Performance of SPS-2 Project in Kansas

Taslima Khanum
Department of Civil Engineering
Kansas State University
2118 Fiedler Hall
Manhattan, KS 66506
taslima@ksu.edu

Mustaque Hossain
Department of Civil Engineering
Kansas State University
2118 Fiedler Hall
Manhattan, KS 66506
mustak@ksu.edu

Andrew J. Gisi
Materials and Research Center
Kansas Department of Transportation
2300 Van Buren
Topeka, KS 66611
agisi@ksdot.org

ABSTRACT

The Long-Term Pavement Performance (LTPP) SPS-2 experiment was designed to study structural factors, such as drainage, base type, concrete strength and thickness, and lane width, of rigid pavements. The SPS-2 experiment section in Kansas, constructed in 1992, is a jointed dowelled plain concrete pavement. The experiment consisted of 12 standard SPS-2 sections and 1 Kansas DOT control section. These sections have been monitored by the LTPP program since construction. Performance monitoring included measurements for ride quality (International Roughness Index [IRI]), faulting, cracking, and surface deflections. Performance parameters analyzed in this study included IRI, faulting, cracking (combined longitudinal and transverse crack lengths), and joint load transfer efficiency. The results show that the project has performed very well to date. Most sections are smooth and crack-free, with negligible faulting. The load transfer efficiency of the sections has been good too. The drainable sections with a permeable asphalt-treated base have performed the best. These sections were built smoother and remained so after 12 years of service. The section with low PCC slab thickness (8 inches) and low concrete design strength (550 psi) on a dense graded aggregate base has performed the worst. The combination of high slab thickness and high concrete strength tends to mask the effect of the base on pavement performance. The Kansas DOT control section with a thick slab (12 inches) over a dense graded portland cement-treated base has also performed very well.

Key words: concrete pavement—Long-Term Pavement Performance—SPS-2

Proceedings of the 2005 Mid-Continent Transportation Research Symposium, Ames, Iowa, August 2005.

INTRODUCTION

The Strategic Highway Research Program (SHRP) was initiated in 1987 to improve the performance of highway pavements and bridges. A part of this national research effort, the Long-Term Pavement Performance (LTPP) program was aimed at determining the effects of various designs and environmental and material performance by monitoring a large number of in-service pavement sections. The LTPP national database was established and is being updated periodically with the performance monitoring information collected from the selected pavement sections. The LTPP program was divided into two programs: General Pavement Studies (GPS), representing pavements that use materials and structural design practices in the United States and Canada from the 1960s to the 1980s, and Specific Pavement Studies (SPS), representing performance and specific structural factors of interest in the 1990s. The SPS-2 experiment entitled “Strategic Study of Structural Factors for Rigid Pavements” was developed to study the structural factors affecting the performance of rigid pavements (SHRP 1990). The experimental design was aimed at determining the effects of the following specific pavement design features: (1) in-pavement drainage system, (2) base type, (3) concrete strength, (4) pavement thickness, and (5) lane width. This paper analyzes the performance of the SPS-2 project in Kansas with respect to drainage and base type. Comparison with a control section designed by the Kansas DOT (KDOT) was also made.

KANSAS SPS-2 PROJECT LAYOUT AND TEST SECTIONS

The Kansas SPS-2 project, constructed in 1992, is located in the westbound driving lane of Interstate 70 near Abilene. The project reconstructed an existing concrete divided interstate highway (Johnson 1993). The roadway consists of two 12-ft lanes, a 10-ft tied outer shoulder, and a 4-ft inner shoulder in the westbound direction. The SPS-2 experiment includes 12 standard sections and 1 KDOT control section, shown in Table 1. Each section is 500 ft long, with transitions of varying length between the sections.

Table 1. Kansas SPS-1 test section details

Test section #	SHRP ID	Base*	Slab thickness (design) (in.)	Concrete strength (design) (psi)	Concrete strength (actual) (psi)	Lane width (ft)
KDOT control	State supplemental	6” PCTB 6”Mod fly ash	12	600	617	12
KDOT 1	200209	4” PATB 4” DGAB	8	550	624	12
KDOT 2	200210	4” PATB 4” DGAB	8	900	924	14
KDOT 3	200211	4” PATB 4” DGAB	11	550	576	14
KDOT 4	200212	4” PATB 4” DGAB	11	900	865	12
KDOT 5	200208	6” LCB	11	900	855	12
KDOT 6	200207	6” LCB	11	550	584	14
KDOT 7	200205	6” LCB	8	550	702	12
KDOT 8	200206	6” LCB	8	900	829	14
KDOT 9	200202	6” DGAB	8	900	803	14
KDOT 10	200201	6” DGAB	8	550	606	12
KDOT 11	200204	6” DGAB	11	900	784	12
KDOT 12	200203	6” DGAB	11	550	595	14

* PCTB: dense graded portland cement-treated base; PATB: permeable asphalt-treated base; LCB: lean concrete base; DGAB: dense graded aggregate base

