Minnesota Local Road Research Board Investigation 864 and, MPR Study 6(022)

Recycled Asphalt Pavement:

MnROAD Study of Fractionated RAP

Task 2 Summary Report:

Construction of Conventional and Fractionated RAP Test Cells at MnROAD

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Eddie N. Johnson
Mn/DOT Office of Materials
1400 Gervais Avenue
Maplewood, Minnesota 55109

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Introduction

This report is intended to convey the activity on this MnROAD research project for the period after specification development and through construction of test sections. Project activity at this time included construction of 500-ft test cells on MnROAD's portion of westbound Interstate Highway 94. The construction was part of state project 8680-157, MnROAD Phase II Construction (1). Additional details can be found in the MnROAD Phase II construction report (2) and the Investigation 864 Task I report (3).

Three fractionated RAP (FRAP) test cells and eight RAP test cells were constructed during Phase II. The FRAP experiment contained Cells 20, 21, and 22. The remaining RAP construction contained Cells 4, 15, 16, 17, 18, 19, 23, and 24.

This report will also attempt to compare the as-built performance of the FRAP cells with the remaining eight RAP cells using falling weight deflection data obtained in the months after construction.

The boundaries, experiment descriptions, and layout for the respective test cells appear in Table 1 (2) and Figure 1.

Table 1 MnROAD Bituminous Cell Boundaries

Cell	Cell Description	Starting Station	Ending Station	Cell Length	Design Life
4	HMA over stabilized base, 0% RAP	1119+85	1125+80	595	5 years
15	WMA 20% RAP over 1993's 0% RAP construction	1194+45	1200+18	573	5 years
16	WMA 20% RAP	1200+18	1205+90	572	5 years
17	WMA 20% RAP	1205+90	1211+50	560	5 years
18	WMA 20% RAP	1211+50	1217+20	570	5 years
19	WMA 20% RAP	1217+20	1222+80	560	5 years
20	30% RAP	1222+80	1228+50	570	5 years
21	30% FRAP	1228+50	1234+35	585	5 years
22	30% FRAP	1234+35	1240+15	580	5 years
23	WMA 20% RAP on RR Ballast	1240+15	1245+85	570	5 years
24	HMA 20% RAP – Low volume section, warm mix control	158+00	163+50	550	5 years

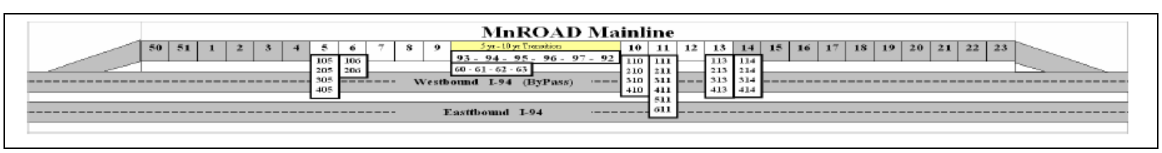

Figure 1 MnROAD layout.

Local surface and subsurface conditions varied as required by the Phase II research plan. The thickness of the asphalt, aggregate base, subbase, and granular fill layers were identical in Cells 19 through 23. Figure 2 shows the materials and layer thicknesses for Cells 20 through 22 (2).

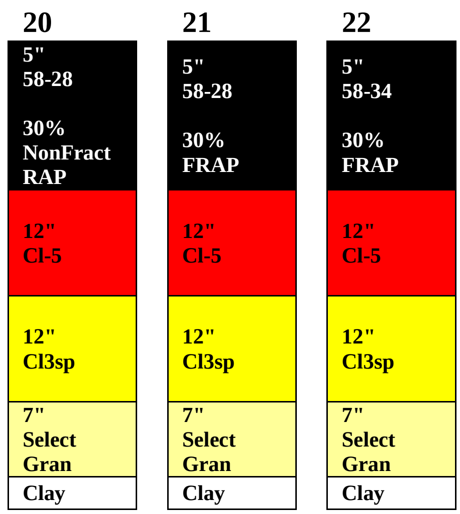

Figure 2 Typical sections for three MnROAD Phase II FRAP Cells. (2)

In the remaining bituminous cells, warm mix was placed in a continuous mat that included Cells 15 – 19 and 23. The Cell 24 mix used the same construction materials, except it was produced at hot mix temperatures. PG 58-34 asphalt was used in all of the cells except for Cell 4, which differed by using PG 64-34 no RAP, and was produced as hot mix.

