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Forensic study of the Ohio SHRP Test Road U.S. 23 flexible test pavement

Etude légale des trottoir flexible sure "l'Ohio SHRP Test Road US23"

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ABSTRACT
A forensic investigation was conducted on four sections of Ohio Test Road developing early longitudinal cracks and rutting. From various non-destructive and destructive tests, it was determined that the longitudinal cracks were top-down cracks initiated by segregation of surface layer asphalt mixtures at the time of construction. Rutting was developed at the base layers and subgrades due to weakening in the presence of excessive moisture which was, in turn, caused by higher than normal air voids in the segregated asphalt mixes.

RÉSUMÉ
Une recherche légale a été conduite sur quatre sections de l'Ohio SHRP Test Road développant de premières fissures longitudinales et rutting. À partir de divers essais non destructifs et destructifs, on a déterminé que les fissures longitudinales étaient les fissures de haut en bas lancées par la ségrégation des mélanges d'asphalte de couche extérieure à l'heure de la construction. Rutting s'est développé aux couches basses et au sous-grade dus à l'affaiblissement en présence de l'humidité excessive qui, alternativement, a été provoquée par des vides plus haut que normalement d'air dans les mélanges isolés d'asphalte.

1 INTRODUCTION

The Ohio Strategic Highway Research Program (SHRP) Test Road, located on U.S. Route 23, about 25 miles north of Columbus Ohio, encompasses forty test sections in the SHRP Specific Pavement Study (SPS)-1, SPS-2, SPS-8 and SPS-9 experiments. The SPS-1 experiment which was opened to traffic on August 14, 1996, was a strategic study of the effectiveness of various structural factors on the performance of flexible pavement. During the summer of 2002, localized distresses were observed in Sections 390103, 390108, 390109, and 390110 of the SPS-1 experiment. During the six year period, the Sections were closed for about 14 months to conduct controlled load tests and other maintenance works. A forensic investigation consisting of destructive and non-destructive testing was designed to determine the possible causes of rutting and fatigue cracks observed in these sections. The pavement designs for these four SPS-1 sections are outlined in Table 1. The layer thicknesses of each section were predetermined as a part of the strategic national study. Typical Ohio Department of Transportation (ODOT) materials were used. Environmental instrumentation was installed in Section 390110 at the time of construction to monitor temperature, moisture, and frost penetration in the pavement structure. Two monitoring wells were also installed at Sections 390103 and 390108 to determine water table elevations.

Table 1. Test Pavement Structure

Section	Thickness		Base Type	Drainage
	AC	Base		
390103	4"	8"	Asphalt Treated Base	No
390108	7"	12"	4" Permeable Asphalt Treated Base 8" Dense Graded Aggregate Base	Yes
390109	7"	16"	4" Permeable Asphalt Treated Base 12" Dense Graded Aggregate Base	Yes
390110	7"	8"	4" Asphalt Treated Base 4" Permeable Asphalt Treated Base	Yes

2 FORENSIC INVESTIGATION PLAN

To complete the forensic investigation of Sections 390103, 390108, 390109 and 390110, several tests and procedures were performed in each of the four test sections. The testing was subdivided into non-destructive and destructive testing. Non-destructive testing included photographs of selected areas that were referenced by station, distress surveys conducted according to the Distress Identification Manual for Long-Term Pavement Performance Project (SHRP, 1993), falling weight deflectometer (FWD) tests, and transverse profiles were taken to measure rutting. Destructive testing included dynamic cone penetration (DCP) tests, trenching, and recovering cores for laboratory testing. During the excavation of the trenches, material sampling, moisture testing, and stiffness testing was also completed.

3 PAVEMENT DISTRESS SURVEY

Visual observations of distresses were performed and are summarized in Table 2. Three different types of cracking were present in the four sections; fatigue cracking, wheel path longitudinal cracking and non-wheel path longitudinal cracking.

Table 2. Distress Summary of Sections

Section	Average Distress Severity	Max. Rut Depth (inch)	Longi-tudinal Cracking (center of lane)	Longi-tudinal Cracking (wheel path)	Avg Crack Width (inch)
390103	High	2.75	100%	90%	0.50
390108	Moderate	0.80	50%	50%	0.38
390109	Low	0.75	10%	10%	0.25
390110	Low	0.50	15%	10%	0.25

Low level fatigue cracking is an area of cracks with none or few connecting cracks and no pumping is present. Moderate severity fatigue cracking is an area of interconnected cracks forming a complete pattern still with no pumping present. High level fatigue cracking is an area of highly concentrated interconnected cracks, pumping may be present, and the pieces of cracked AC may move subject to traffic or pop out.