The sections incorporated two thicknesses (8 and 11 in.), two strength classes (design modulus of rupture of 550 and 900 psi at 14 days), three base types (permeable asphalt-treated base [PATB], lean concrete base [LCB], dense graded aggregate base [DGAB]), and two lane widths (12 ft and 14 ft). The KDOT control section consists of a 12-in. concrete slab over a 6-inch dense graded portland cement-treated base (PCTB). The design modulus of rupture for this section was 600 psi. Subgrade soils were silty clay. Since this project involved reconstruction of an existing concrete highway, the top subgrade layer was reworked and recompacted after incorporating the existing granular subbase and shoulder material. Construction was difficult due to the wet climate (Johnson 1993). Thus, a Class C fly ash was added to dry and stabilize the wet subgrade. As a result, all sections have a six-inch Class C fly ash-modified subgrade. The project was initially classified to be in the dry-freeze zone of the LTPP program. Later it was reassigned to the wet-freeze zone, since the annual precipitation at this site (32 inches/year) is greater than the 20 inches/year for the LTPP dry-freeze zone. The freezing index was 259 ^{o}C-days. The base year annual average daily traffic on this section was 13,750, with 21.4% trucks. The estimated 18-kip equivalent single axle load (ESAL) in the SPS-2 lane was 1,300,678, with a total of 26,013,550 18-kip ESALs over the 20-year design period.

Layout and Construction

The test sections were laid out starting at the west end of the project and according to the base type, as shown in Figure 1. Lane width and surface thickness were not considered. The KDOT control section was first, followed by those with PATB over DGAB (KDOT sections 1, 2, 3, and 4). The sections with LCB were placed next (KDOT sections 5, 6, 7, and 8). The last sections were those containing DGAB (KDOT sections 9, 10, 11, and 12). The construction of the test sections started in June 1992 and was completed in July 1992. The project was opened to traffic in early August of 1992 (Johnson 1993).

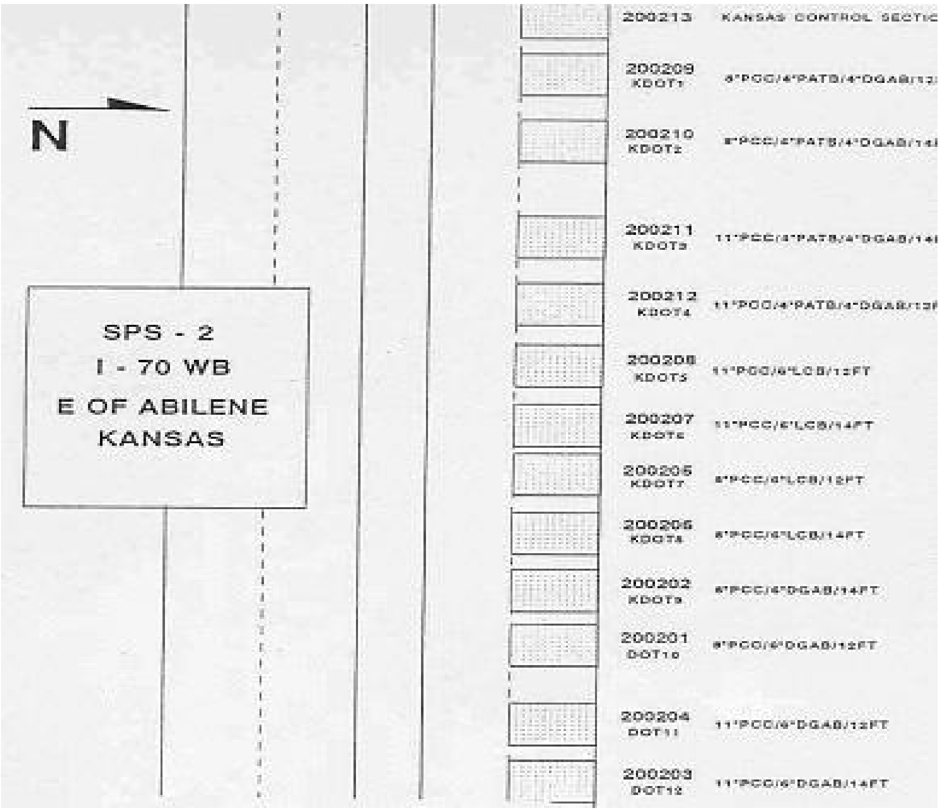


Figure 1. Layout of SPS-2 sections

Table 2 shows the mix design details. Type II cement was used in all mixes. The cement content varied from 279 lbs per cubic yard for LCB to 862 lbs for the 900-psi mixture. All mixtures, including the lean concrete base and paving concrete, used 70% natural sand and 30% crushed stone. Crushed limestone was used in the LCB and in the 550-psi concrete mix. The 900-psi mix had calcite-cemented sandstone for the coarse aggregate part to help increase the flexural strength. The design water-cement ratios for the LCB, 550-psi mix, and 900-psi mix were 1.0, 0.5, and 0.35, respectively (Johnson 1993). The mixes were air-entrained, and a water-reducing admixture was used in the 900-psi mix.