The map of typical sections (Figure 3) shows that although base materials vary, Cells 16 – 23 are similar to the FRAP cells with respect to layer thickness of the surface, base, subbase, and subgrade materials.

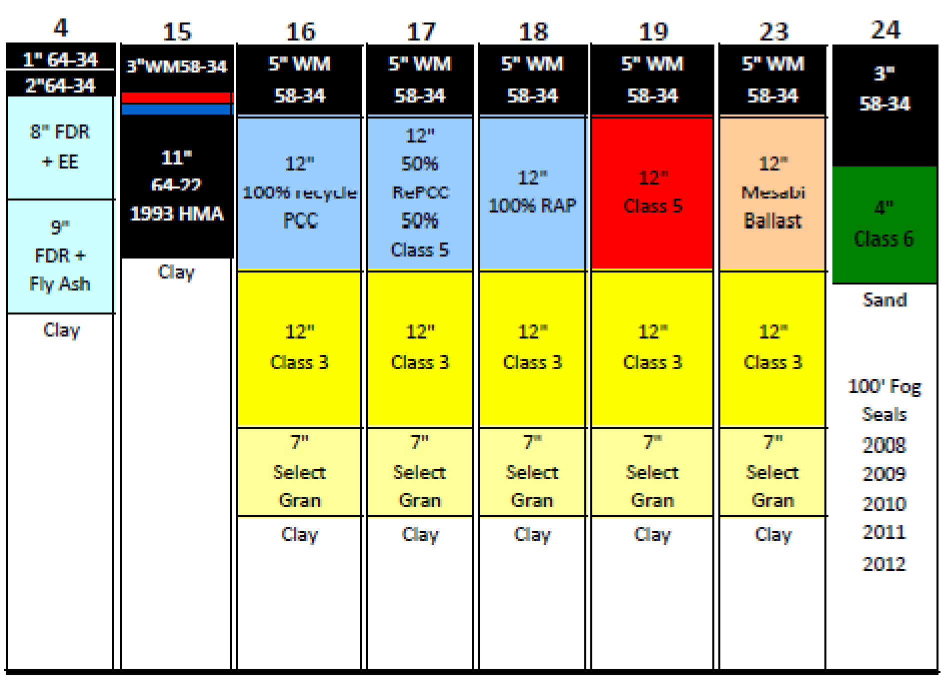

Figure 3 Typical sections for eight MnROAD Phase II bituminous cells. (2)

Construction: Fractionated RAP and Bituminous Test Cells

Portions of the following description are adapted from the Phase II construction report (2). The Phase II grading and base work was performed by PCI, who was also the general contractor. The asphalt paving work was performed by Hardrives using mixtures produced at their plant in Becker, MN.

Figure 4 shows the typical section for Cells 20 – 22 prior to Phase II construction. Preparation for construction required converting the existing variable thickness structure in this part of MnROAD to a 36-in. structure comprised of layers of equal thickness.

Work on these cells began on May 7, 2008 with the milling of approximately 8-in. of in-place hot mix asphalt (HMA).

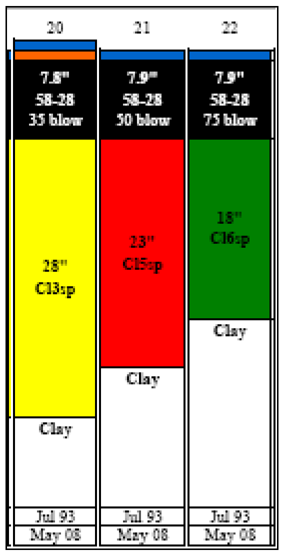

Figure 4 MnROAD Phase I Cell 20 – 22: 1993 construction plus maintenance.

Sub-cutting of aggregate base materials began during the first two weeks of June. PCI then began grinding and blending material from cells 21-23 for use as Select Granular. Extra Class 3 base material was also salvaged from the MnROAD mainline and used to produce the Select Granular.