Low severity level longitudinal cracking indicates a long crack, not interconnected to others, with a mean crack width of less than ¼ inch. Moderate level cracking indicates a crack with a mean width greater than ¼ inch and less than ¾ inch. High severity level longitudinal cracking are cracks greater than ¾ inch.

Section 390103 showed the worst overall distress. High levels of rutting and longitudinal cracking were the most prevalent in this section. The longitudinal cracking was present in the center of the lane for the entire length of section 390103, with a mean crack width of about ½ inch. Also, longitudinal cracking of the same magnitude was noted along the inside edge of both wheel paths. Cold patch had been used to repair some of this area (Figure 1). The patching was classified as high severity patch. Extreme distress was indicated at this location. Fatigue cracking was present in approximately 25% of the right and left wheel paths, mostly concentrated at a short section. This fatigue cracking was classified as moderate in severity. Some fatigue cracking was also noticed on the shoulder throughout the length of the section.

Section 390108 generally displayed minor rutting, ruts less than 4/5 inch deep, and longitudinal cracking, over approximately 50% of the length of the center lane and along the inside edges of the wheel paths. The average crack width of the longitudinal cracking was approximately 3/8 inch. This section was classified as having moderate overall distresses.

Section 390109 experienced moderate overall rutting of less than ¾ inch deformation, and fatigue cracking over less than 10% of the total area of the section. Longitudinal cracks less than ¼ inch wide were very apparent in both wheel paths and in the center of the lane for the entire section length. This section was classified as having low overall distresses.

Section 390110 was categorized as having mild rutting and moderate longitudinal cracking. The maximum rut depth for this section was approximately ½ inch and the average longitudinal crack width was about ¼ inch. Overall this section was also classified as having low level distresses.

Figure 1. Distress photograph of Section 390103 (left) and typical longitudinal cracks (right)

3.1 Longitudinal cracking

The longitudinal cracking observed in all four sections during trench excavation, was initiated on the pavement surface and was considered to be top-down with low to moderate severity as shown in Figure 2. Unlike the conventional longitudinal cracks which develop at the bottom of asphalt layers under excessive tensile stresses, the top-down cracks initiate from the surface of pavement and seldom reach the bottom of the asphalt layers. Holewinski et al. (2003) summarized several mechanisms and causes of the top-down crack. For each section, the longitudinal crack consistently occurred in the center of the lane in all four sections and did not stray from a straight line path. The longitudinal wheel path cracking occurred on the edge of the wheel path and also was consistent in forming a straight line. The wheel path cracks were shallower than the center line cracks. None of the longitudinal cracks extended all the way to the bottom of the base, most were within the first four inches of the surface. Very similar observations were made during the recent Colorado top-down crack study (Harmelink and Aschenbrener, 2003). Of twenty-five longitudinal crack sites in Colorado, 72% were top-down cracking and 67% of the top-down cracking associated with visual segregation at the bottom of the surface layer. Figure 2 shows the segregation, i.e., a relatively large portion of coarse aggregates are distributed at the bottom half of the surface layer. The Colorado study further identified the source of the segregation. Certain models of pavers caused the early longitudinal cracking at the pavement locations corresponding to the edges of the slat conveyors and the center point of the paver. This explains the straight line longitudinal cracks shown in Figure 1.

Figure 2. Top-down longitudinal crack and segregation of surface layer

3.2 Rutting

Rutting is defined as a surface depression located in the wheel path. Two methods were used to determine the profiles of the pavement; dipstick and laser profilometer. Thirteen profiles were taken for each section approximately forty feet apart. Transverse profiles from Section 390103 for the dipstick and profilometer shown in Figure 3, illustrate significant variations in profile from the proposed design. Rutting is not classified according to severity levels, but by the rut depth. The maximum rut depths for each section are outlined in Table 2. It should be noted that the profiles measured with the dipstick and profilometer were very similar, and differences between the two can be attributed to each instrument starting at a slightly different reference point on the pavement.

4 NON-DESTRUCTIVE TESTING

Falling Weight Deflectometer (FWD) tests were conducted every fifty feet along the centerline and right wheel path on the surface of the asphalt pavement. The tests were staggered to provide better coverage. In FWD test, the adjustable weight is dropped onto a rubber cushioned circular loading plate with a diameter of 12 inches. Once the weight is dropped, the vertical displacement is measured by a series of geophones placed at equal distances. The data is recorded and can be used to calculate elastic modulus values for pavement layers.