Table 2. SPS-2 mix design data

Feature	Lean concrete base	550-psi concrete	900-psi concrete
Strength requirement	500–750 psi comp. (7-day cure)	550 ± 60 psi flex. (14-day cure)	900 ± 100 psi, flex. (14-day cure)
% Air/air ent. admix	4–9%	2.6 oz.	7.7 oz.
Slump required	1”–3”	1¾” ± ¾”	1¾” ± ¾”
Cement type	II	II	II
Cement content (lbs/yd^3)	279	532	862
Water content (lbs/yd^3)	280	266	301
Coarse agg. content (lbs/yd^3)	929	891	1349
Fine agg. content (lbs/yd^3)	2169	2071	1347
Unit weight (lbs/ft^3)	135.4	139.21	143

The construction of the project was uneventful except for the PATB layer, which was placed too thick but then trimmed to the required thickness (Johnson 1993). Compaction of the PATB was problematic too. Post-construction coring and flexural beam tests showed that most sections had concrete that exceeded the design strength, as shown in Table 1. The strength gain over the design strength was most significant for the 550-psi mixture.

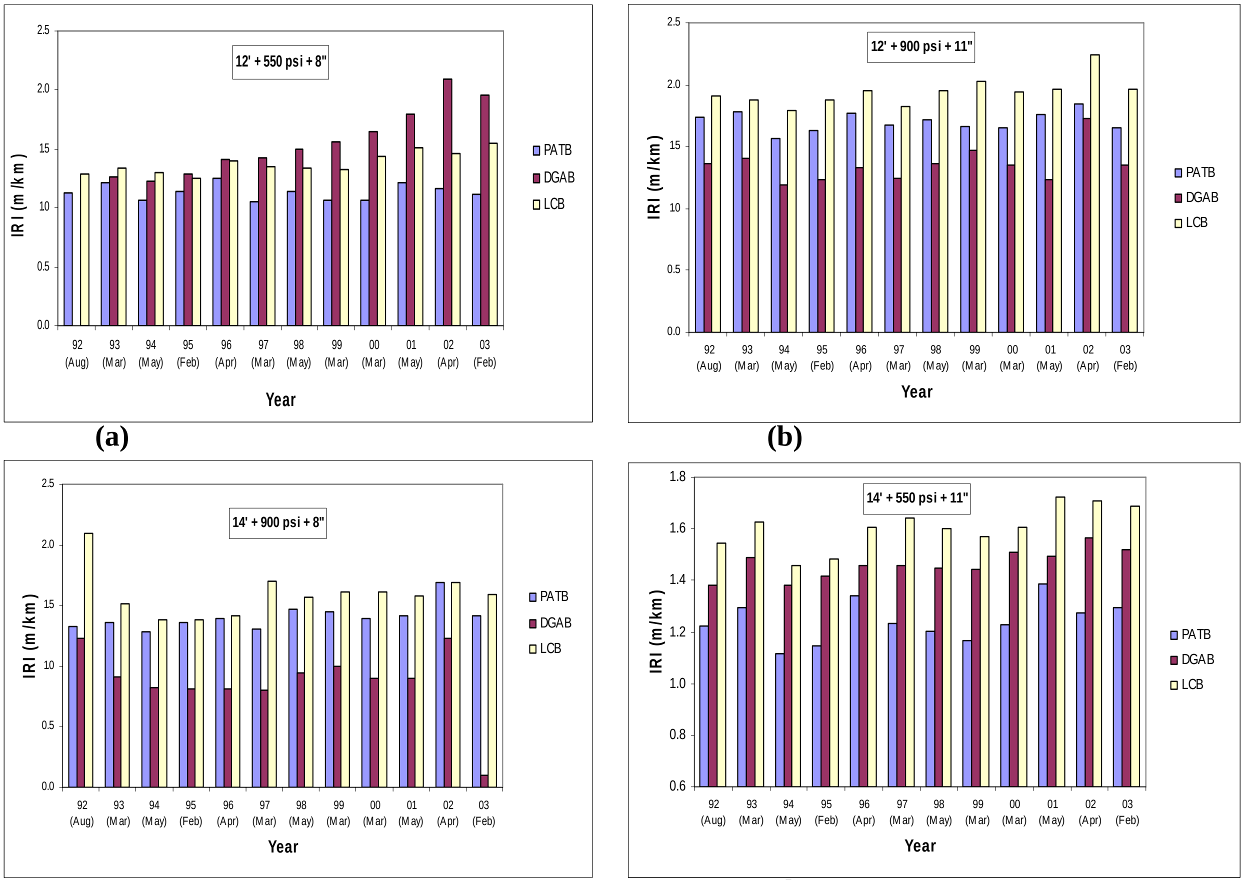
PERFORMANCE MONITORING, DATA ANALYSIS, AND RESULTS

The Kansas SPS-2 project has been monitored by the LTPP program since its construction. A Toledo Model 930 high-speed weigh-in-motion system was installed to provide automatic high-speed weighing, classifying, and traffic data collecting. The test sections have carried 6.6 million ESALs from 1992 to 2000. The truck traffic has been lower than that anticipated during the design process. Performance monitoring of these sections included annual measurements for ride quality (International Roughness Index [IRI]), faulting measurements since 1999, cracking measurements since 1993, and falling weight deflectometer (FWD) testing since 1993. All performance data used in this study were retrieved online from Datapave, release 18, of July 2004. This version of Datapave contains the following data elements for key performance measures: (a) IRI, every year between 1993 and 2003; (b) faulting for 1999, 2001–2003; (c) cracking for 1993, 1996, and 1999–2003; and (d) FWD deflection data for every other year between 1993 and 2003. From the wheel path FWD deflection data, joint load transfer efficiency (LTE) values were computed for all sections. Thus, performance parameters analyzed in this study included IRI, faulting, cracking (combined longitudinal and transverse crack widths), and joint LTE corresponding to the design features incorporated in the experiment.