The third week of June included sub-cutting and preparing the clay subgrade and installing instrumentation infrastructure. Work continued to progress so that during the last week of June Class 5 was placed on Cells 20-22 and Select Granular was placed on Cells 19 and 23. After the contractor was finished with each layer, researchers tested with the Intelligent Compaction roller, falling weight deflectometer, lightweight deflectometer, dynamic cone penetrometer, nuclear gauge, and sand cone. In addition, all of the grading materials were sampled for testing at the Maplewood Lab.

In September the contractor completed final grading in preparation for paving then the paving subcontractor constructed the 2-in. non-wear lifts on Cells 20-22. Two longitudinal and two transverse asphalt strain gauges were placed at the bottom of this layer in each cell.

During the second week of September the contractor placed class 5 aggregate on the shoulders on Cells 20-22. The paving contractor constructed the wearing course on Cells 20-22, and MnROAD, Federal Highway Administration, and the National Center for Asphalt Technology (NCAT) obtained loose mix samples. Samples of asphalt binder, RAP, and aggregate were also obtained for future laboratory studies. Mix samples from Cells 20-22 were delivered to the University of Minnesota for use in the Low Temperature Cracking Phase II project and the contract to perform low temperature fracture tests on all the MnROAD HMA mixes for material characterization. Samples were also provided for testing programs at Ohio University and the Texas Transportation Institute. Results of the testing will be discussed in a separate section.

Unbound Granular Materials

Quality testing was performed on the granular materials to ensure conformance to Mn/DOT Specification 3149 for Select Granular borrow and to Specification 3138 for Class 3 and Class 5 granular base. Granular materials were samples and evaluated for gradation, optimum moisture, and maximum density. Selected results are shown in Table 2 to Table 6 and Figure 5 to Figure 7.

Select Granular Fill Material

According to Mn/DOT Specification 3149, Select Granular Borrow may be any pit- or crusher-run material where the ratio of mass passing the 75 mm (#200) sieve to that passing the 25 mm (1 in.) sieve may not be greater than 12 percent. Oversize particles are not allowed.

Table 2 Phase II Select Granular Material Test Results: Mn/DOT 3149

Sieve, mm	**Cell 20 (a)**	**Cell 20 (a)**	**Cell 21 (b)**	**Cell 21 (a)**	**Cell 22 (b)**	**Cell 22 (a)**	**field test**	**MnROAD (b)**	**Mean**	**COV**
25	100	100	100	100	99	100	100	100	100	0.4%
19	98	98	99	98	96	98	98	98	98	0.9%
16	97	96	96	95	94	94		86	94	3.9%
12.5	92	93	93	91	89	90		91	91	1.6%
9.5	87	89	87	85	84	83	85	87	86	2.3%
4.75	74	77	71	71	70	67	67	73	71	4.8%
2.36	65	66	59	60	57	55	65	62	61	6.6%
2	62	63	56	57	54	52		59	58	7.0%
1.18	53	54	47	48	45	44		50	49	7.8%
0.6	37	37	31	32	30	30		34	33	9.3%
0.425	28	28	23	23	22	23	10	26	23	25.0%
0.3	21	22	17	17	16	18		20	19	12.2%
0.15	13	13	10	9	9	11		12	11	15.7%
0.075	8.7	8.7	6.1	6	5.7	7.7	7	8	7.2	16.8%
#200/1	8.74	8.73	6.12	3.01	5.75	NA	7	8	6.8	30.1%
Opt moisture	8	8.9	8.5	8.1	8.2	8.5	NA	NA	8.4	4.0%
Max Density	130.6	128.6	128.4	129.9	128.4	128.8	NA	NA	129.1	0.7%
(a) For information only (b) Meets requirements										

Class 3 and 5 Base Material

Mn/DOT Specification 3149 requires Class 3 and 5 granular meet the gradation in Table 3. Note that there is overlap in portions of the gradation specification, and that the averages shown in Figure 6 and Figure 7 show the in-place Class 3 to be slightly finer than the Class 5 and Select Granular. Portions of tests with failing values are noted with red font.

