCC) slabs in numerous ways. Temperature differences between the top and the bottom of the PCC slabs causes curling. A higher temperature at the bottom of the slab results in a positive temperature gradient and causes the corners and the free edges of the slab to curl downwards. A higher temperature at the bottom of the slab results in a negative temperature gradient and causes the corners and the free edges of the slab to curl upwards.

Westergaard provided closed form solutions for corner, edge, and interior loading conditions based on elastic foundation analysis (Westergaard 1926). Westergaard's first paper, accounting for stress and deflection analysis for slabs on grade under a temperature distribution throughout the thickness, was published in 1927 (Westergaard 1927). Bradburry (1938) extended Westergaard's solution to the case of slabs of finite size with Westergaard's assumption fully intact. Over the years, sophisticated finite element tools were developed for analyzing pavement systems with two or more layers and allowing separation between layers (Korovesis 1990; Khazanovich 1994). These tools are also suitable for temperature analysis. Analysis with a non-linear temperature gradient was subsequently adapted to the finite element model (FEM) program, ILSL2 (Khazanovich 1994; Ioannides et al. 1998). ILSL2 was modified to model several support and load transfer conditions and is now called ISLAB2000 (Khazanovich et al. 2000).

Several studies have been made to better understand the actual behavior of the slab under environmental conditions. This paper includes a study of curling in jointed PCC (JPCC) pavements. The study involves site measurement, laboratory testing, and computer analysis. The data obtained from the site study and the laboratory testing were used to model JPCC pavement behavior. In the analysis, a powerful finite element program, ISLAB2000, was utilized. Comparison between the predicted FEM results and the measured results showed that the FEM estimated the shape of the curves reasonably well.

METHODOLOGY

Field data were collected from a project on a Platteville bypass road on US Highway 151. In the project, a 25 cm JPCC pavement was placed over a 10-cm–thick open-graded base layer on top of a 7.5-cm–thick dense-graded base material. The joints were dowelled and tied. In the longitudinal joints, dowel bars were 38 mm in diameter, 460 mm in length, and spaced 305 mm apart. In the transverse joints, tie bars were 12.5 mm in diameter, 600 mm in length, and spaced 900 mm apart.

Two test slabs were instrumented. The first slab was built on October 20, 2004 at 9:30 am CST. It was 4.3 m long and 4.4 m wide. The second slab was constructed on October 27, 2004 at 16:00 pm CST. Its dimensions were 4.4 m in length 4.5 m in width.

iButton temperature sensors were used to collect temperature data. The sensors were placed at seven different locations at 50 mm, 114 mm, 146 mm, 178 mm, 190 mm, 216 mm, and 241 mm from the top of the slab; they were all placed 1 m away from the edge of the pavement. The top view of the installation is given in Figure 1. They were programmed to read every five minutes. Air temperature was also collected continuously during monitoring time.

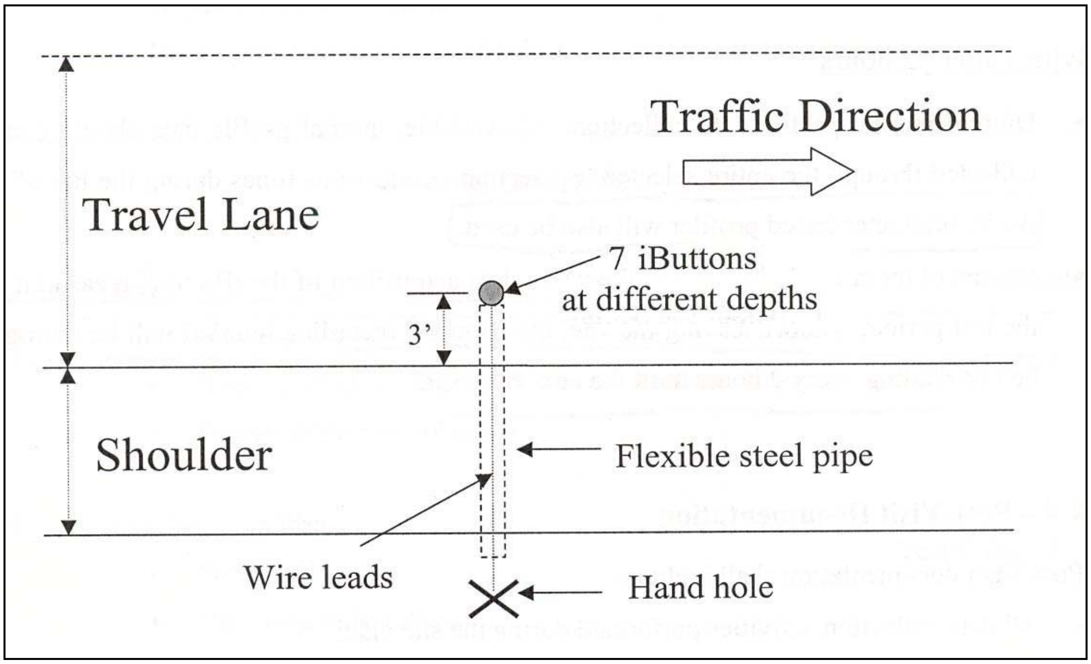

Figure 1. Installation of iButtons

For the first slab, temperature data were collected from October 20, 2004 at 9:45 am CST to October 27, 2004 at 18:25 pm CST. The temperature profile is plotted in Figure 2. For the second section, temperature data were collected from October 20, 2004 at 16:15 pm CST to October 27, 2004 at 17:35 pm CST. The data are shown in Figure 3.