Drainage

As mentioned, different base types were constructed to compare drained and undrained sections. The drained sections in this study are KDOT 1 (8” PCC/550-psi/12’), KDOT 2 (8” PCC/900-psi/14’), KDOT 3 (11” PCC /550-psi/14’), KDOT 4 (11” PCC/900-psi/12’). All drained sections were on 4-in. PATB and the PATB layer was over 4-in. DGAB. The undrained sections in the experiment include KDOT 5 (11” PCC /6” LCB/900-psi/12’), KDOT 6 (11” PCC/6” LCB/550-psi/14’), KDOT 7 (8” PCC/6” LCB/550-psi/12’), KDOT 8 (8” PCC/6” LCB/900-psi/14’), KDOT 9 (8” PCC/6” DGAB/900-psi/14’), KDOT 10 (8” PCC/6” DGAB/550-psi/12’), KDOT 11 (11” PCC/6” DGAB/900-psi/12’), KDOT 12 (11” PCC/6” DGAB/550-psi/14’) and KDOT control (12” PCC/6” PCTB/600-psi/12’).

Figure 2 (a) shows the IRI history of the sections with 12-ft lane width, 550-psi design strength, and 8-in. PCC slab thickness. The figure compares the ride quality of KDOT 1 (PATB), KDOT 10 (DGAB), and KDOT 7 (LCB). It is clear that the drained PATB section (KDOT 1) remained smoother than the undrained sections for the past 12 years. The IRI of this section in 2003 was only 70 inches/mi. This section was also the smoothest after construction. The DGAB section (KDOT 10) is progressively becoming rougher than the LCB section (KDOT 7) with common design features mostly due to cracking. The section had extensive cracking in 2000 (75 ft of longitudinal and transverse cracking) and was repaired. For the 12-ft lane width, thicker PCC slabs (11 inches), and higher slab strength (900-psi), the section with DGAB (KDOT 11) was the smoothest, PATB was next, and LCB was the roughest, as shown in Figure 2 (b). LCB performs the worst among all base types. Faulting on all sections until 2003 was minimal.



(a) (b)

(c) (d)

Figure 2. Change of IRI with time for the drained and undrained sections

Figure 2 (c) shows the IRI progression on the sections with a 14-ft lane width, 900-psi design strength, and 8-in. PCC slab thickness. The sections are KDOT 2 (PATB), KDOT 9 (DGAB), and KDOT 8 (LCB). The section with the DGAB base (KDOT 9) showed the lowest increase in roughness, whereas the section with LCB showed the largest. However, KDOT 9 (DGAB) had some longitudinal and transverse cracking. No cracking was observed on the other sections until 2003. The increased roughness with LCB is also evident for the section with a 14-ft lane width, 550-psi design strength, and 11-in. PCC slab thickness, as shown in Figure 2 (d). For this design feature, the section with PATB (KDOT 3) was initially the smoothest after construction, and remained so over time. For these design features, the DGAB section, but not the others, showed some cracking. Faulting on all sections was also minimal until 2003.

Figure 3 shows the typical LTE vs. time relationships for the sections with 12-ft lane widths, 550-psi design strengths, and 8-in. PCC slab thicknesses. The LTE values appear to be good for all sections. As expected, the sections with stabilized bases showed higher LTE values than the sections with DGAB. The trends are similar for other SPS-2 sections with different design features. Some fluctuations were observed in the LTE values over the years because of the time/temperature variations during FWD testing. For example, during the 1997 testing, some sections showed low LTE values. However, in 2003 these sections had LTE values greater than 80%.

