National Open House
Two-Lift Concrete Paving
October 15 – 16, 2008
Salina/Abilene, KS – Interstate 70

KANSAS
DEPARTMENT OF TRANSPORTATION

KOSS
CONSTRUCTION CO.

U.S. Department of Transportation
Federal Highway Administration

National Concrete Pavement
Technology Center

CP Tech Center

Introduction

Construction of a two-lift pavement in the United States was the highest priority implementation recommendation of the team that participated in the Long-Life Concrete Pavement Scan conducted in May 2006. Working together, the Kansas Department of Transportation (KDOT), Koss Construction Company and the Federal Highway Administration (FHWA) have successfully fulfilled this objective. In June 2008, a pilot two-lift test section was constructed on a section line road near Pleasanton, Kansas; this was followed in September, 2008 by the construction of multiple two-lift sections on Interstate 70 in Saline County, Kansas (Figure 1).

Figure 1 Location of Two-Lift Pavement Construction 2008

The purpose of the pilot demonstration was to allow Koss Construction and KDOT to become comfortable with both the construction of a two-lift pavement and an exposed aggregate surface treatment before embarking on construction of a full scale section of I-70 in central Kansas. Lessons learned from construction of the pilot section included:

- Width and alignment of the two pavers placing the two lifts requires special attention.
- While important for all slipform paving operations, consistent delivery of uniform concrete is even more critical for the construction of two-lift pavements.
- Curing compound applied over the surface retardant appeared to interfere with the effectiveness of sweeping operations for exposing the aggregate.

Based on these observations, the following adjustments were made by Koss Construction for the I-70 two-lift sections:

- The paver placing the bottom lift was set approximately 1" narrower than the paver for the top lift.
- A central mix plant and end dump haul units were utilized for the batching, mixing and delivery of the top lift as opposed to the pilot project where a dry batch plant and transit mix trucks were used.
- Initial curing was accomplished with polyethylene sheeting placed after the surface retardant instead of a liquid membrane curing compound.

A comprehensive report of the two-lift pavements will be available in December, 2008; after all materials testing can be completed. The final report will be available for download from the National Concrete Pavement Technology Center's web site at: http://www.cptechcenter.org/.

Typical Sections

Figures 2 through 4 represent the existing typical section, as-built typical section and the as-designed typical section.

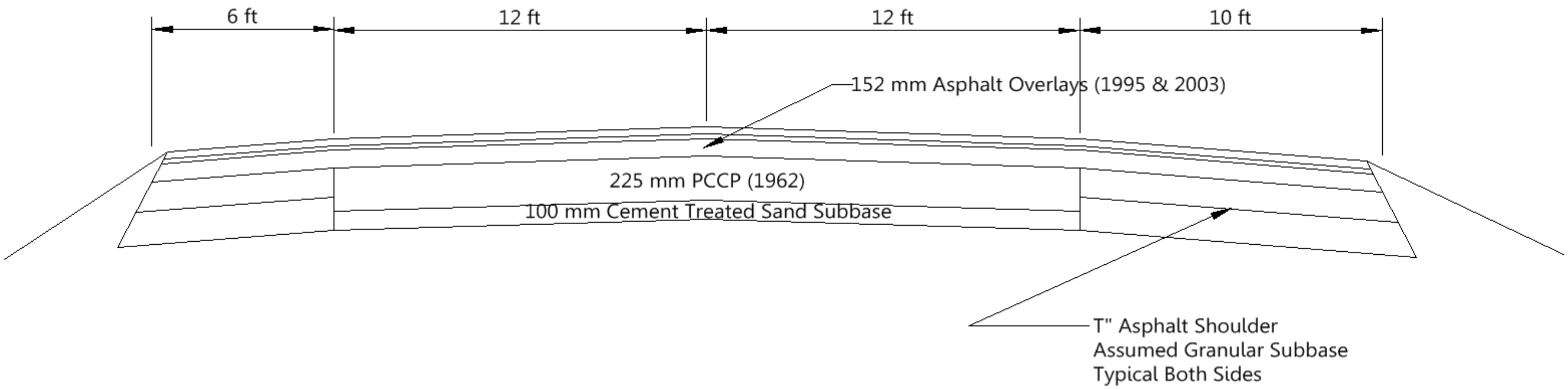

Figure 2 Existing Typical Section

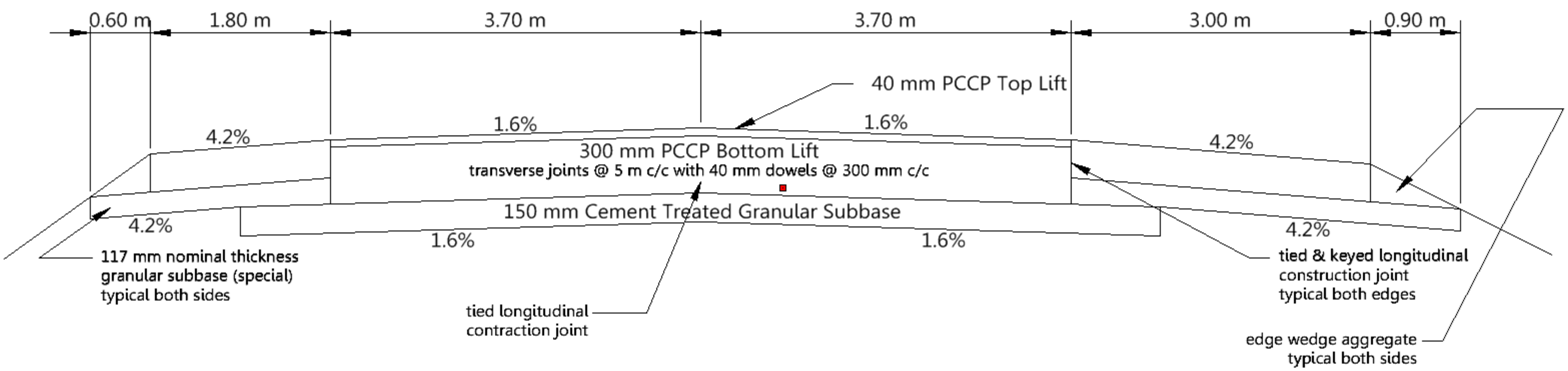

Figure 3 As-Built Typical Section

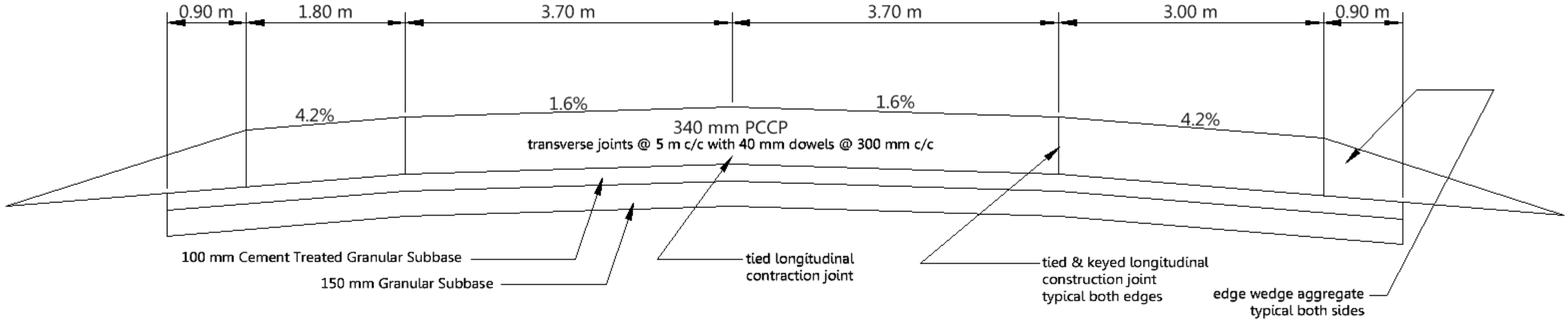

Figure 4 As-Designed Typical Section

Layout of Test Sections

Multiple two-lift sections were constructed on the eastbound lanes of I-70. The primary difference between these sections is the surface texture. A layout of the various surface textures constructed is shown in Figure 5.