Table 3 Mn/DOT 3138 Granular Base Specification

Sieve, mm	Class 3	Class 5
50	100	
37.5	- -	
25	- -	100
19	- -	90 - 100
9.5	- -	50 - 90
4.75	35 - 100	35 - 80
2	20 - 100	20 - 65
0.425	5 - 50	10 - 35
0.075	5.0 - 10.0	3.0 - 10.0

Table 4 Phase II Class 3 Material Test Results: Mn/DOT 3138

Sieve, mm	Cell 20	Cell 20	Cell 21	Cell 21	Cell 22	Cell 22	field test	MnROAD	Mean	COV
25	100	100	100	100	100	100	100	100	100	0.0%
19	100	100	100	100	100	100	100	100	100	0.0%
9.5	99	99	99	98	99	98	98	99	99	0.5%
4.75	93	93	92	92	92	92	89	92	92	1.4%
2	80	80	82	82	81	82	80	82	81	1.2%
0.425	40	39	40	41	41	42	34	40	40	6.2%
0.075	13.1	12.2	12	12.2	12.2	12.4	10.3	10.2	11.8	8.7%
Opt moisture	9.1	9	9.3	9.2	9.5	9.2	NA	NA	9.2	1.9%
Max Density	128.8	129.1	129	128.7	128.2	128.7	NA	NA	128.8	0.2%

Table 5 Phase II Class 5 Material Test Results: Mn/DOT 3138

Sieve, mm	Cell 20	Cell 20	Cell 21	Cell 21	Cell 22	Cell 22	Mean	COV
25	100	100	100	100	100	100	100	0.0%
19	98	100	96	98	96	97	98	1.6%
16	NA	NA	92	95	92	94	93	1.6%
12.5	NA	NA	88	92	86	91	89	3.1%
9.5	83	96	83	88	81	86	86	6.3%
4.75	NA	89	72	78	67	73	76	11.0%
2	71	78	54	66	52	57	63	16.4%

0.85	NA	NA	40	49	37	38	41	13.4%
0.425	33	38	25	29	21	22	28	23.7%
0.25	NA	NA	14	16	12	12	14	14.2%
0.15	NA	NA	9	10	8	8	9	10.9%
0.075	9.5	10.9	6.8	7.5	5.7	6.1	7.8	26.4%
Opt moisture	8.8	9.8	8.3	9.5	10.7	9.9	9.5	9.0%
Max Density	130.2	128.1	130.3	128.2	127.7	128.5	128.8	0.9%

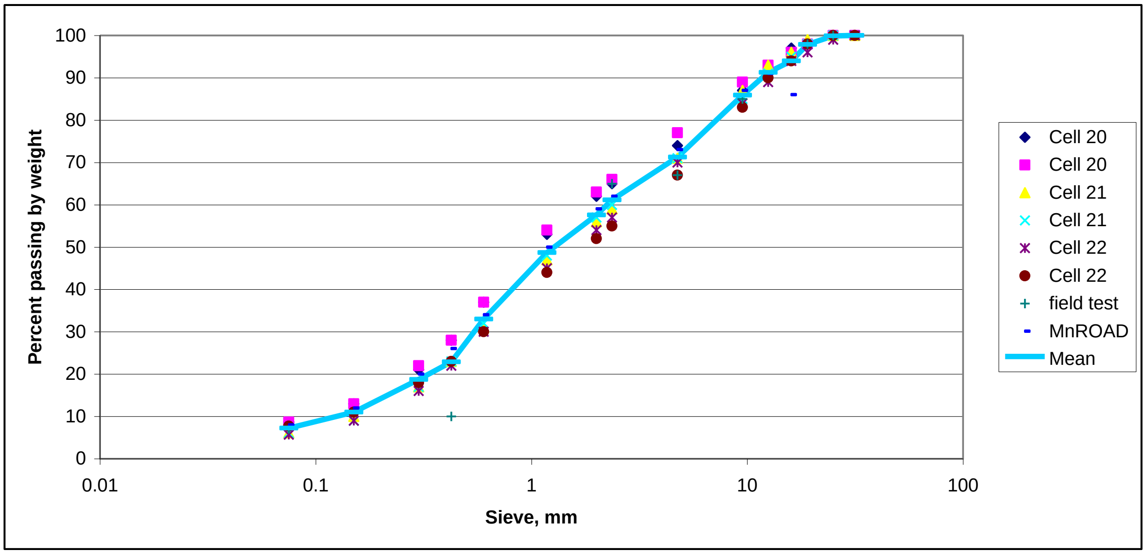

Figure 5 Select Granular Gradations, Phase II.