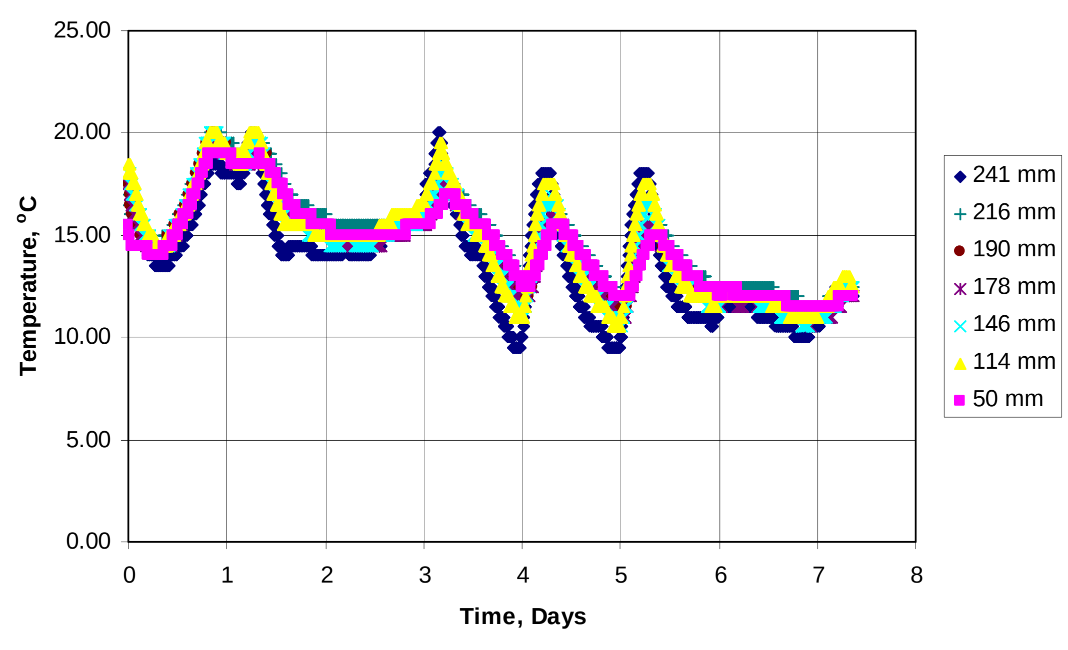

Figure 2. Temperature variation in the first section during the first seven days after pour

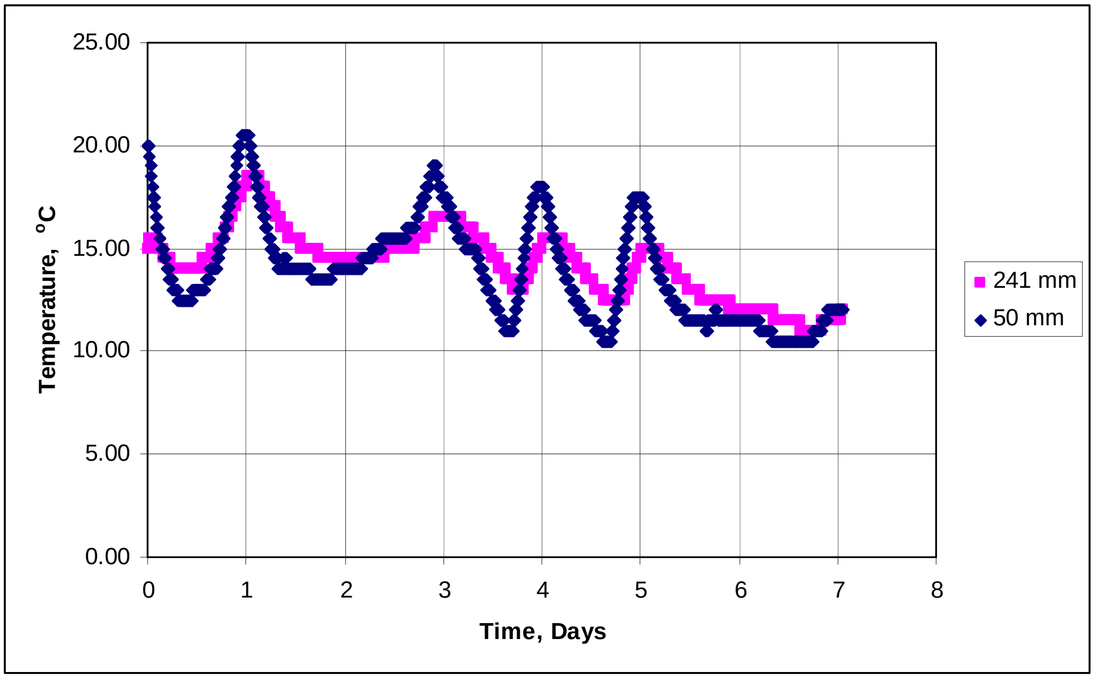

Figure 3. Temperature variation in the second section during the first seven days after pour

Deflection measurements were done using linear variable differential transformers (LVDT). The stroke length of LVDTs is ± 5.0 mm with a sensitivity of 54 mV/V/mm. Five-cm–diameter cores were drilled and steel rods were pounded in these holes without any contact with the concrete slab. LVDTs were clamped to these rods. One of the installed LVDTs from the first section can be seen in Figure 4. Eight LVDTs in the first section and seven LVDTs in the second section were used to profile the deflection of the slabs. In the first slab, deflections were measured from October 21, 2004 at 5:20 pm CST to October 27, 2004 at 5:40 pm CST, and in the second slab measurements were collected from October 22, 2004 at 3:30 pm CST to October 27, 2004 at 5:20 pm CST, every 10 minutes. Layouts of the LVDTs in the first and in the second section are shown in Figure 5.