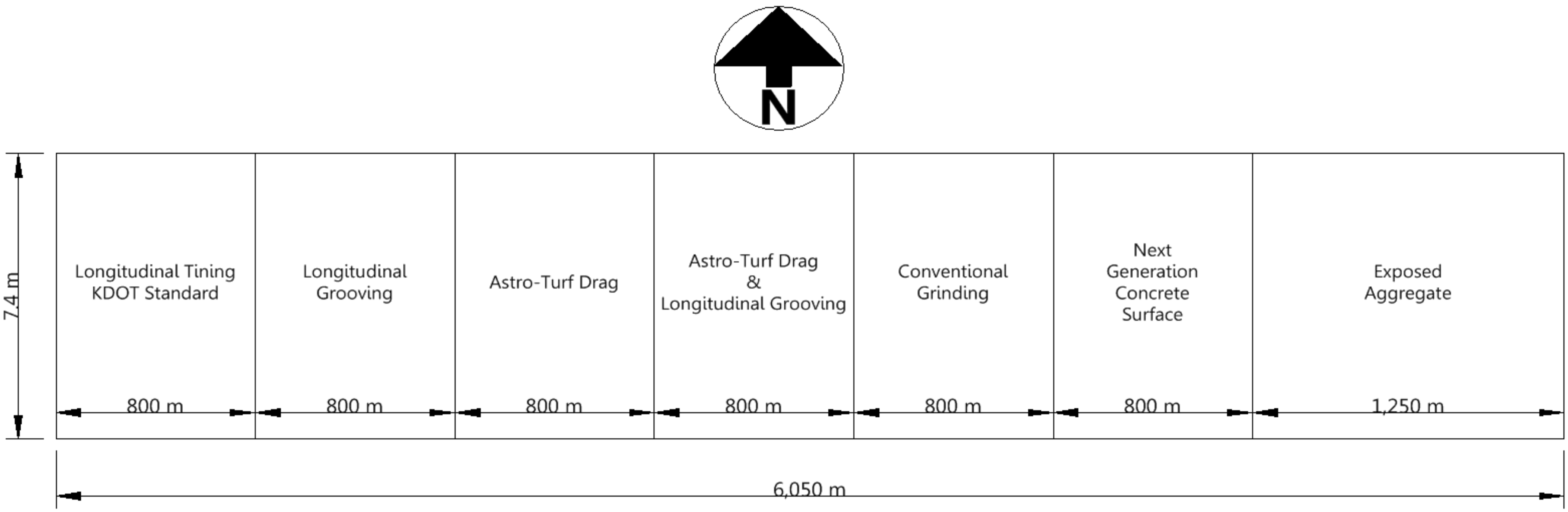

Figure 5 Two-Lift Surface Texture Variables

Concrete Mix Proportions

The same concrete mixture proportions were utilized for the bottom lift of all sections. Two different concrete mixture proportions were used for the top lift sections; a durable mix and an exposed aggregate mix (Table 1).

Item	Bottom Lift		Top Lift Textured Sections (Durable Lift)		Top Lift Exposed Aggregate Section	
	lb/yd^3	kg/m^3	lb/yd^3	kg/m^3	lb/yd^3	kg/m^3
Portland Cement (Monarch Type I/II)	548	325	438	260	526	312
Fly Ash Class F (Ash Grove Durapoz)			110	65	132	78
Coarse Aggregate (CA-6, Limestone, Hamm @ Woodbine)	1743	1033				
Coarse Aggregate (5/8", Rhyolite, Hanson @ Davis, OK)			1576	934		
Coarse Aggregate (1/2" x #10, Rhyolite, Hanson @ Davis, OK)					2071	1228
Fine Aggregate (MA-3, Natural, Konza @ Junction City)	1221	724	1518	900		
Fine Aggregate (Mason Sand, Natural, Konza @ Junction City)					855	507
Water	236	140	236	140	270	160
Coarse Agg.:Fine Agg. Ratio	60:40		50:50		70:30	
W/CM	0.43		0.43		0.41	
Design Air Content	6.5%		6.5%		6.5%	
Air Entraining Admixture (Euclid AEA 92S)(oz/yd^3)	14		20		29	
Mid-Range Water Reducer (Euclid Plastol 341)(oz/cwt)	5					
Anti-Bleed/Anti-Segregation Admixture (Eucon ABS)(oz/yd^3)	5.5					
Type A Water Reducer (Eucon WR-91)(oz/cwt)			5		5	

Table 1 Concrete Mixture Proportions

Combined Gradation of Concrete Mixtures (Figures 6 and 7):

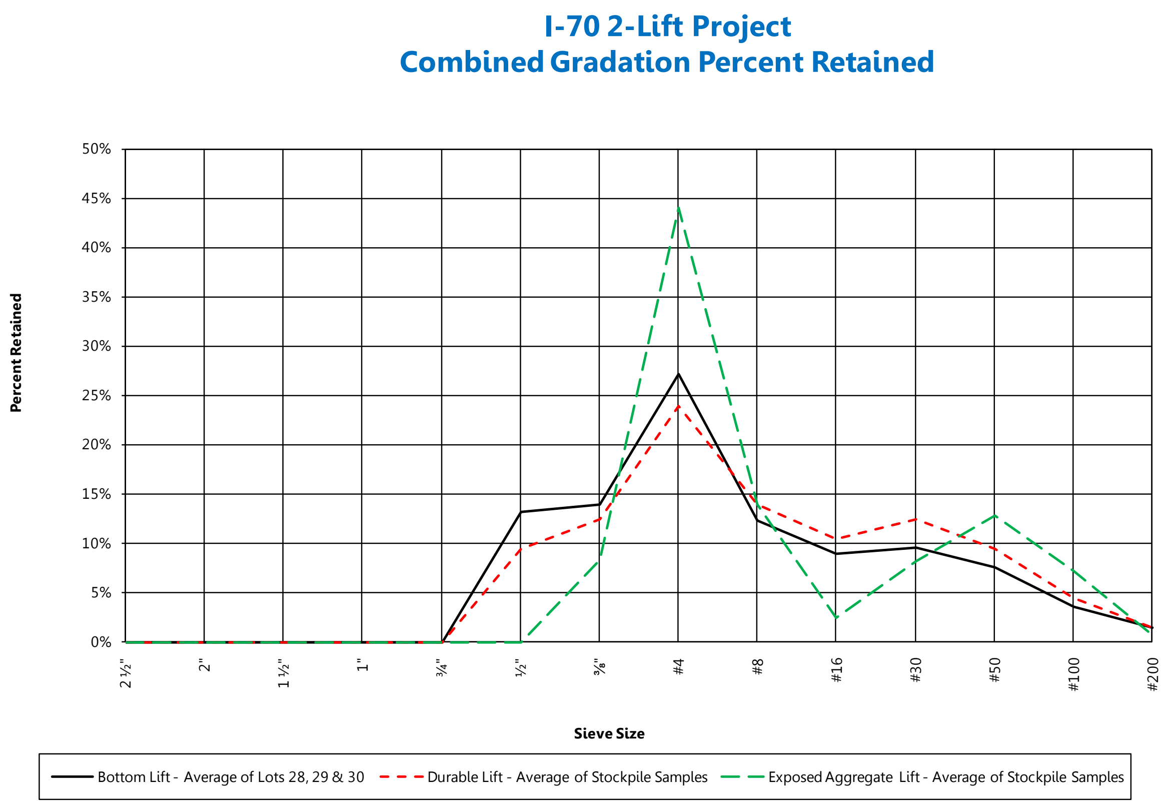

Figure 6 Combined Percent Retained

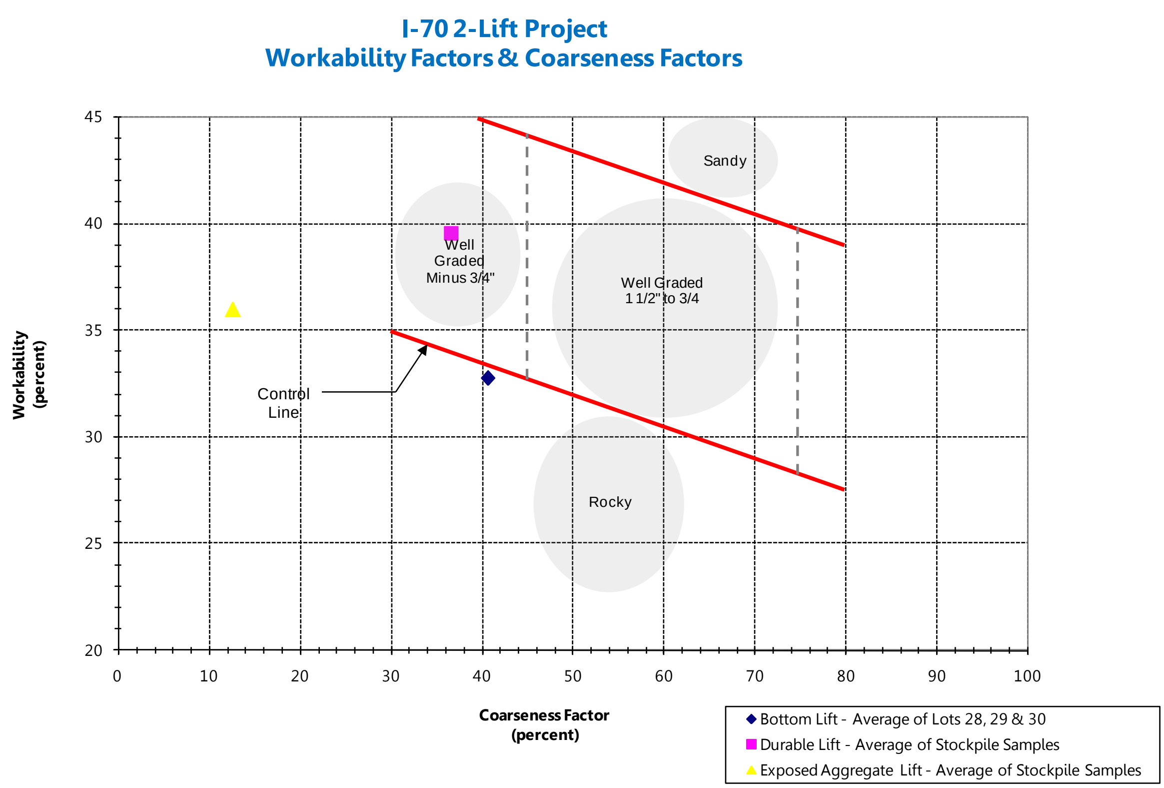

Figure 7 Workability and Coarseness Factors

Fresh Concrete Properties

Bottom Lift (Table 2 and Figures 8 through 13):

	air content (%)	slump (in)	unit weight (lb/ft^3)	concrete temp. (°F)	microwave w/cm	ava spacing factor (mm)
n	79	79	79	57	6	61
minimum	4.2	0.5	134.1	65.7	0.44	0.180
maximum	9.0	3.5	143.5	82.6	0.47	0.442
average	7.0	1.3	139.0	75.6	0.45	0.285
standard deviation	0.9	0.5	1.7	3.4	0.01	0.062