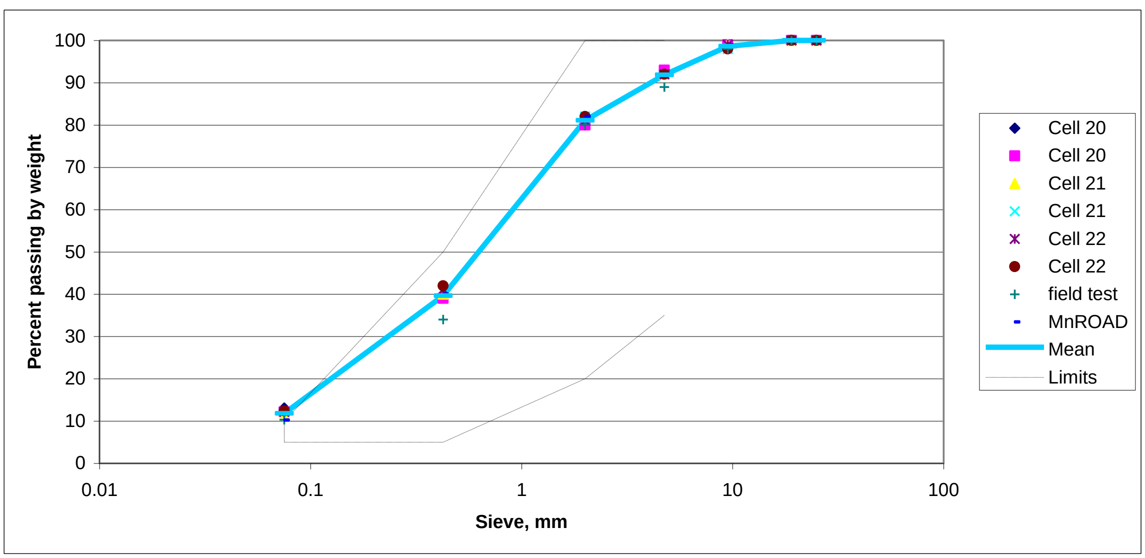

Figure 6 Class 3 Gradations, Phase II.

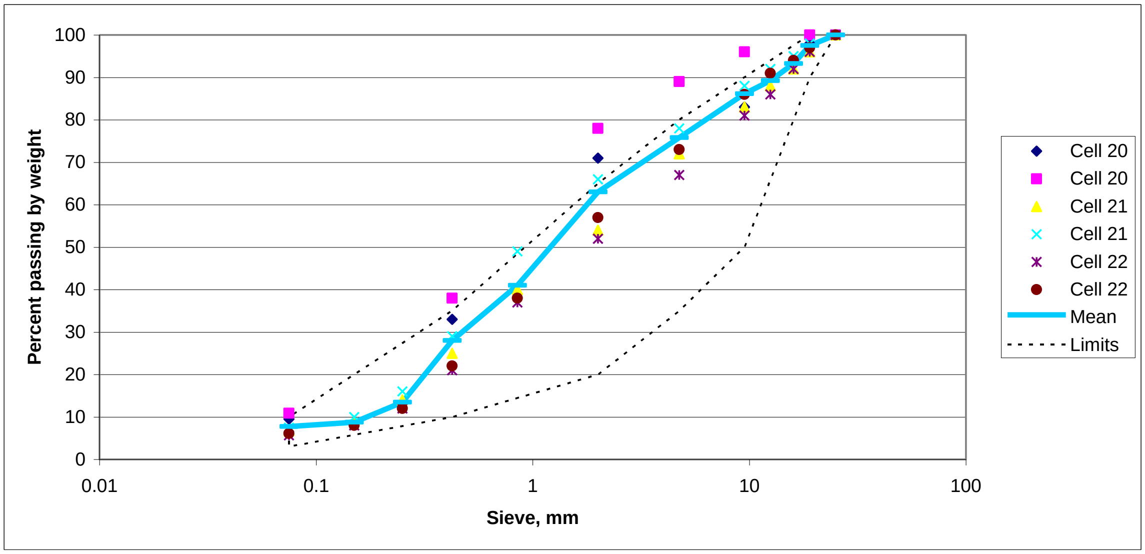

Figure 7 Class 5 Gradations, Phase II.