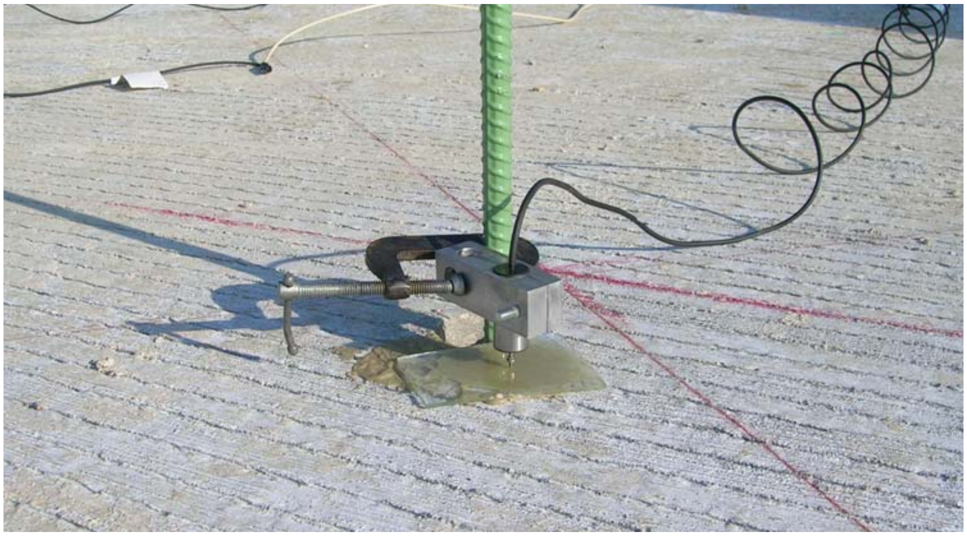

Figure 4. Deflection measurement setup from the first slab

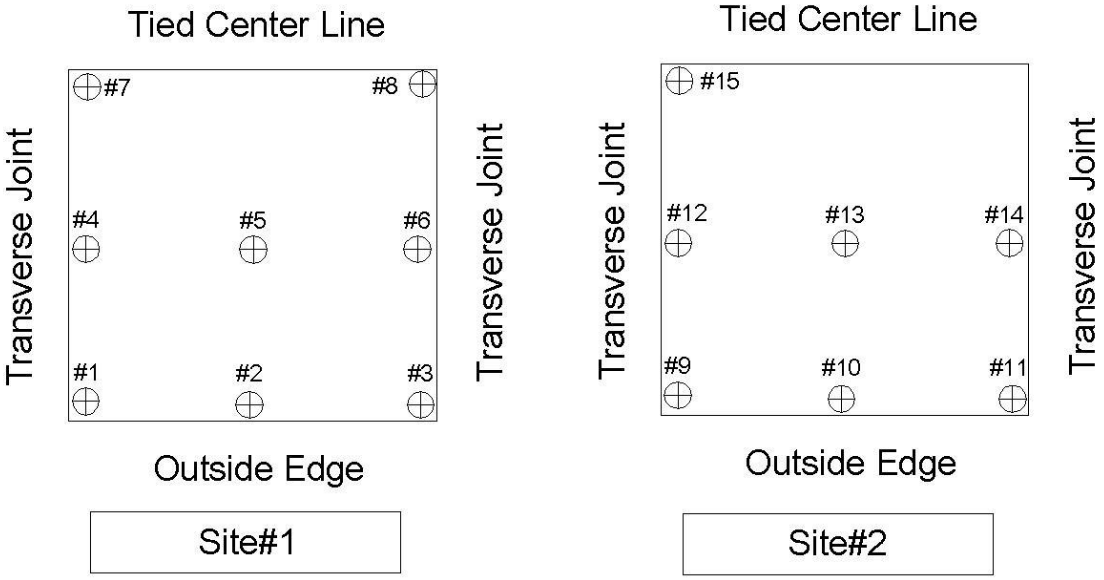

Figure 5. Layouts of the LVDTs in the first and the second site

LVDTs are sensitive devices and can be easily affected by environmental factors. The measurements from three LVDTs (#4, #5, and #7) in the first slab and one LVDT (#15) in the second slab were discarded and not used in the analysis, since it was concluded that the measurements were unreliable.

The tests for the determination of the elastic modulus and the coefficient of thermal expansion were carried out at the Iowa State University Mobile Laboratory and the Iowa DOT, respectively. PCC elastic modulus tests were conducted at interim ages of 12 hours, 1 day, 2 days, 4 days, 7 days, 28 days, and 56 days of age, according to ASTM C 469. The coefficient of thermal expansion of PCC was conducted at 56 days of age, according to AASHTO TP-60.

ANALYSES

In the first slab, the maximum temperature difference was observed on October 25, 2004 from 14:00 pm CST to 14:20 pm CST, with a top-bottom temperature difference of 9 ^{o}C. The minimum temperature difference was observed on October 24, 2004 from 7:30 am CST to 7:50 am CST, with a top-bottom temperature difference of -5 ^{o}C. The temperature of the top of the slab was assumed to be the air temperature. Temperature profiles of the maximum and minimum gradients in the first slab are plotted in Figure 6.