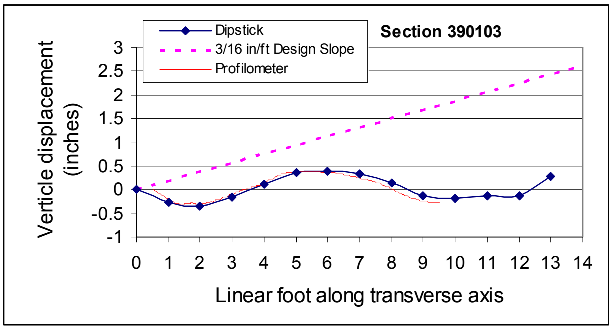

Figure 3. Transverse profile of Section 390103

Maximum deflection locations for each section shown as a large spike in the FWD deflection profile along the length of the Sections correlate with where the worst distresses took place in each section. Also in comparing the transverse profiles with the FWD plots, the greatest rutting is located in the same general location as the higher deflection points.

FWD tests were also conducted during construction after completion of each pavement layer. All FWD profiles along the length of the Sections for subgrade, base, and surface layer were uniform without a large deflection spike, indicating no flaw in the layers of the pavement during construction.

The resilient modulus for each structural layer was also estimated by a back calculation technique using FWD data. The back calculation program selected for this analysis was MODULUS 4.2 (Michalak and Schllion, 1995). This program based on the multilayer linear elasto-static theory. It should be noted that when a layer thickness is thin such as 390103 AC layer, the back-calculated modulus may be inaccurate. However, since the calculation algorithm used in this study is less user-input-dependent, comparison of resilient moduli before and after distress could be used as a measure of the extent of distress.

Resilient moduli determined just after completion of construction are compared with the moduli determined from this forensic investigation and shown in Table 3. It is clearly seen from the comparison that all the layers in four sections showed a decreased in resilient modulus. This indicates that the pavement structure was weakened by the various distresses.

Table 3. Resilient moduli just after construction and after development of distresses

Section	Layer	MR (ksi) after: Construction	Distress	% Change
390103	AC	2762	2053	-25.7
	ATB	83	33	-59.9
	Subgrade	16	11	-30.6
390108	AC	781	315	-59.7
	PATB	83	57	-31.4
	DGAB	41	12	-70.5
	Subgrade	24	23	-5.4
390109	AC	843	369	-56.2
	PATB	124	119	-4.4
	DGAB	24	17	-29.2
	Subgrade	23	26	12.2
390110	AC	708	524	-26.0
	ATB	163	191	17
	PATB	51	31	-40.2
	Subgrade	19	22	13.7

Figure 4. Measurement of lift layers at a trench

5 DESTRUCTIVE TESTING

5.1 Trenches

Lateral trenches roughly five feet wide and four feet deep were excavated at locations in each section representing various levels of distress. Three trenches were excavated in Sections 390103 and 390110, and two trenches in Sections 390108 and 390109. The longitudinal cracks were visually inspected as previously shown in Figure 2.

The thickness of individual pavement and base lifts were also measured at three foot intervals with a standard tape measure along the length of each trench and estimated to the nearest ¼ inch (Figure 4). In some locations it was difficult to see the layer interfaces. While the extent of rutting was very apparent in some sections, the thickness of the pavement layers remained consistent with their design thickness throughout the transverse length of all the trenches, indicating minimal, if any rutting in the asphaltic material. Some consolidation of the base layers was noted.

In-situ subgrade stiffness was measured at different depths in the trenches with a Humboldt Stiffness Gauge. Measurements were taken at six and twelve inch depths at the same transverse location as the trenches were excavated. Overall, the data revealed considerable variability in stiffness with depth in each section. In Section 390103 a strong trend in the data showed the stiffness escalating at a location of twenty-four inches below the surface as shown in Figure 5. This trend was present in all sections in at least one trench. In Section 390108 the trend was present in trench #1 in the wheel path location, and in Section 390110 in trench #1 for the wheel path and center line locations. Section 390109 seems to also follow the same pattern, with the higher stiffness measurement being at the same depth in the subgrade.

5.2 Percent air void and asphalt content of cores

During the forensic study, cores were taken from each section. Cores taken from the wheel-pass tended to have a slightly lower air void than cores taken from the center of the lane due to traffic loading. The differences between them were small, and the average values were used for discussions. Air voids of surface and intermediate layers ranged between 9.5% to 13%.

All surface and intermediate layers were dense graded mixes which would, in normal practices, have about 7% air void just after construction and would reach the 4% design air void after a few years of consolidation under traffic. However, cores

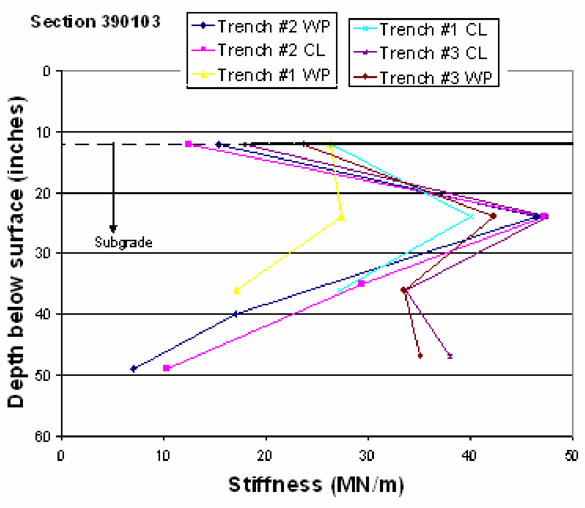

Figure 5. Humbolt subgrade stiffness of Section 390103

taken from the test sections had a much higher air void content after 4.5 years of heavy traffic loading. This is believed to be due to segregation as previously shown in Figure 2. Asphalt mixes with high air voids generally lead to a high permeability which will allow moisture infiltration.