Table 2 Summary of Bottom Lift Fresh Concrete Test Results

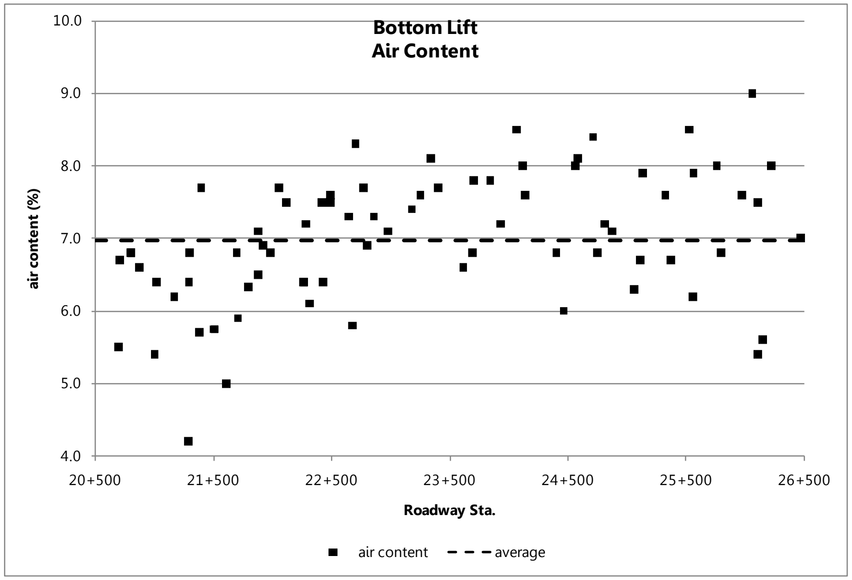

Figure 8 Bottom Lift Pressure Air Content

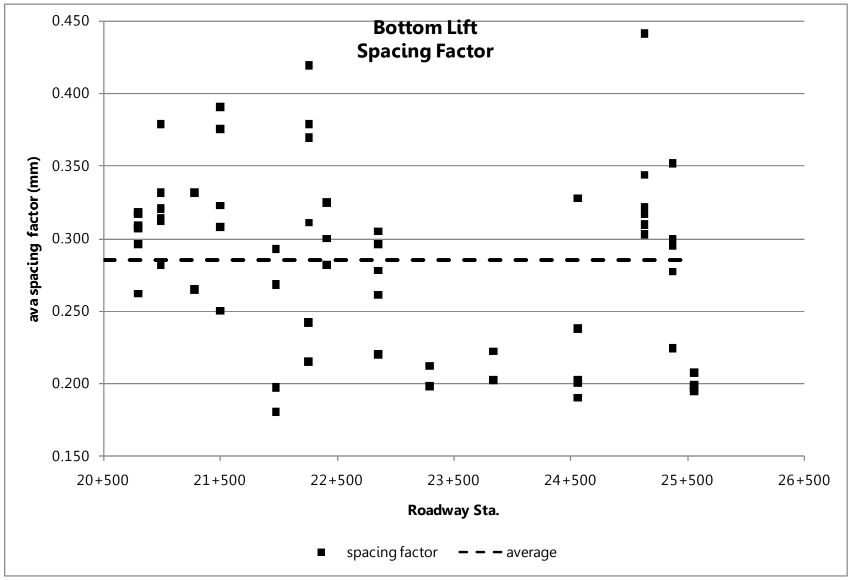

Figure 9 Bottom Lift AVA Spacing Factor

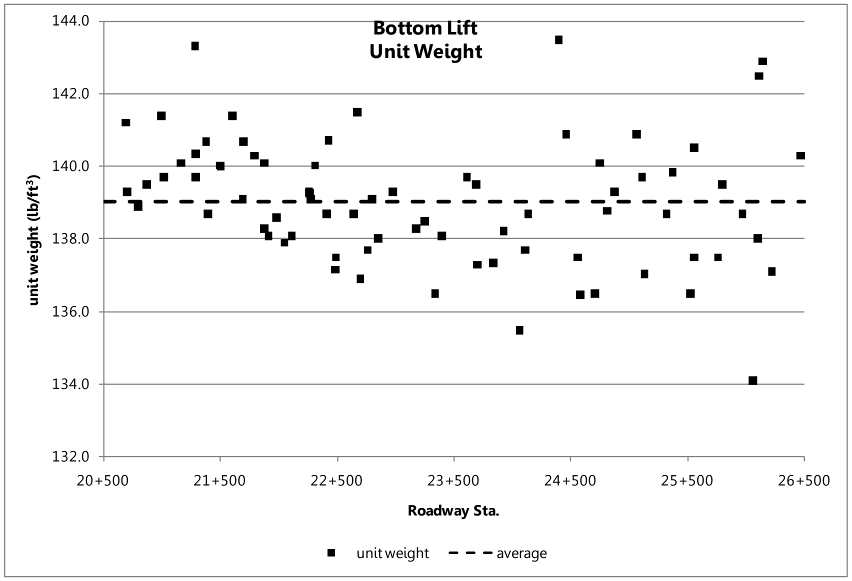

Figure 10 Bottom Lift Unit Weight

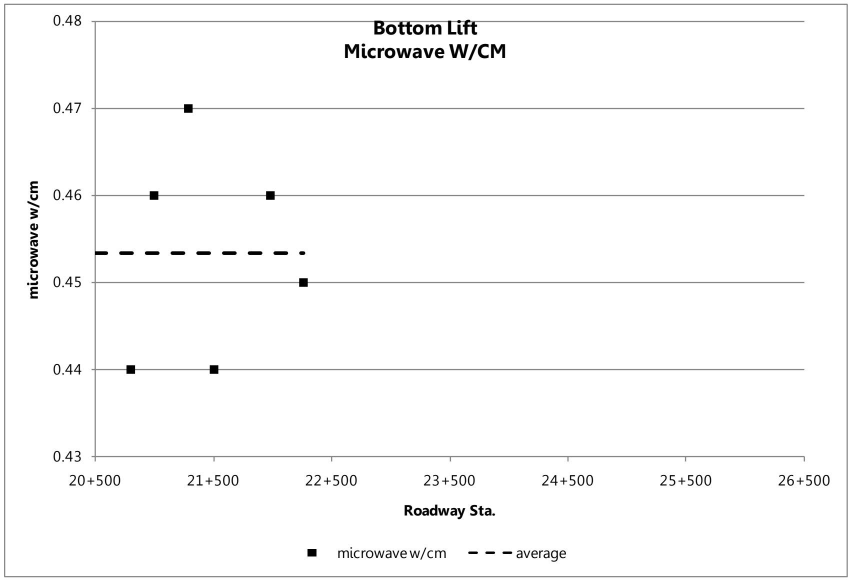

Figure 11 Bottom Lift Microwave W/CM

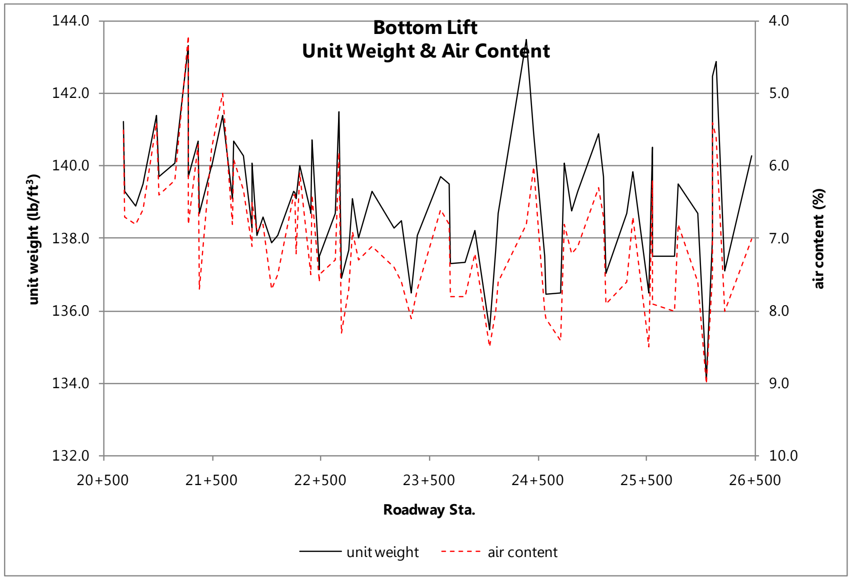

Figure 12 Bottom Lift Unit Weight and Air Content

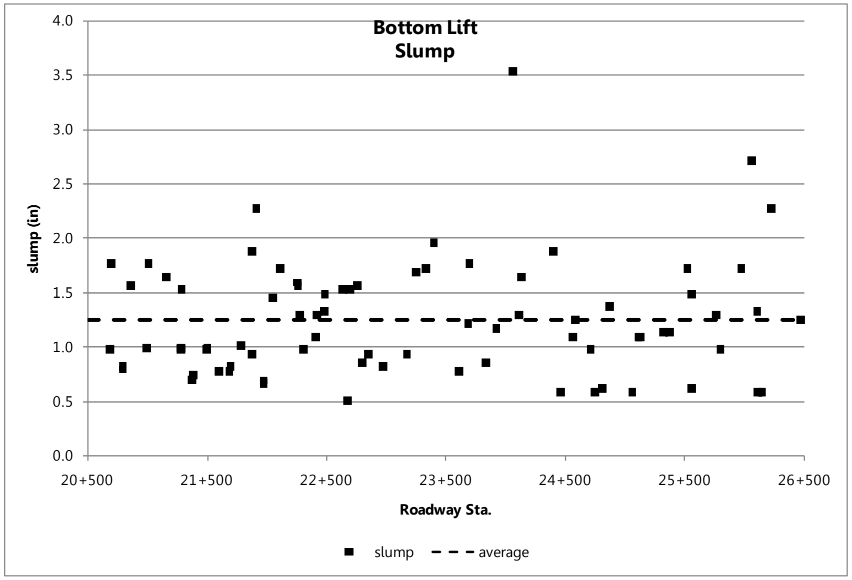

Figure 13 Bottom Lift Slump

Durable Lift (Table 3 and Figures 14 through 19):

	air content (%)	slump (in)	unit weight (lb/ft^3)	concrete temp. (°F)	microwave w/cm	ava spacing factor (mm)
n	62	62	60	42	6	55
minimum	5.4	0.5	136.7	65.1	0.41	0.137
maximum	11.8	3.3	148.8	81.0	0.48	0.507
average	7.5	1.9	142.4	75.9	0.44	0.234
standard deviation	1.4	0.7	2.4	3.8	0.03	0.079