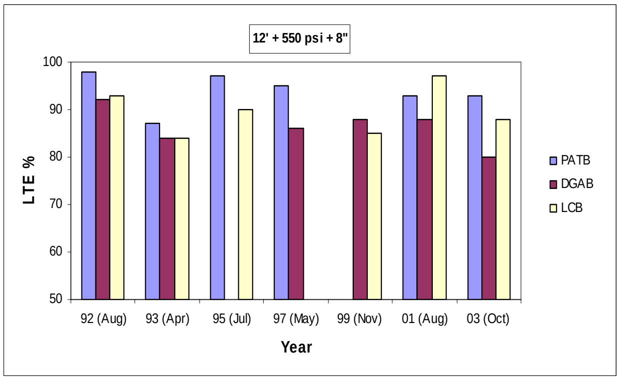


Figure 3. Change of LTE values with time

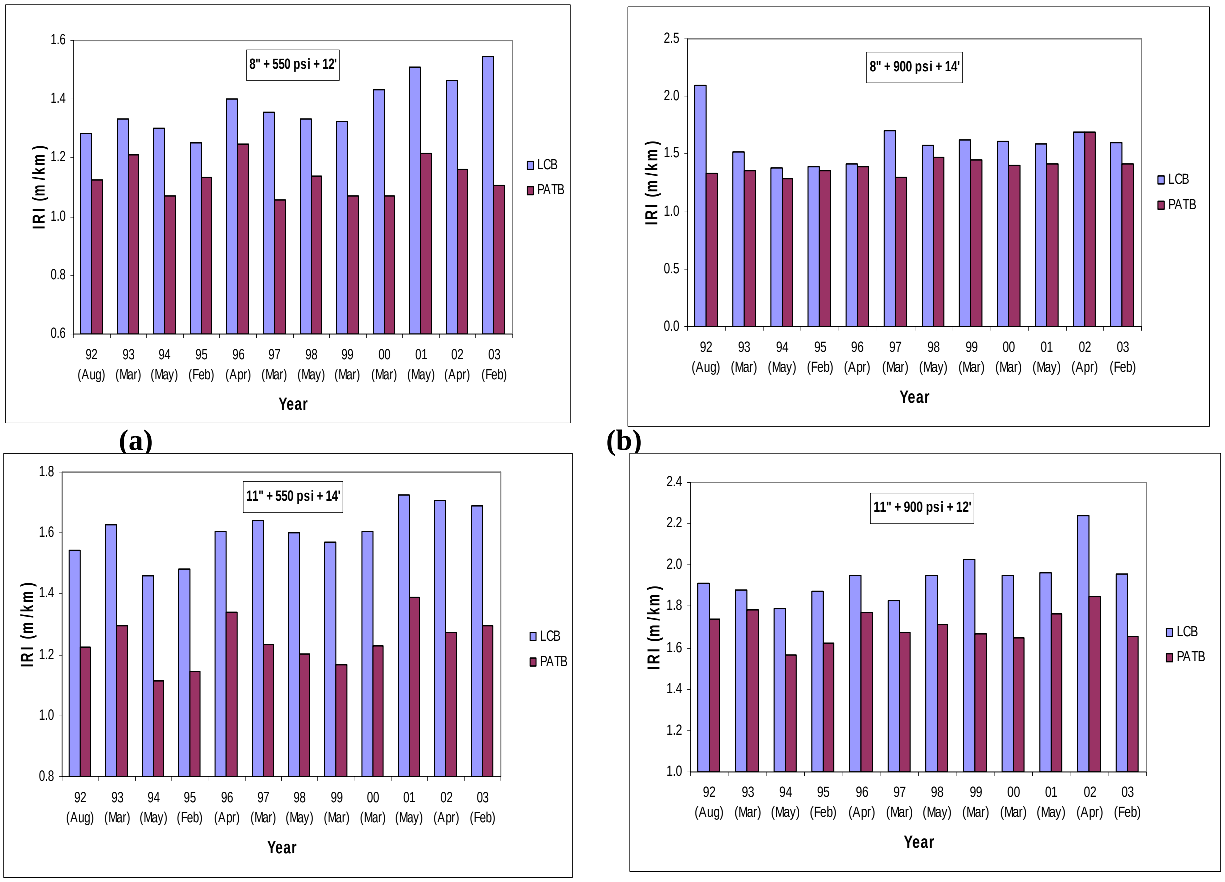
Base Type

PATB vs. LCB

Figures 4(a) through 4(d) compare IRI values for the sections with stabilized bases (PATB and LCB). The figures show that, for most design feature combinations, the PATB sections outperformed the LCB sections. The PATB sections were also built smoother initially. For the widened lane (14-ft) and high-strength sections, the IRI values are somewhat comparable, but for all other design features, the PATB sections are much smoother. It is noted that LTE values for some years are missing on some sections because no FWD tests at the joints were done on those sections during those years. On a few sections, LTE values were computed to be more than 100%, indicating locked joints, and were ignored during comparison.

Faulting is negligible on all sections. The PATB sections for the 12-ft lane width, 550-psi design strength, and 8-in. thickness and the 12-ft lane width, 900-psi design strength, and 11-in. thickness showed a very small amount of cracking (1.65 ft in 2003). For the 12-ft lane width, 550-psi design strength, and 8-in. thickness and the 14-ft lane width, 900-psi design strength, and 8-in. thickness, the PATB sections also showed higher LTE values with time than the LCB sections, in Figures 5(a) and 5(b), respectively. For other design features, both sections show comparable LTE values during recent years (Figures 5[c] and

5[d]). Based on the time-series trends of the performance measures in this study, the PATB sections outperformed those with LCB.