5.3 *Moisture content of subgrade*

Moisture content was determined by three methods; traditional laboratory methods, a nuclear gauge, and TDR probes. Soil samples and nuclear gauge readings were taken at approximately six and twelve inch depths during excavation of the trenches. The soil samples were then transferred to the laboratory in sealed containers, and tested for moisture.

As shown in Table 4, an inverse relationship between stiffness and moisture content was noted. When the moisture content was higher, the stiffness of the subgrade was low, and vice versa. Further examination of the stiffness moisture relationship may suggest that moisture was seeping up through the subgrade, and also down through the pavement structure. The increase in stiffness indicated by the Humboldt readings and lower moisture content at a depth of twenty-four inches may indicate the moisture had not gotten to this point from either direction.

TDR data suggested a significant increase of moisture readings between January and later in the summer showing a strong seasonal variation in moisture.

A seasonal variation was also observed at the water table. Observations made on two monitoring wells showed that the peak water elevations occur mainly in the spring months of April and May each year, and the low point elevations mainly in the late fall months each year. The highest water table elevations recorded for the two wells were 3.42 and 5.37 feet below the surface of the subgrade. With the water table being so close to the surface of the subgrade in this area, adequate drainage systems are crucial to the endurance of the pavement.

From the nuclear gauge data, it was determined that the subgrade soil was very close to being fully saturated (80-100%) in the sections tested with the nuclear gauge.

Free water was observed between the layers in the subgrade, between the asphalt pavement and base layers, and water could also be seen "seeping" from the subgrade which is another indication of saturation. This indicated a lack of adequate drainage in the four pavement structures, even though Sections 390108, 390109, and 390110 were constructed with edge drains.

Table 4. Gravimetric moisture content and modulus of subgrade

Section	Moisture Content Range		Resilient Modulus, ksi	
	Low	High	DCP	FWD
390103	14.7%	30.2%	12.6	11.1
390108	5.8%	25.6%	24.4	22.7
390109	5.6%	23.3%	21.1	25.8
390110	12.9%	27.0%	22.5	21.6

5.3 *Dynamic cone penetration*

Dynamic Cone Penetration (DCP) tests were conducted every 100 feet in both the centerline and wheel path, and also at trench locations. This data was also used to calculate the resilient modulus of the subgrade.

The resilient modulus (M_R) of the subgrade was calculated for each section from the DCP tests. The M_R was determined from DCP data using following equations (Lvneh, 1987).

$$M_R = 1200 \times CBR$$

$$\log_{10}(CBR) = 2.20 - 0.71 \times \log_{10}(PI)^{1.5} \pm 0.075$$

Where,
PI = the DCP penetration index (mm/blow), and
CBR = California Bearing Ratio.

The average resilient modulus of the upper level of subgrade in all four sections are given in Table 4. The resilient modulus of the subgrade determined from FWD which is given in Table 3 were also presented in Table 4 for easy comparison with DCP derived modulus values. Unlike FWD, DCP could provide continuous characterization of soil with depth. DCP profiles of all sections indicated similar subgrade soils. Moduli determined by FWD and DCP showed fair agreement.

6 CONCLUSIONS

Despite the use of various base materials and the presence of edge drains in three sections, higher than anticipated levels of subgrade moisture were present in all four pavement sections. This moisture was the underlying cause of rutting and cracking. While edge drains probably removed some moisture infiltrating down from the pavement surface, they provided little benefit for moisture migrating up through the subgrade. Laboratory measurements and DCP field tests showed the subgrade soil in three sections with edge drain to have similar values of resilient modulus and moisture content regardless of the type of base used. The thickness of the AC pavement layer remained constant across the right wheel path in all test sections, indicating that rutting observed in the pavement surface had reflected up from the base and subgrade. The longitudinal cracks were top-down cracks initiated by the segregation of surface layer asphalt mixtures. The segregation across the entire test sections is evident from visual inspection and from unusually high air void contents. The high air void would have contributed to a high moisture content at the underlying layers. The straight line nature of the cracks suggests that the augers or spreaders in the pavers are the most likely cause of these defect as identified in Colorado study.

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