Table 3 Summary of Durable Lift Fresh Concrete Test Results

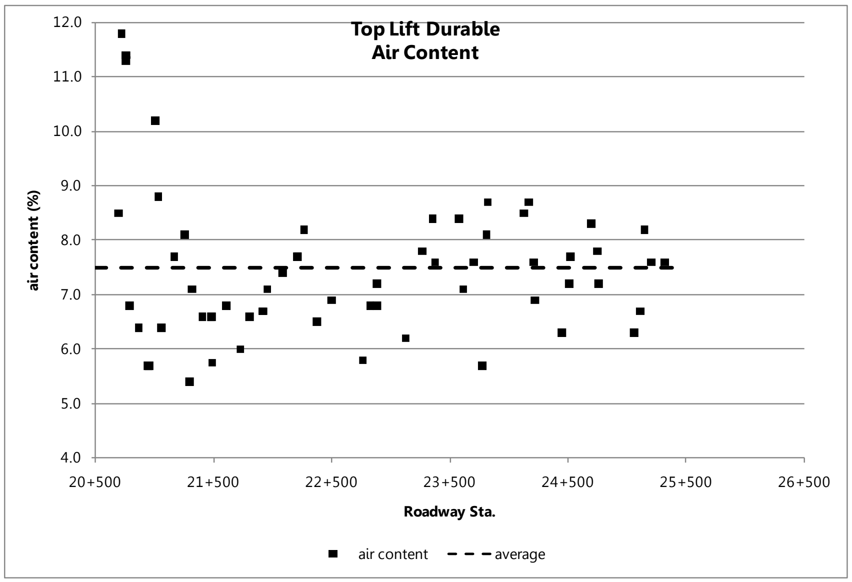

Figure 14 Durable Lift Pressure Air Content

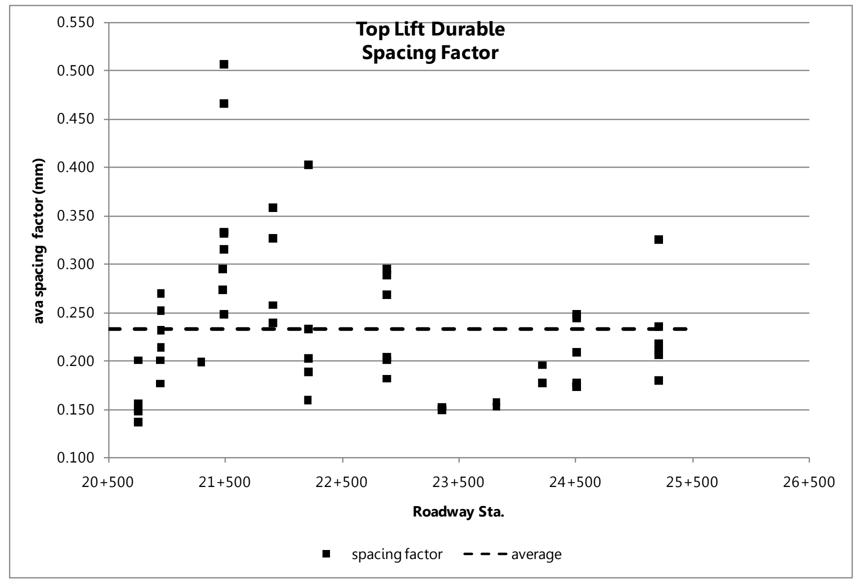

Figure 15 Durable Lift AVA Spacing Factor

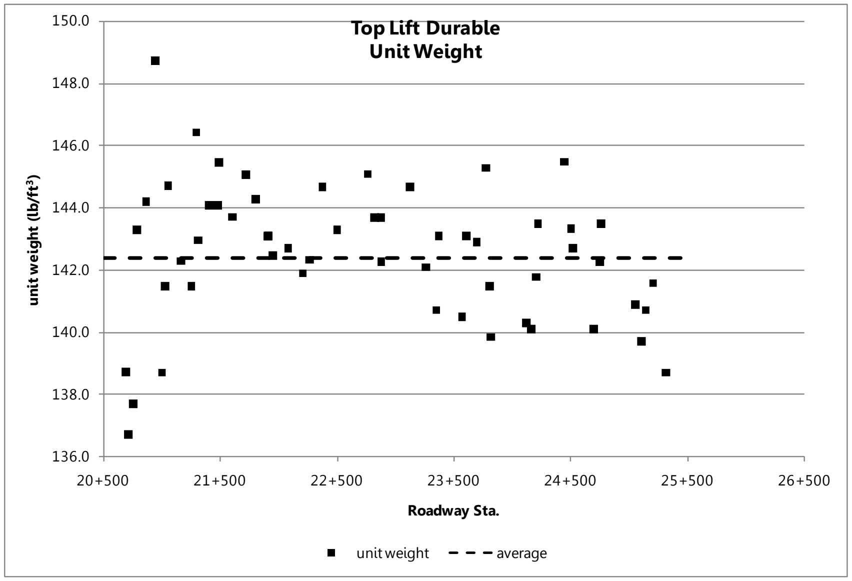

Figure 16 Durable Lift Unit Weight

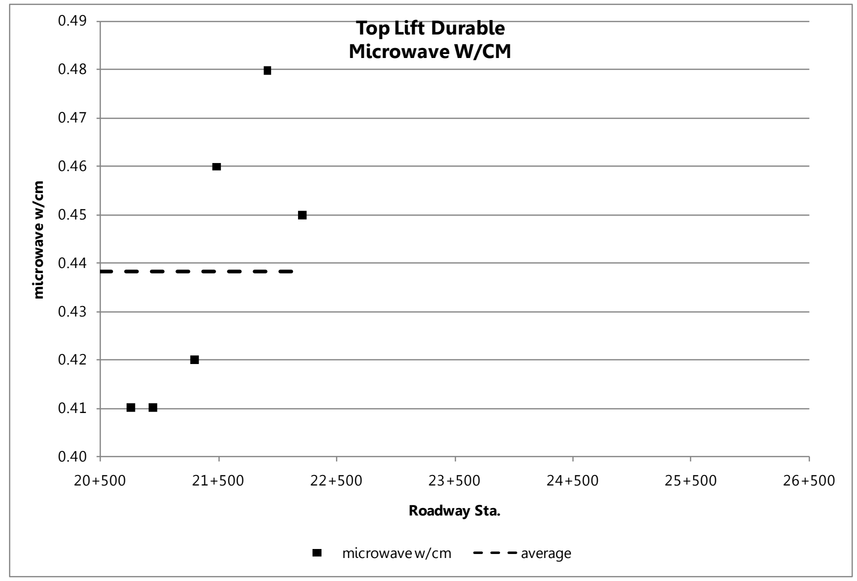

Figure 17 Durable Lift Microwave W/CM

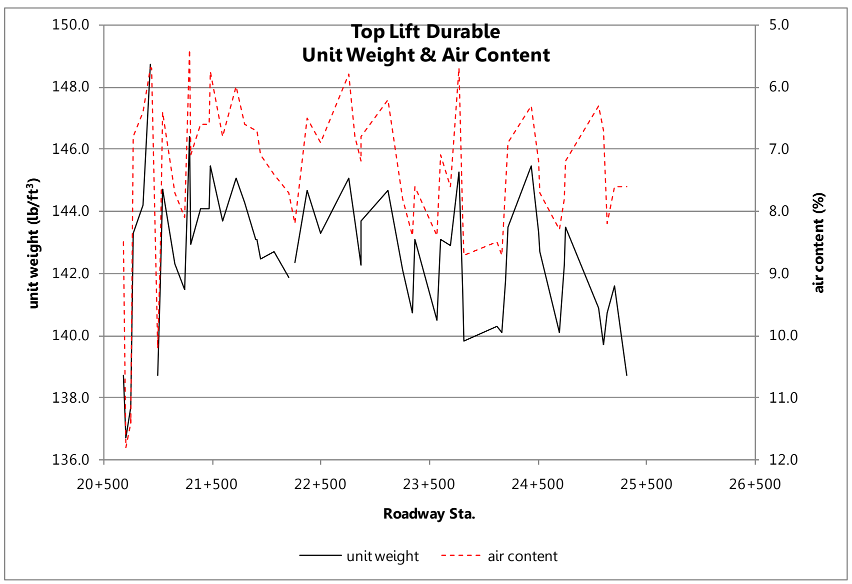

Figure 18 Durable Lift Unit Weight and Air Content

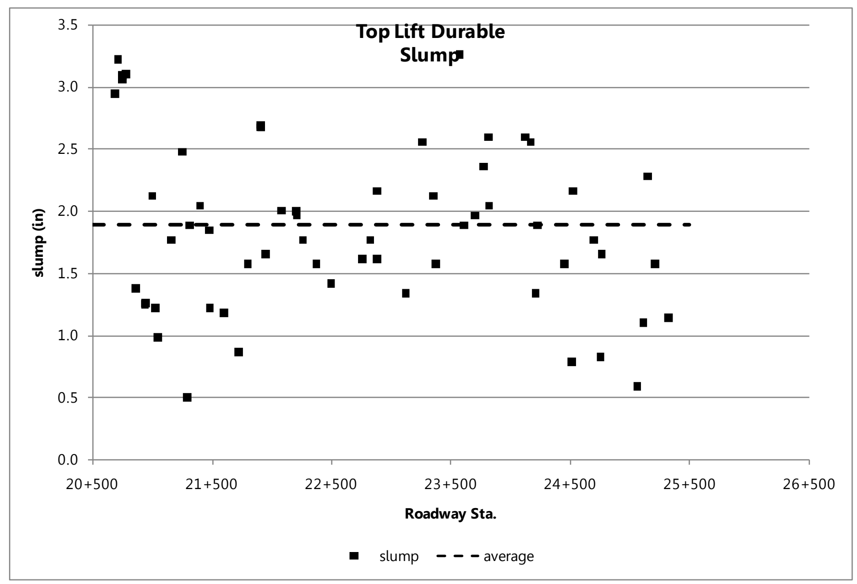

Figure 19 Durable Lift Slump

Exposed Aggregate Lift (Table 4 and Figures 20 through 25):

	air content (%)	slump (in)	unit weight (lb/ft^3)	concrete temp. (°F)	microwave w/cm	ava spacing factor (mm)
n	15	15	15	11	3	23
minimum	5.0	0.5	138.9	73.0	0.44	0.136
maximum	8.1	3.7	146.6	84.2	0.47	0.342
average	6.8	2.2	141.9	79.7	0.45	0.238
standard deviation	1.0	0.8	2.1	3.3	0.02	0.053