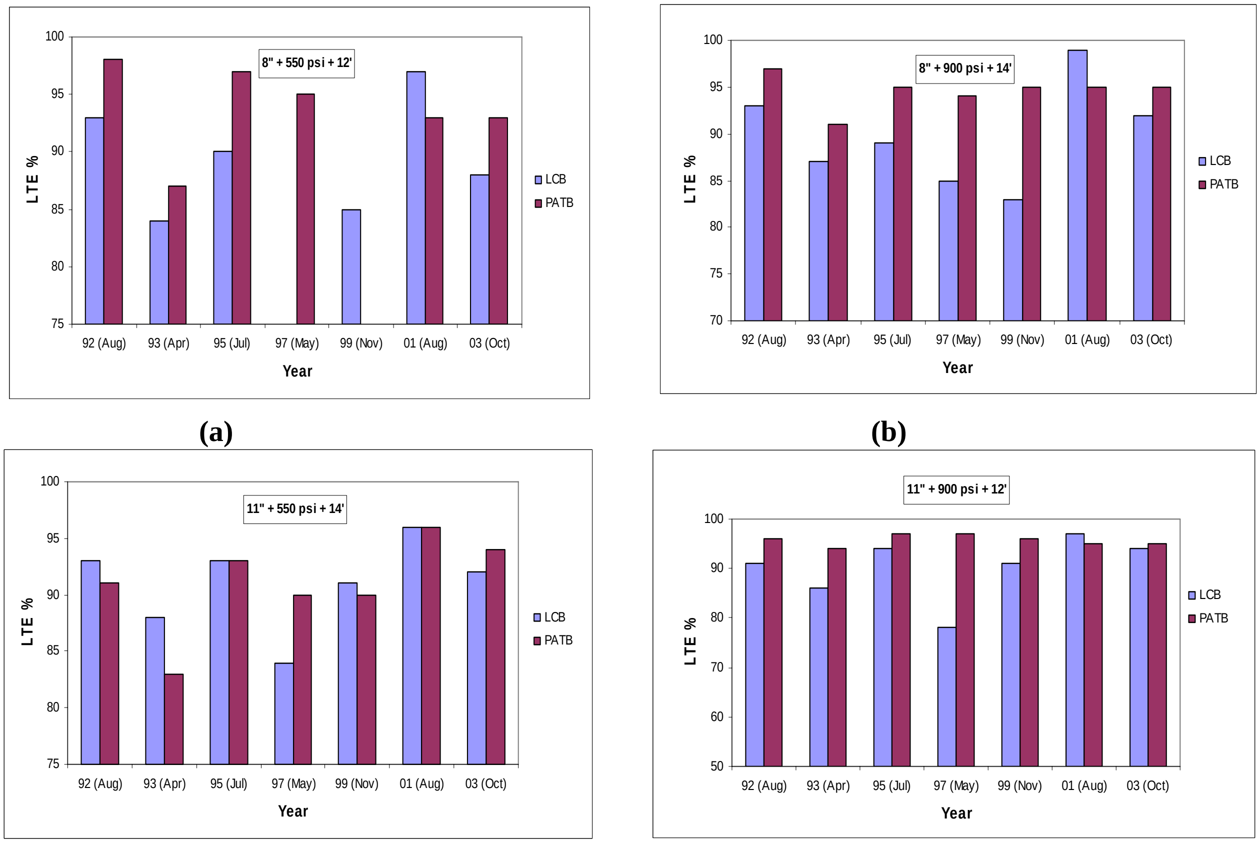
(a) **(b)**

(c) **(d)**

Figure 4. Change in IRI with time for the sections with stabilized base

LCB vs. DGAB

Figure 6 shows that for 12-ft lane width, 550-psi design strength, and 8-in. thickness, the DGAB section has become rougher more quickly than the LCB section. As mentioned, this DGAB section had a considerable amount of cracking and was repaired recently. For all other design features, the LCB sections have higher IRI values than the DGAB sections. The differences have recently become more prominent. Again, faulting has been very low on all sections, but since 2001, the section with DGAB and a widened lane (14 ft) has developed some negligible cracking. No cracking has been observed on the DGAB section with high strength and high thickness. It appears that the effect of the base layer is masked by higher PCC slab strength and thickness. The LTE values on the DGAB sections have been lower than those with LCB over the years (Figures 7(a) through 7(d)). However, the LTE values are generally good.