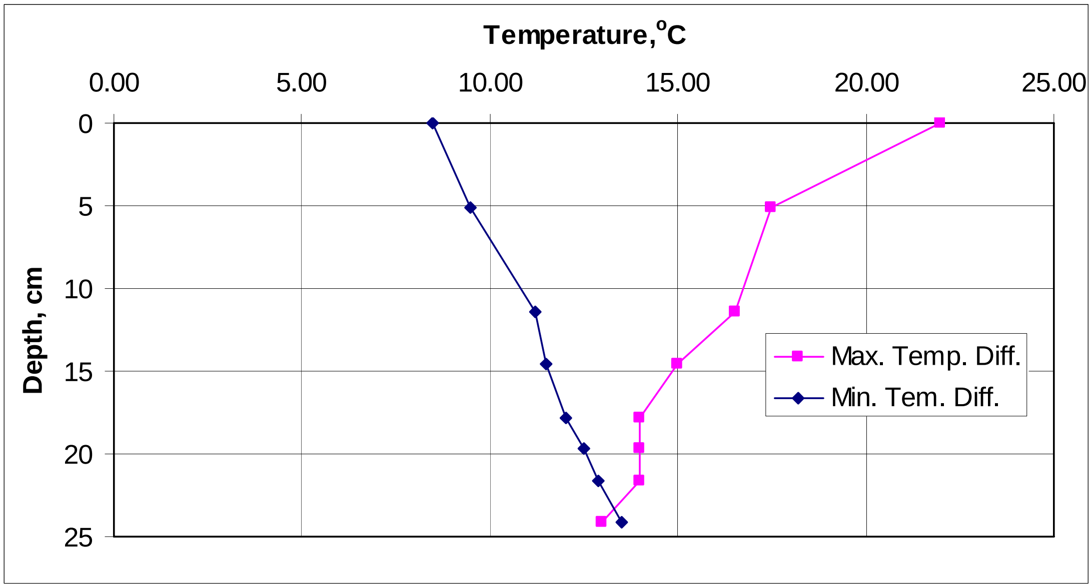

Figure 6. Measured temperature distribution through JPCP thickness at peak gradients in 1st slab

In the second slab, the maximum temperature difference was observed on October 25, 2004 from 14:10 pm CST to 14:20 pm CST, with a top-bottom temperature difference of 8.5 ^{o}C. The minimum temperature difference was observed on October 24, 2004 from 7:20 am CST to 7:40 am CST, with a top-bottom temperature difference of -5.5 ^{o}C. The temperature of the top of the slab was assumed to be the air temperature. Temperature profiles of the maximum and minimum gradients of the second slab are plotted in Figure 7.

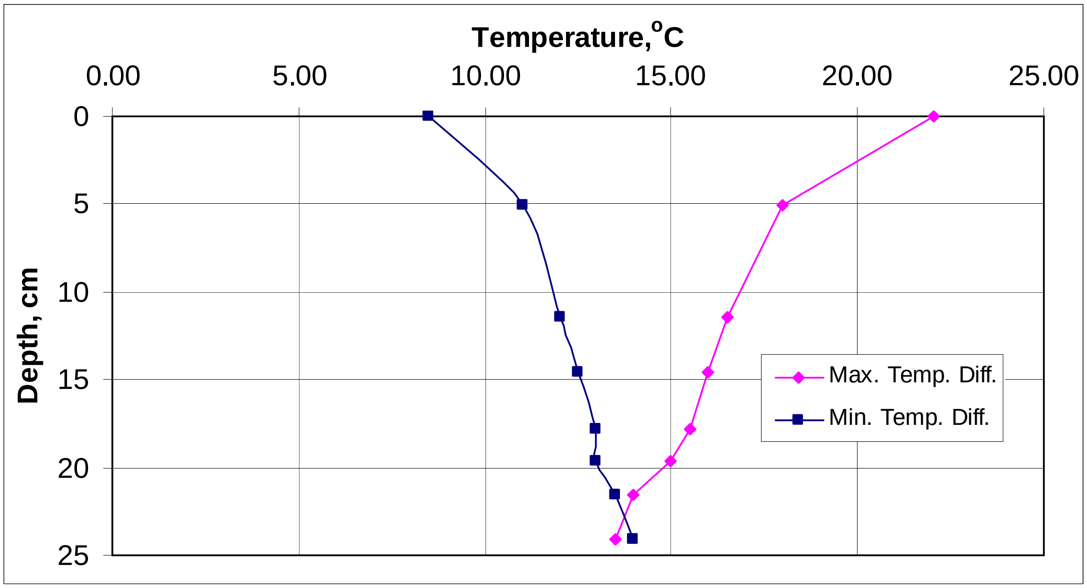

Figure 7. Measured temperature distribution through JPCC thickness at peak gradients in 2nd slab

Material properties determined from the laboratory tests were used in modeling with the FEM program, ISLAB2000. The maximum and minimum temperature difference conditions were modeled in the two sections. Laboratory tests were used to interpolate the modulus of elasticity at the peak gradient time. A modulus value of 20.01 GPa was used for the concrete. The coefficient of thermal expansion, from the laboratory tests of specimens cast in the field, was determined to be 10.4x10^{-6}/^{o}C. For the subgrade, a k-value of 54.2 Kpa/mm was assumed, and dowel bars and tie bars are specified for the joint parameters. For the first site, longitudinal free edge transverse joint measurements and modeling results for the maximum and minimum temperature difference cases are plotted in Figures 8–11.