Table 4 Summary of Exposed Aggregate Lift Fresh Concrete Test Results

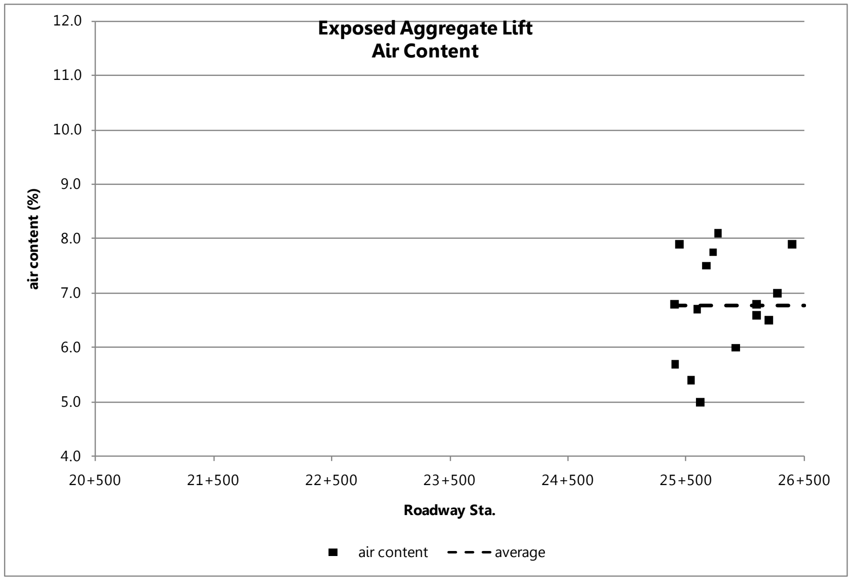

Figure 20 Exposed Aggregate Lift Pressure Air Content

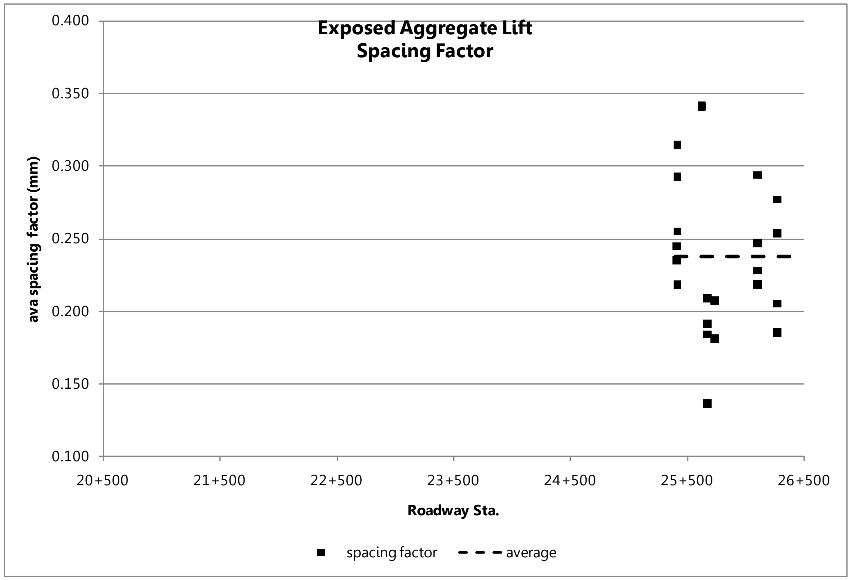

Figure 21 Exposed Aggregate Lift AVA Spacing Factor

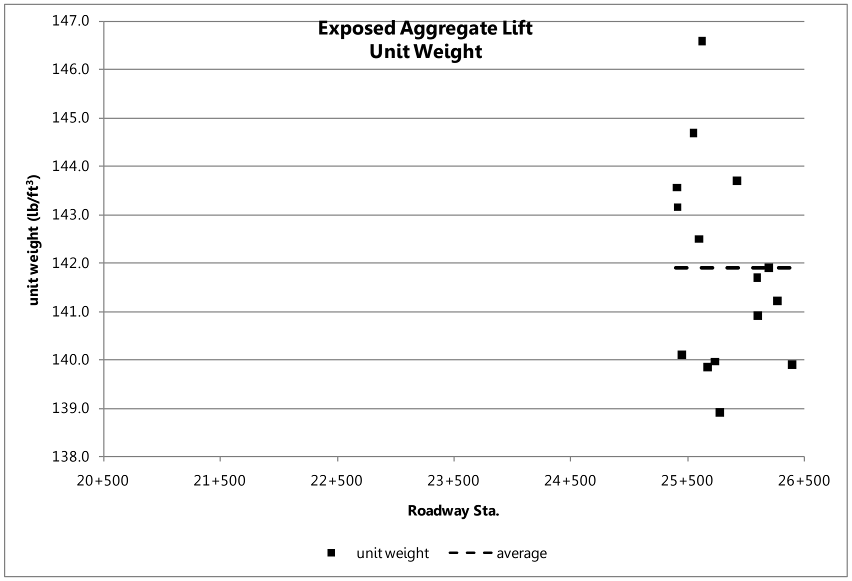

Figure 22 Exposed Aggregate Lift Unit Weight

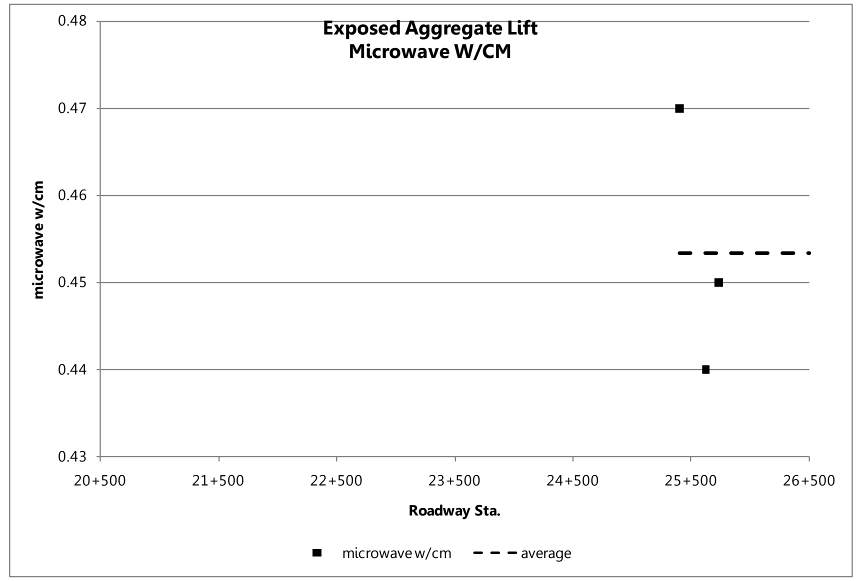

Figure 23 Exposed Aggregate Lift Microwave W/CM

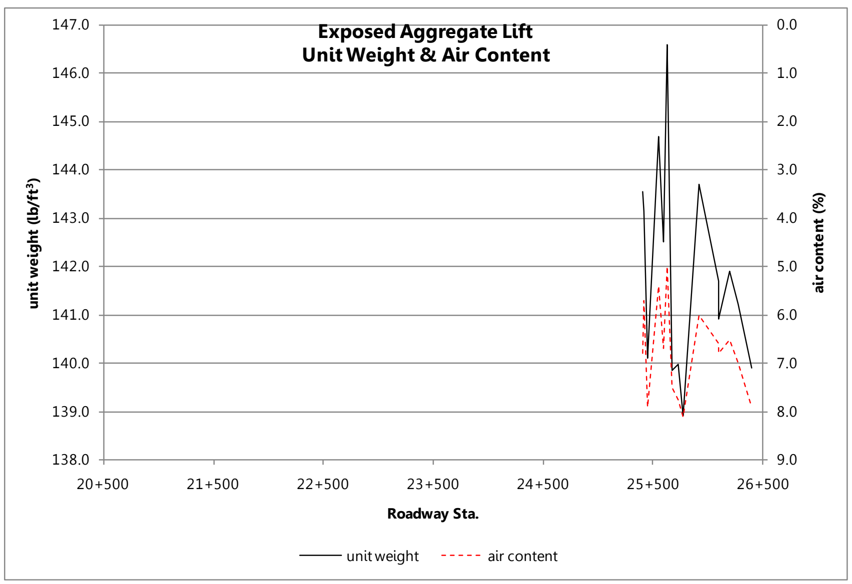

Figure 24 Exposed Aggregate Lift Unit Weight and Air Content

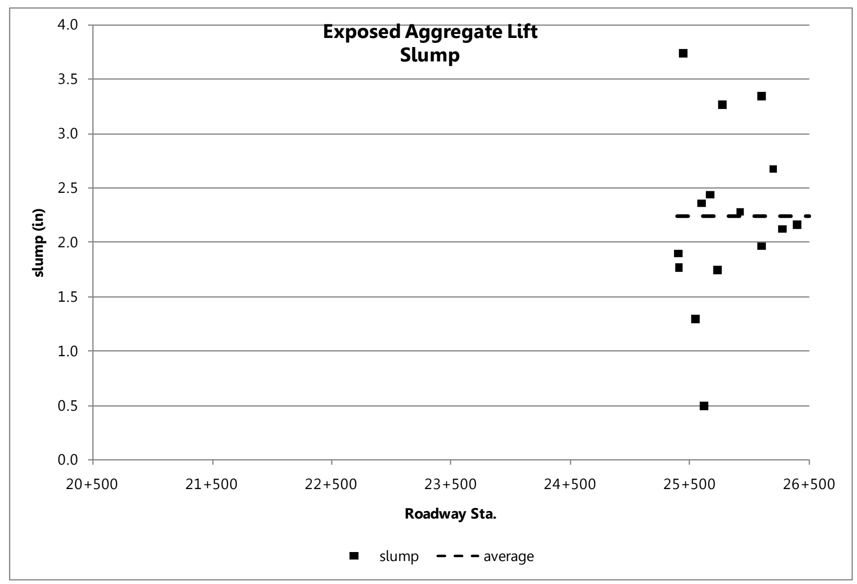