(a) **(b)**

(c) **(d)**

Figure 5. Change of LTE with time for sections with a stabilized base

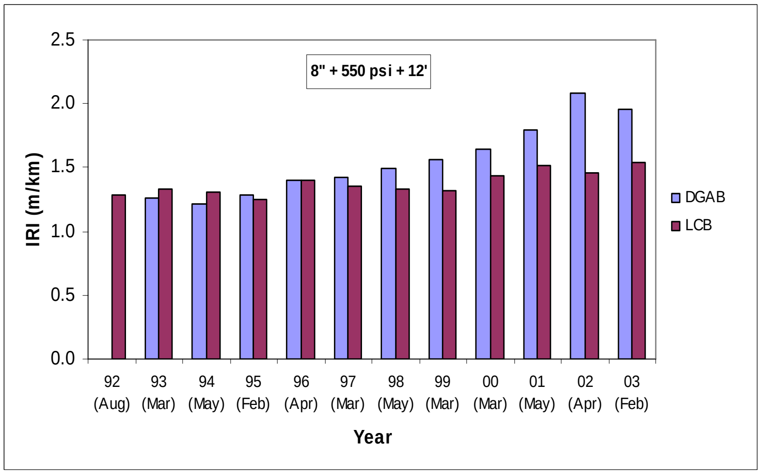
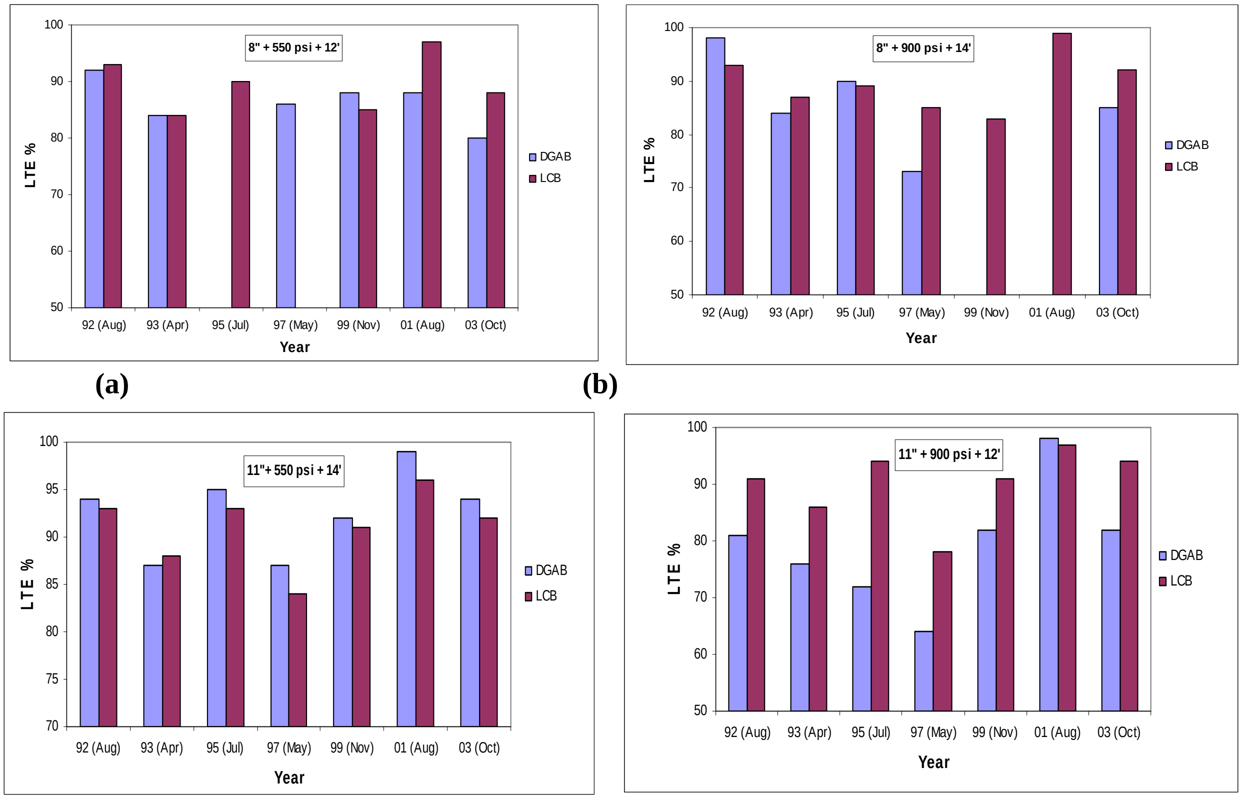


Figure 6. Comparison of IRI values for the sections with DGAB and LCB



(a) (b)

(c) (d)

Figure 7. Comparison of LTE values with time for the sections with DGAB and LCB bases

Control section vs. DGAB

As mentioned, the KDOT control section consists of a 12-in. PCC slab over a 6-in. dense graded portland cement-treated base (PCTB). This section's performance has been compared with the four DGAB-based sections: DGAB-1 [KDOT 10], DGAB-2 [KDOT 9], DGAB-3 [KDOT 12], and DGAB-4 [KDOT 11].

Figure 8 shows the change of IRI values with time for the sections with a DGAB base and the KDOT control section with a stabilized base. It is evident that the section (KDOT 9) with the widened lane (14 ft) and 900-psi design strength has remained the smoothest over time. However, this section has also showed some cracking recently (Figure 9) and has been repaired.

The KDOT control section can be described as the second best in terms of smoothness or IRI. The KDOT 10 (DGAB-1) section with 8-in. PCC slab thickness and 550-psi design strength has shown the highest increase in roughness. As mentioned earlier, this section has shown some distresses (Figure 9) and repairs have been made.

The joint LTE values of different sections with DGAB bases have also been compared with the values for the KDOT control section with PCTB, as shown in Figure 10. As expected, the KDOT control section has shown very good (greater than 80%) LTE values with time. However, all sections have shown good LTE most of the time. The LTE values for sections KDOT 9 (DGAB-2) and KDOT 11 (DGAB-4) have shown very high fluctuations over time.