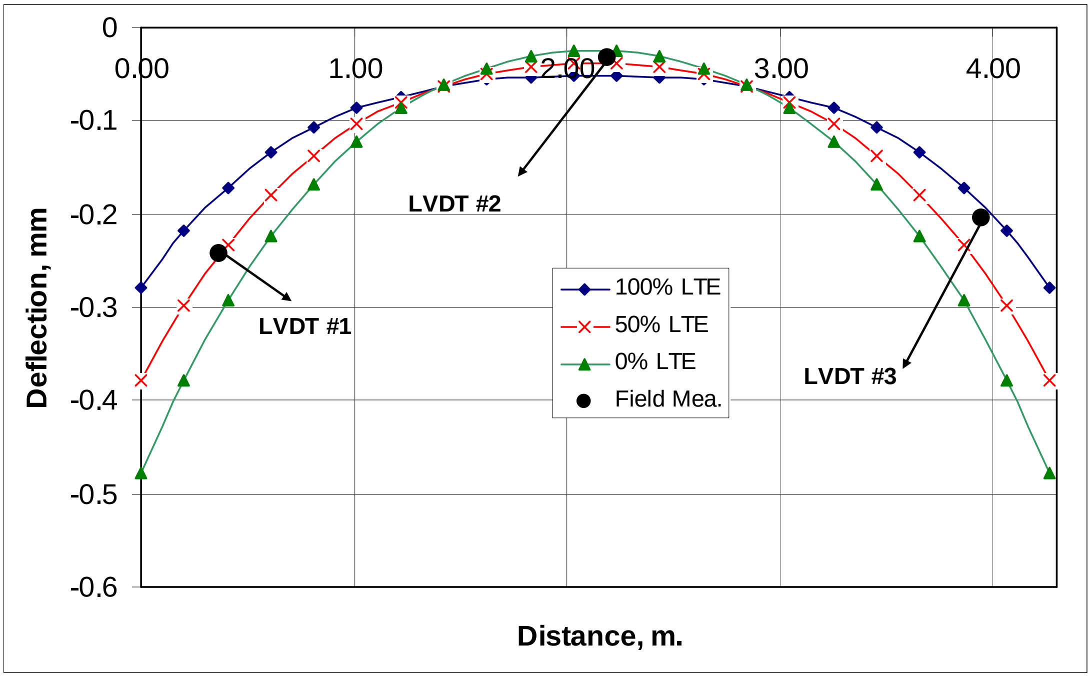

Figure 8. Longitudinal free edge measurements for the curl down case using LVDTs #1, #2, and #3 and the modeling results for the first site

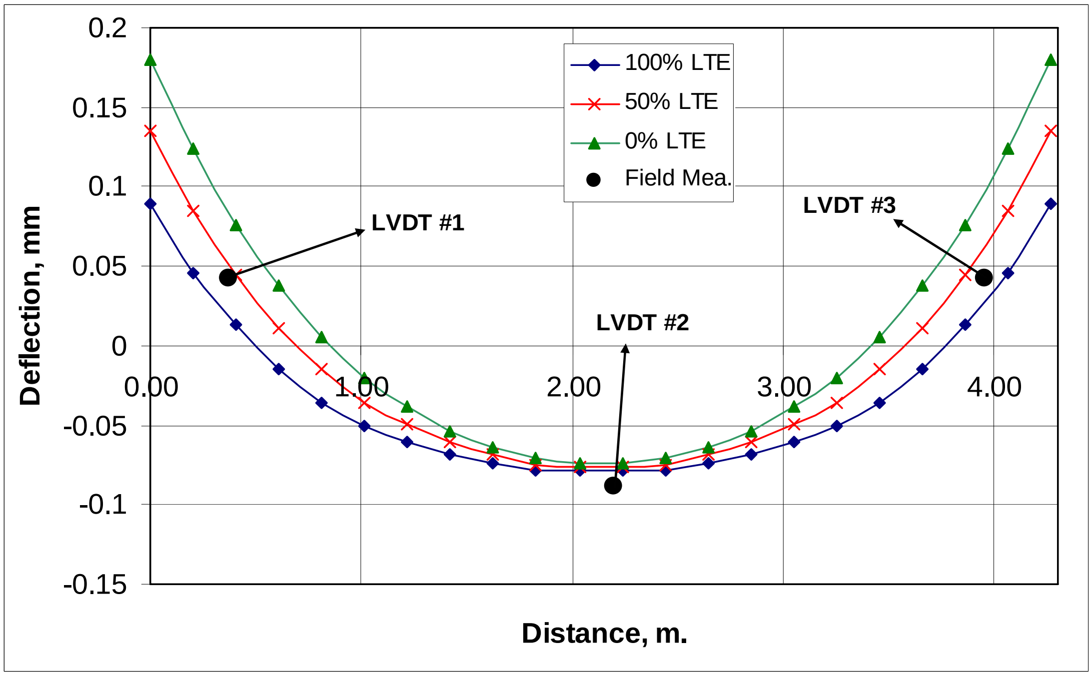

Figure 9. Longitudinal free edge measurements for the curl up case using LVDTs #1, #2, and #3 and the modeling results for the first site