Figure 25 Exposed Aggregate Lift Slump

Set Time, Heat Signature and Pavement Temperature:

A series of tests was performed in an attempt to relate the time when sweeping for the exposed aggregate surface treatment commenced to the time of final set. The most widely used method for determining set time is penetration resistance of a mortar specimen (ASTM C 403) (Figure 26). Test results for the durable lift are included for information only.

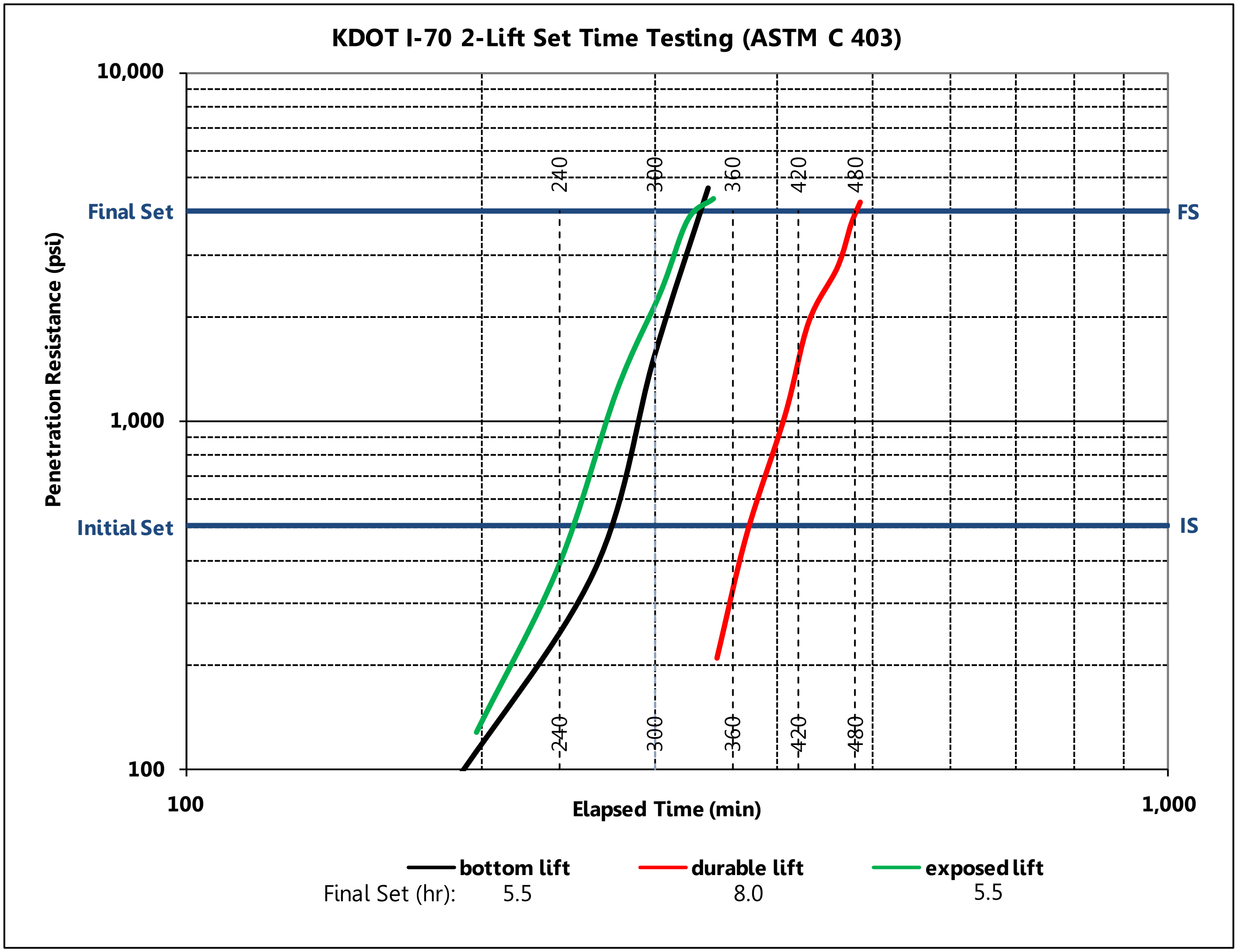

Figure 26 Set Time Test Results (ASTM C 403)

Calorimeters were used to estimate set times using the fractions method (Figure 27).