Table 6 Selected Phase II Grading and Base QA Tests

Cell	Material	Test #	Station	Offset ft	Grading Number	Moisture %	SEAT in	DPI in/blow
19	Class 3	1	121800	15	5.0-5.5	N/A	2.0	0.4
		2	121950	12	5.0-5.5	N/A	2.5	0.7
		3	122000	-10	5.0-5.5	N/A	1.1	0.5
		4	122100	-22	5.0-5.5	N/A	2.3	0.5
	Class 5	1	121800	16	4.4	N/A	1.1	0.3
		2	121950	10	4.4	6.0	1.0	0.6
		3	122080	-10	4.4	N/A	1.4	0.5
		4	122130	-24	4.4	6.0	1.3	0.3
	Select Granular	1	121800	18	4.1-4.5	5.6	1.9	0.6
		2	121900	10	4.1-4.5	N/A	1.5	0.5
		3	122000	-10	4.1-4.5	N/A	1.5	0.5
		4	122200	-16	4.1-4.5	5.8	2.0	0.6
20	Class 3	1	122300	24	5.1	5-8	2.6	0.8
		2	122400	-8	5.1	5-8	1.8	0.6
		3	122500	10	5.1	5-8	2.4	0.8
		4	122700	18	5.1	5-8	2.1	0.6
	Class 5	1	122200	18	4.1-4.5	5-8	1.2	0.3
		2	122400	8	4.1-4.5	5-8	1.0	0.5
		3	122500	-10	4.1-4.5	5-8	1.0	0.4
		4	122700	-24	4.1-4.5	5-8	1.5	0.4
	Select Granular	1	122300	-15	4.3	5.8	2.4	0.7
		2	122500	-20	4.3	5.8	2.4	0.5
		3	122600	14	4.3	5.8	2.2	0.7
		4	122700	8	4.3	5.8	2.2	0.7
		5	122750	-8	4.3	5.8	1.5	0.5
21	Class 3	1	122900	-16	5.1	5.1-5.5	2.6	0.6

		2	123000	-8	5.1	5.1-5.5	2.1	0.5
		3	123200	10	5.1	5.1-5.5	1.5	0.5
		4	123400	15	5.1	5.1-5.5	2.5	0.6
	Class 5	1	122900	14	4.4	N/A	1.6	0.4
		2	123000	10	4.4	N/A	1.4	0.5
		3	123200	-10	4.4	N/A	1.7	0.5
		4	123400	-22	4.4	N/A	1.6	0.3
	Select Granular	1	122950	15	4.3	5.8	1.7	0.6
		2	123100	-18	4.3	5.8	1.4	0.5
		3	123200	8	4.3	5.8	2.3	0.8
		4	123305	-10	4.3	5.8	1.4	0.5
22	Class 3	1	123500	-25	5.1	5.1-5.5	3.4	0.8
		2	123600	-15	5.1	5.1-5.5	1.6	0.5
		3	123800	8	5.1	5.1-5.5	1.2	0.4
		4	124000	18	5.1	5.1-5.5	2.3	0.7
	Class 5	1	123500	-14	4.4	N/A	1.6	0.4
		2	123600	-5	4.4	5.8	2.3	0.4
		3	123700	12	4.4	N/A	1.0	0.5
		4	123400	15	4.4	N/A	1.3	0.5
	Select Granular	1	127400	24	4.3	6.0	1.7	0.6
		2	125200	8	N/A	N/A	1.4	0.3
		3	123000	-10	6.1	5.8	2.3	0.6
		4	122400	-16	N/A	N/A	1.4	0.4

Similar results exist for Cells 4, 15 – 19, 23 and 24 as part of the MnROAD Database, and are available by request.

Construction evaluation of the granular materials also included Dynamic Cone Penetrometer (DCP). DCP results were reported in terms of the DCP Penetration Index (DPI), where stiffer or stronger materials have a relatively smaller DPI. Figures Figure 8 through Figure 11 summarizes the DPI results from Cells 16 – 23. The term “Class 7” refers to recycled base material. Figure 10 The level of DPI variation was consistent for the materials and construction in Cells 19 to 22, at nearly 22 percent, but was greater for the recycled and remaining cells.