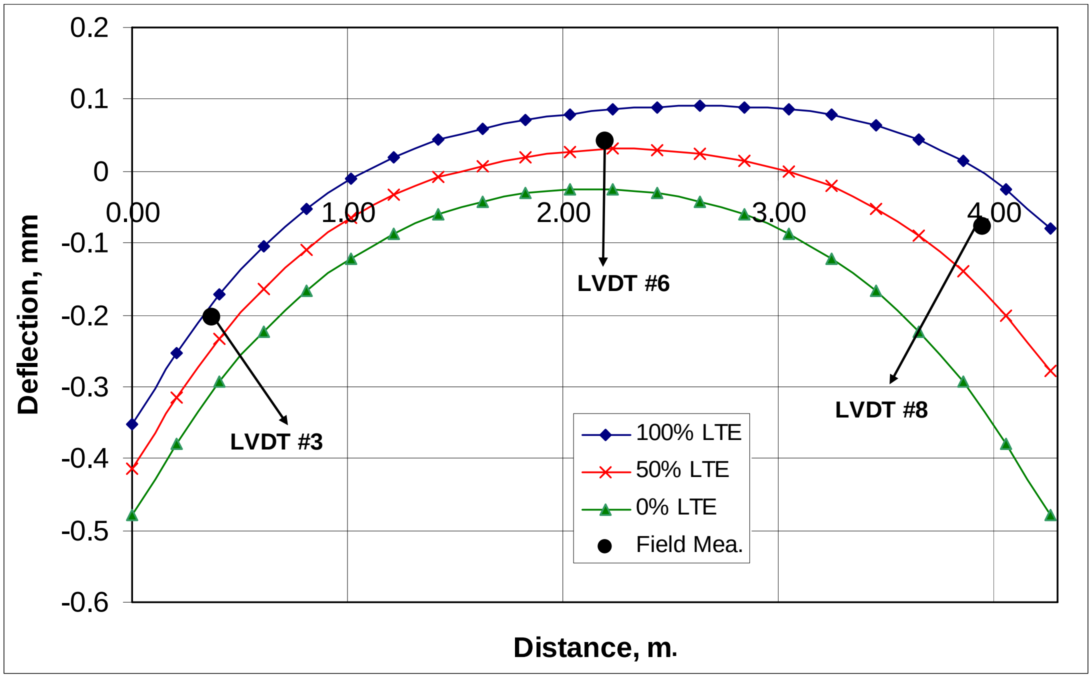

Figure 10. Transverse joint edge measurements for the curl down case using LVDTs #8, #6, and #3 and the modeling results for the first site

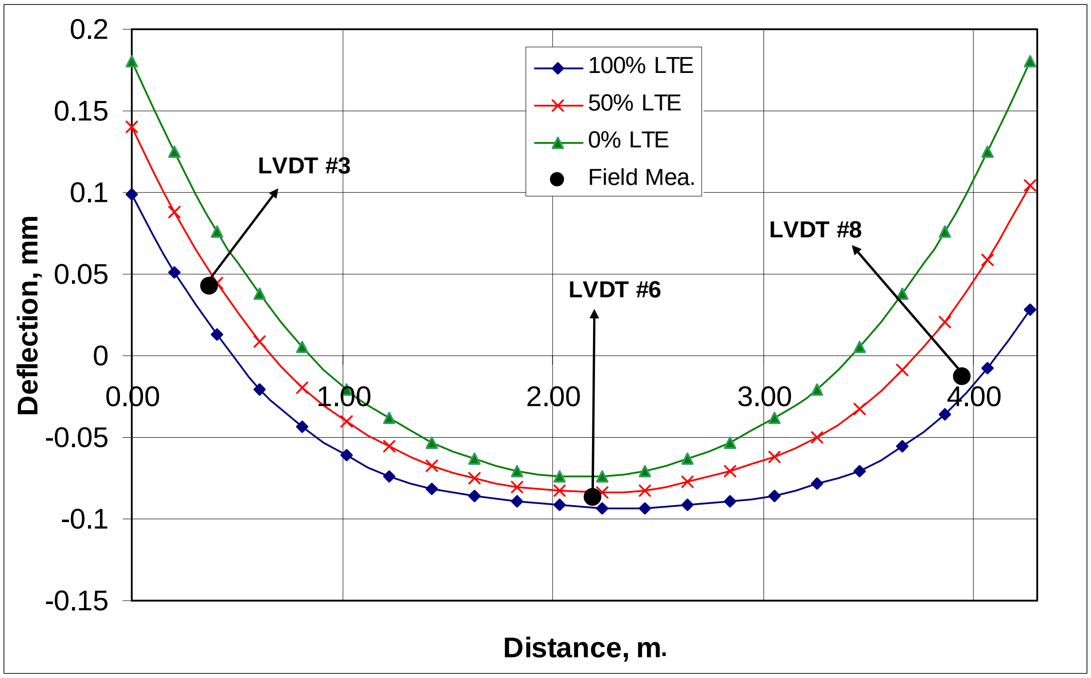

Figure 11. Transverse joint edge measurements for the curl up case using LVDTs #8, #6, and #3 and the modeling results for the first site

For the second site, longitudinal free edge centerline measurements and the modeling results for the maximum and minimum temperature difference cases are plotted in Figures 12–15.