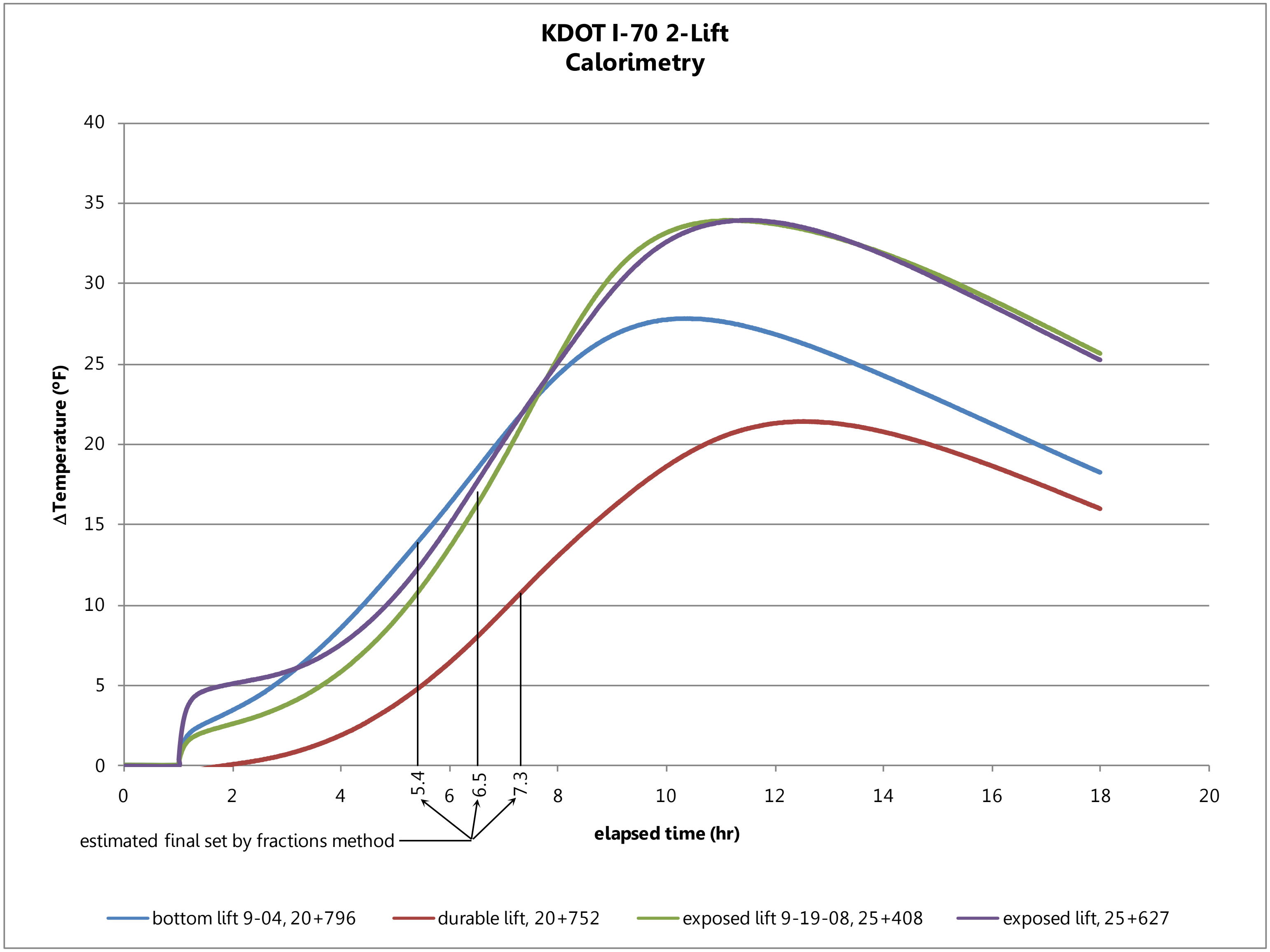

Figure 27 Concrete Mixture Heat Signature Curves and Estimated Final Set Times (Fractions Method)

Temperature loggers placed in the pavement approximately one hour after paving show the relationship between estimated final set times in the field (fractions method) and when sweeping occurred (Figure 28).

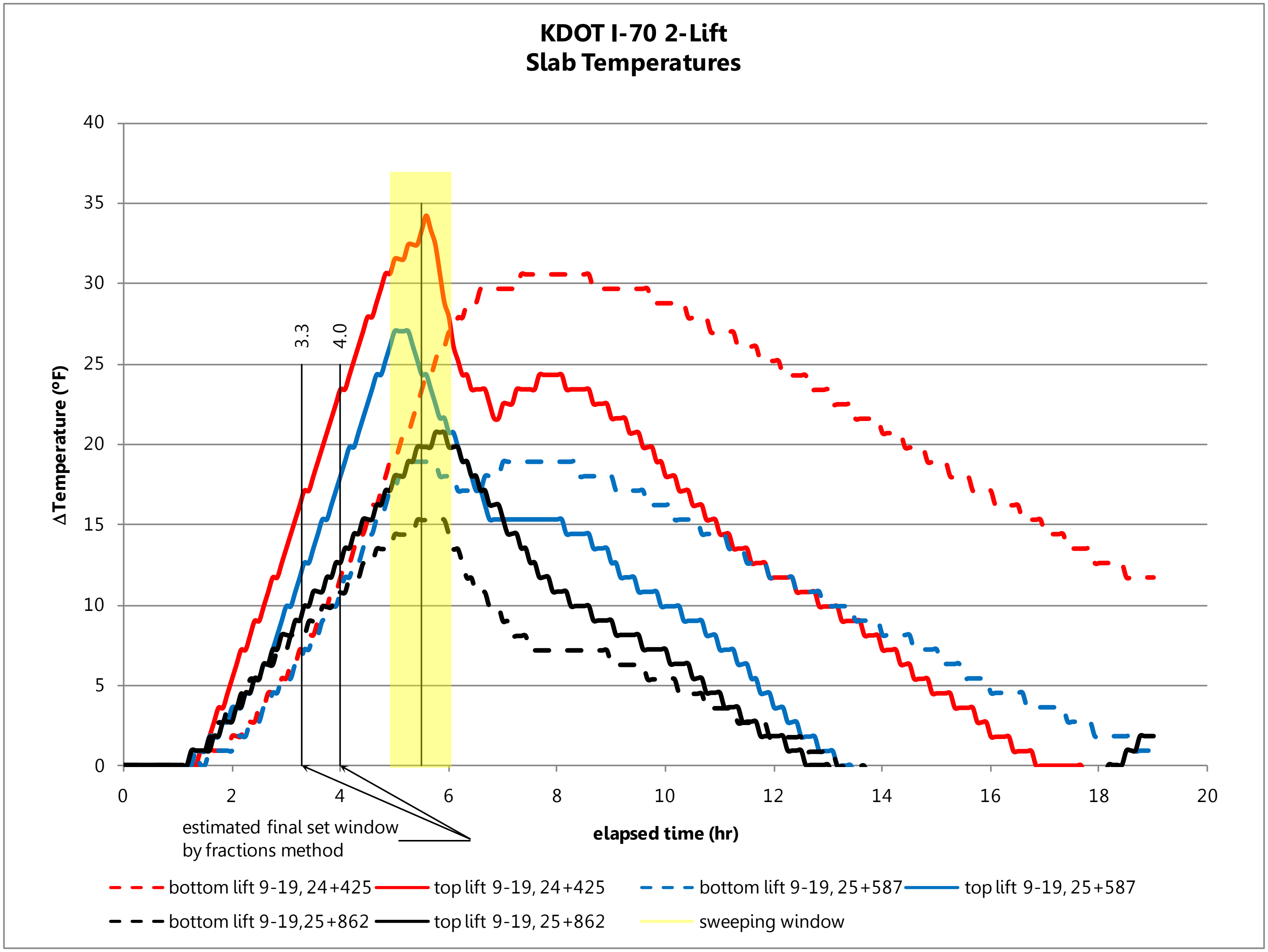

Figure 28 Slab Temperatures, Estimated Final Set and Sweeping Window

Hardened Concrete Properties

At the time of printing for the open house, limited data from hardened concrete testing was available. All test data will be presented in the final report which will be available in December 2008. The following tests performed on cores or cylinders for each lift are scheduled:

- Coefficient of Thermal Expansion (AASHTO TP 60)
- Permeable Voids (boil test) (ASTM C 642)
- Rapid Chloride Penetration (ASTM C 1202)
- Entrained Air Properties (ASTM C 457 by RapidAir apparatus)
- Modulus of Elasticity (ASTM C 469)
- Compressive Strength (ASTM C 39)

Pull-Off Testing (ACI 503-30):

Bond strength between the top lift and bottom lift was tested in the field at approximately seven days after placement using a Dyna Z series pull-off tester. Average pull-off strength was 320 psi; a summary of test results is shown below (Table 5):

Kansas: I-70 2-Lift Pavement

Bond Strength - Pull Off Test Worksheet

Date	Time	Sta.	Distance Off EB Edge (ft)	Gauge Readout (N/mm^2)	Diameter (mm)	Pull Off Strength (psi)	Comments
~~29-Sep-08~~	~~4:35 PM~~	~~21+283~~	~~1.00~~	~~0.830~~	~~48.00~~	~~130.62~~	~~epoxy break~~
29-Sep-08	4:40 PM	21+283	1.00	1.380	48.00	217.18	surface fail 1 mm
29-Sep-08	4:45 PM	21+283	1.00	2.220	48.00	349.38	surface fail 1 mm
29-Sep-08	4:50 PM	21+365	1.00	2.850	48.00	448.52	bottom fail 75 mm
29-Sep-08	4:55 PM	21+365	1.00	1.940	48.00	305.31	bottom fail 75 mm
29-Sep-08	5:00 PM	21+365	1.00	1.980	48.00	311.61	bottom fail 38 mm
29-Sep-08	5:15 PM	25+408	1.00	1.890	48.00	297.44	surface fail 4 mm
29-Sep-08	5:20 PM	25+408	1.00	1.960	48.00	308.46	surface fail 2 mm
29-Sep-08	5:25 PM	25+408	1.00	2.360	48.00	371.41	surface fail 4 mm
29-Sep-08	5:45 PM	25+627	1.00	1.990	48.00	313.18	surface fail 2 mm
29-Sep-08	5:50 PM	25+627	1.00	1.730	48.00	272.26	surface fail 3 mm
29-Sep-08	5:55 PM	25+627	1.00	2.140	48.00	336.79	bottom fail 75 mm

Table 5 Pull-Off Test Results

Construction Process and Observations

Construction of the pilot and I-70 two-lift pavements was accomplished with standard paving equipment and methods. Without a doubt, there were some details that required special attention by the contractor. The following items provide discussion of those details as well as an illustrated description of the two-lift paving process used on the I-70 project.