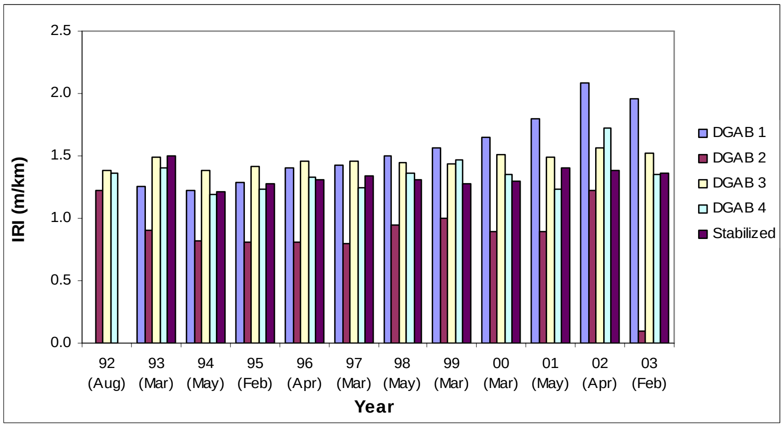


Figure 8. Change in IRI with time for the KDOT control section

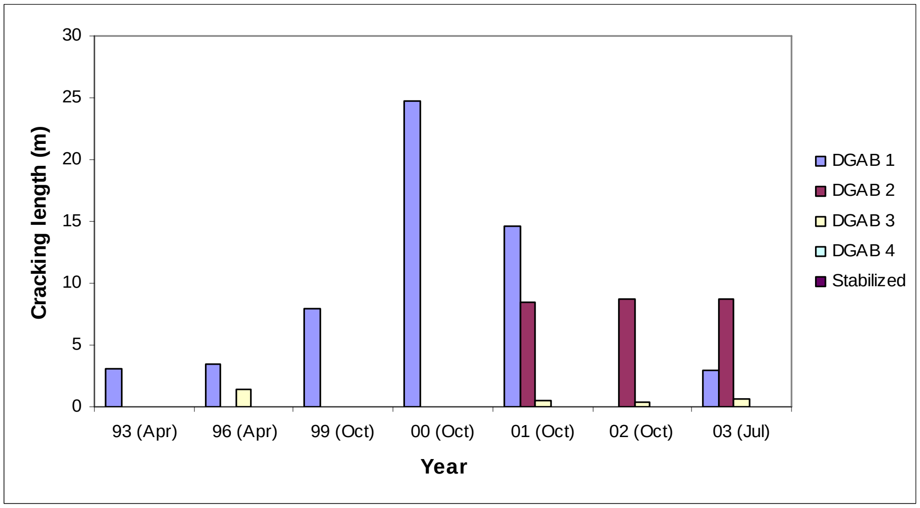


Figure 9. Cracking on the sections with DGAB bases

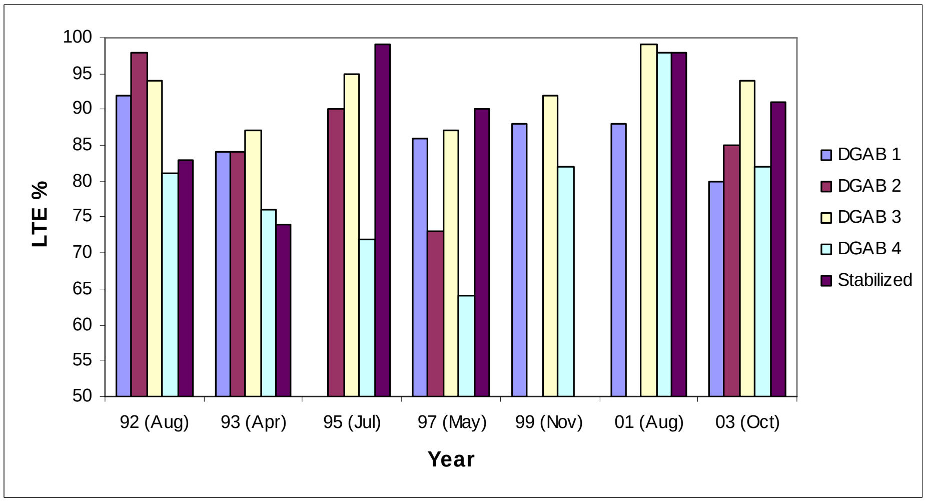


Figure 10. Change in LTE with time for the KDOT control section

LTPP EVALUATION OF KANSAS SPS-2 PROJECT

The LTPP program recently published a report on the initial evaluation and analysis of all SPS-2 projects using performance data up to 2000 (Jiang and Darter 2005). The study has found that the Kansas SPS-2 project is in good shape. The report presents the following findings for the SPS-2 project in Kansas:

(1) Designed vs. constructed performance is generally good. The key deviations from the LTPP guidelines are the following:

- Mean slab thickness values for five sections are more than 1/2 in. higher than the designed values.
- Mean 14-day flexural strength values for the lower strength concrete are more than 10% above the design values.
- Construction difficulties and deviations are relatively minor.

(2) Data availability is excellent overall.

- Site condition data are good, except for deficient traffic data and missing automatic weather station data.
- Only 66% of the cores have been tested.
- Good monitoring data, except for deficient faulting data, are available.

CONCLUSION

The 12-year performance of the Kansas SPS-2 project has been analyzed in this study with respect to the design features of drainage and base type. Based on this study, the following conclusions can be drawn:

- The Kansas SPS-2 project has performed very well to date. Most sections are smooth, crack free, and have negligible faulting. The LTE of the sections has been good too.
- The drainable PATB sections have performed the best. These sections were built smoother and remained so after 12 years of service.
- The LCB sections have not performed well in terms of smoothness, although they have maintained very good LTE.
- The section with low PCC slab thickness (8 inches) and low concrete design strength (550 psi) on DGAB has performed the worst.
- The combination of high slab thickness and high design strength tends to mask the effect of the base on pavement performance.
- The KDOT control section with a thick slab (12 inches) over dense graded portland cement treated base has also performed very well.

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