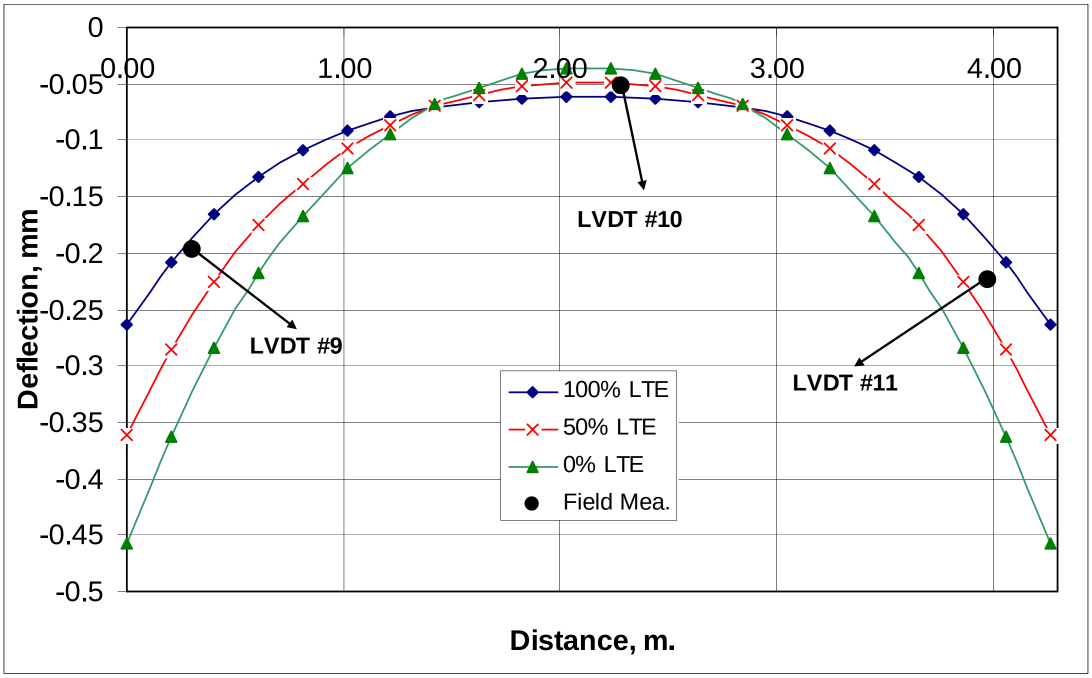

Figure 12. Free edge measurements for the curl down case using LVDTs #9, #10, and #11 and the modeling results for the second site

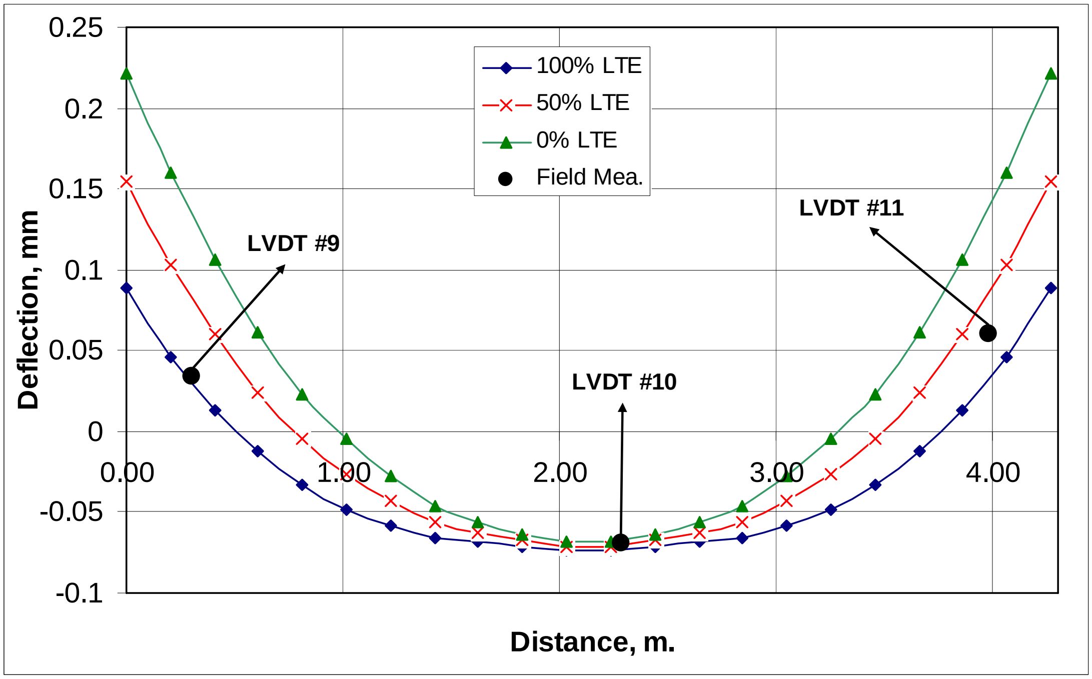

Figure 13. Free edge measurements for the curl down case using LVDTs #9, #10, and #11 and the modeling results for the second site