Logistics:

Delivering the appropriate concrete mixture to the appropriate belt placer/spreader was a detail that needed to be addressed. Both concrete mixtures were batched and mixed at the same central mix concrete plant. Batch plant personnel would identify to the driver which mixture they were transporting through the use of a green card for the bottom lift or a red card for the top lift. Truck drivers then displayed a card of the appropriate color in the windshield of their truck. The belt placers/spreaders were identified with green and red paint as an additional safeguard against improper delivery of the two concrete mixtures.

Paving Train:

The paving train consisted of the following equipment (Figures 29 through 33):

- Belt placer/spreader for the bottom lift.
- Slipform paver for the bottom lift. Paver width was set approximately 1″ to 1½″ narrower than the second paver width.
- Belt placer/spreader for the top lift. This spreader was modified slightly with the addition of a grid fabricated from square steel tubing that was placed under the discharge end of the belt to reduce the potential for deformation of the bottom lift while concrete was being unloaded from the belt on to the bottom lift.
- Slipform paver for the top lift. Vibrators were raised above the elevation of the extrusion pan to avoid co-mingling of the two concrete mixtures during consolidation. Maintaining consistent horizontal alignment between the two pavers was also a detail that required extra attention. If the steering would drift slightly to one side or the other, edge problems were observed behind the second paver.
- Burlap drag, astro-turf drag and cure/texture equipment and processes were identical to single lift paving procedures.

Figure 29 I-70 Two-Lift Paving Equipment Train

Figure 30 Bottom Lift Belt Placer/Spreader and Paver

Figure 31 Top Lift Belt Placer/Spreader and Paver

Figure 32 Initial Burlap Drag Following Top Lift Paver

Figure 33 Texture/Cure Machine Following Final Finishing

Paving Process:

In general, the two-lift paving process was executed in the following sequence:

- Batching, mixing and transporting – a dual drum central mix plant was used for batching and mixing both concrete mixtures. Concrete was transported in tractor-trailer end dumps and tandem axle dump trucks.
- Start of day header – bottom lift was pulled out approximately 150′ and put on hold until the top lift header could be finished to the point where both lifts could be consistently placed in unison.
- Spreading of bottom lift.
- Paving of bottom lift – centerline tie-bars were inserted in front of the bottom lift paver.
- Spreading of top lift.
- Paving of top lift – keyway was formed in the edges and bent tie-bars were inserted.
- Finishing – a burlap drag was attached to the float pan of the top lift paver. Normal finishing procedures were used for the tined and astro-turf drag sections. Minimal finishing (primarily edging and transverse mop) was performed on the ground and exposed aggregate sections.
- Final burlap drag attached to the texture cure machine.
- Curing compound applied by a texture/cure machine, except for the exposed aggregate section which was sprayed with retarder and initially cured with polyethylene sheeting then final cured with curing compound after sweeping.
- Exposed aggregate surface treatment section – sweeping was accomplished with two power brooms equipped with wire bristles. The initial broom was a front mounted sweeper and the second broom was a mid-mounted sweeper. Approximately 5 to 6 hours elapsed between the finishing operations and the start of the sweeping process.
- Final curing for exposed aggregate section.
- Sawing – normal operations.

Exposed Aggregate Surface Treatment:

Details of the exposed aggregate surface treatment process include the following:

- Retarder was sprayed on the surface with a texture/cure machine at coverage rate of approximately 150 to 170 ft^2/gal.
- Polyethylene sheeting was unrolled and used to cover the pavement for initial curing.
- After approximately 5 hours polyethylene sheeting was removed in 100′ segments (Figure 34) and a wire bristled brush was used as an indicator of when sweeping should commence; typically 5 to 6 hours after initial placement.

Figure 34 Removing Polyethylene Sheeting in 100′ Segments

- Sweeping was accomplished in approximately 100’ segments with two power brooms (Figures 35 through 37).

Figure 35 Sweeping Operations

Figure 36 Nighttime Sweeping Operations

Figure 37 Exposed Aggregate Surface

Observations, Questions and Discussion:

From an independent observer's perspective, the construction of the two-lift pavement sections on I-70 was a success. Time will tell if the two-lift system as constructed on I-70 achieves the desired durability. Some of the items that should be addressed through continued monitoring of the I-70 pavement and future research activities include the following:

- Additional admixtures were utilized to create a bottom lift that was very stiff, so that it would not deform when the top lift was placed. How stiff is stiff enough? Are alternative spreading methods available that would eliminate this requirement?
- Is there a method for determining the minimum and/or optimum thickness of the top lift? What is the minimum thickness of top lift that can practically be constructed?
- Deltas for labor and equipment costs between two-lift pavements and traditional single lift pavements need to be quantified to effectively determine if material and/or life-cycle costs can offset the cost deltas on a project specific basis.
- Both concrete mixtures used for the top lift were susceptible to segregation. Further research should identify combinations of materials and pavement vibrator systems that will minimize the potential for segregation (decreased durability) yet still yield the desired surface characteristics.
- Additional effort should be directed at refining the mixture proportions for both lifts with the ultimate goal of a durable and economical system; this includes reduced cementitious content, increased use of supplementary cementitious materials, identification of admixtures necessary for construction of two-lift pavements and incorporating recycled materials in the bottom lift when economically beneficial.
- Modeling should be performed to characterize the relationship between varying coefficients of thermal expansion between the two lifts and the minimum bond strength required to overcome differential expansion and contraction between the two lifts.
- Best practices should be developed for controlling the thickness of both lifts through superelevation transitions.

Summary of Surface Characteristics

Sand patch tests of the astro-turf drag and exposed aggregate sections were performed by the CP Tech Center (Table 6). Comprehensive surface characteristic testing was performed by Transtec and will be available in the final report.

Kansas: I-70 2-Lift

Sand Patch Worksheet

Date	Time	Sta.	Lane	Distance Off Edge (ft)	Volume of Glass Spheres (mm^3)	Mass of Glass Spheres (g)	d_1	d_2	d_3	d_4	Average Diameter (mm)	Mean Texture Depth (mm)
11-Sep-08	12:00 PM	22+637	EB	5.00	24600	37.000	205	200	200	190	198.8	0.8
Turf Drag				3.00	24600	37.000	210	255	215	180	215.0	0.7
				6.67	24600	37.000	220	205	185	190	200.0	0.8
											Average Mean Texture Depth	**0.8**
18-Sep-08	1:30 PM	23+140	EB	2.33	24600	37.000	180	170	155	160	166.3	1.1
Turf Draf				4.50	24600	37.000	180	165	150	180	168.8	1.1
				7.33	24600	37.000	170	170	165	165	167.5	1.1
				10.50	24600	37.000	170	170	150	165	163.8	1.2
											Average Mean Texture Depth	**1.1**
18-Sep-08	1:45 PM	23+172	EB	2.42	24600	37.000	180	165	160	150	163.8	1.2
Turf Drag				4.58	24600	37.000	170	160	190	170	172.5	1.1
				6.67	24600	37.000	150	135	150	135	142.5	1.5
				8.17	24600	37.000	155	160	155	170	160.0	1.2
											Average Mean Texture Depth	**1.2**
18-Sep-08	2:00 PM	23+215	EB	2.00	24600	37.000	195	225	205	205	207.5	0.7
Turf Drag				3.33	24600	37.000	200	210	190	200	200.0	0.8
				5.00	24600	37.000	195	165	165	150	168.8	1.1
				6.50	24600	37.000	150	200	180	165	173.8	1.0
											Average Mean Texture Depth	**0.9**
29-Sep-08	12:00 PM	25+408		1.00	24600	37.000	150	140	145	160	148.8	1.4
Exposed Aggregate				2.00	24600	37.000	140	140	130	140	137.5	1.7
				4.00	24600	37.000	150	170	140	145	151.3	1.4
				6.00	24600	37.000	150	145	140	160	148.8	1.4
											Average Mean Texture Depth	**1.5**
29-Sep-08	12:10 PM	25+600		1.00	24600	37.000	220	240	210	210	220.0	0.6
Exposed Aggregate				2.00	24600	37.000	190	170	150	160	167.5	1.1
				5.00	24600	37.000	185	170	175	190	180.0	1.0
				8.00	24600	37.000	175	190	180	165	177.5	1.0
											Average Mean Texture Depth	**0.9**
29-Sep-08	12:20 PM	25+627		2.00	24600	37.000	180	195	180	170	181.3	1.0
Exposed Aggregate				4.00	24600	37.000	155	140	130	150	143.8	1.5
				5.00	24600	37.000	170	150	160	165	161.3	1.2
				8.00	24600	37.000	160	165	170	157	163.0	1.2
											Average Mean Texture Depth	**1.2**

Table 6 Mean Texture Depth Test Results