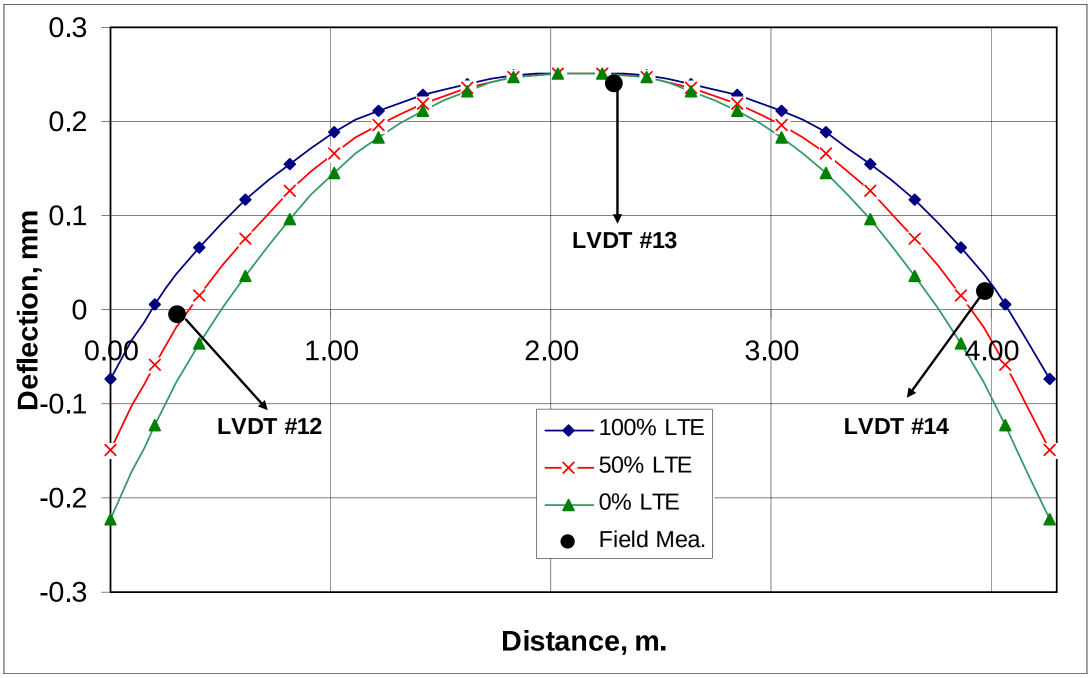

Figure 14. Center line measurements for the curl down case using LVDTs #12, #13, and #14 and the modeling results for the second site

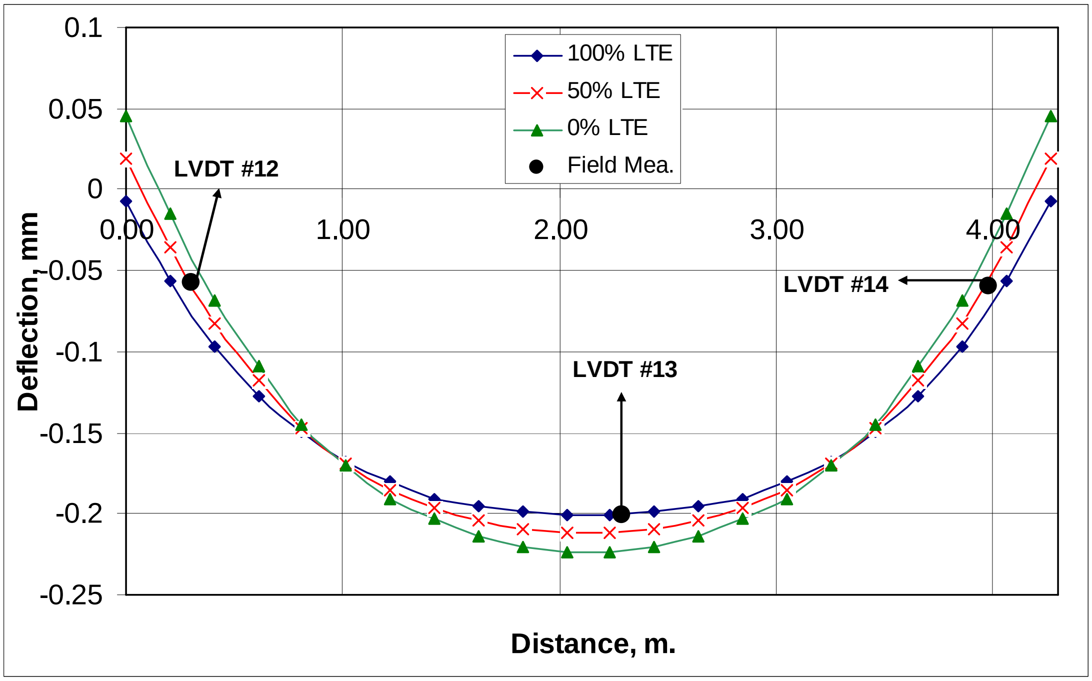

Figure 15. Center line measurements for the curl up case using LVDTs #12, #13, and #14 and the modeling results for the second site.

A comparison between the predicted FEM results and measured results showed that the FEM model estimated the shape of the curves reasonably well. Measured displacement values were usually between the 100% load transfer efficiency (LTE) curves and 50% LTE curves. In the transverse joint edge measurements, free edge measurements (LVDT #3) are more than the tied corner measurement, which is to be expected. Free edge and center line measurements are almost symmetrical, due to the different restraining conditions, such as different load transfer efficiency levels in the joints and different base modulus values. Perfect symmetrical conditions in the measurements cannot be expected. Moreover, a discrepancy between the measured and predicted values might occur because of the moisture difference between the top and bottom of the slab, which is not accounted for in the study. However, according to the national weather station, the average humidity value on the casting day and the monitoring time averages are 85% and 80.67%, respectively. The authors believe that the moisture difference between the top and the bottom of the slab did not play a big role during the monitoring period.

CONCLUSION

The early-age behavior of jointed plain concrete pavements under varying temperature profiles has been the focus of this study. Pavement deflection data collected from instrumented slabs at a Platteville, Wisconsin bypass road have been analyzed. Extensive concrete testing was conducted using the Iowa State University Mobile Concrete Laboratory and the concrete testing laboratories located at Iowa State University and the Iowa DOT. Using the laboratory and field-collected data, the early-age behavior of the jointed plain concrete pavements was modeled by the ISLAB2000 finite element model. The comparison of the field data and the FEM results showed that the early age behavior of the jointed plain concrete pavements under varying temperature profiles can properly be modeled.

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