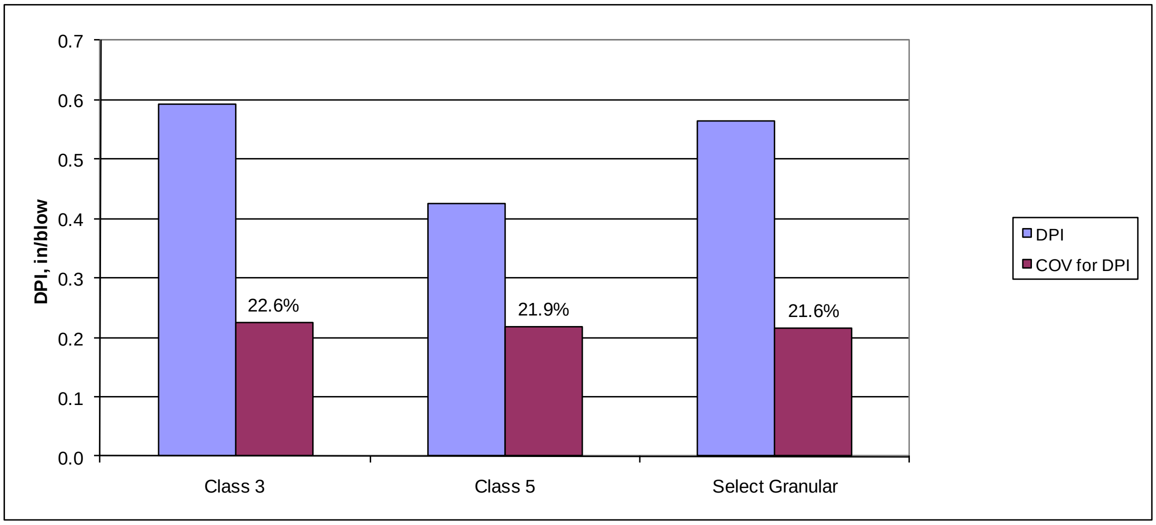

Figure 8 Average DPI and variation for subsurface materials on Cells 19 to 22.

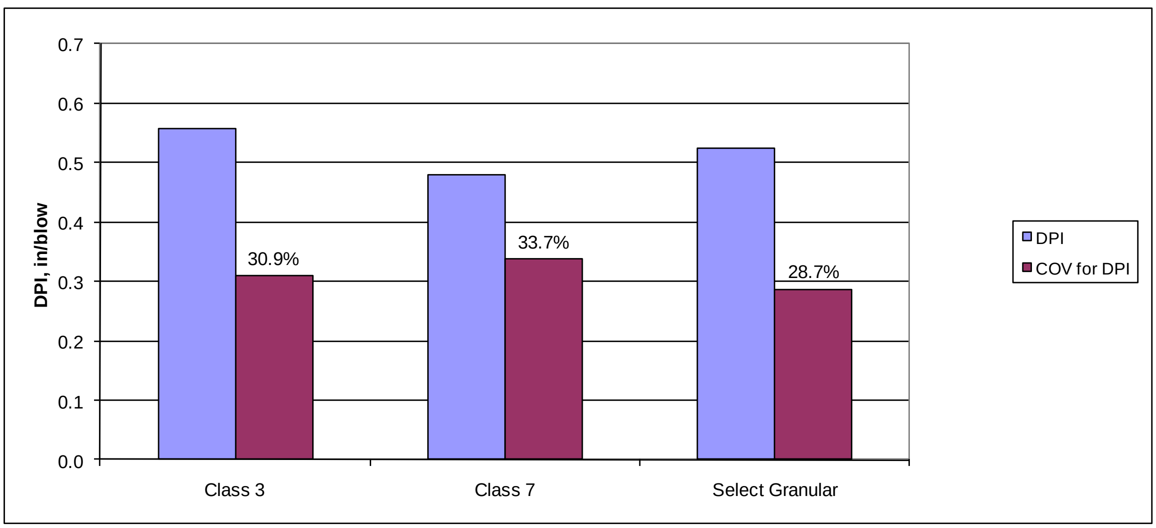

Figure 9 Average DPI and variation for subsurface materials on Cells 16, 17, and 23.

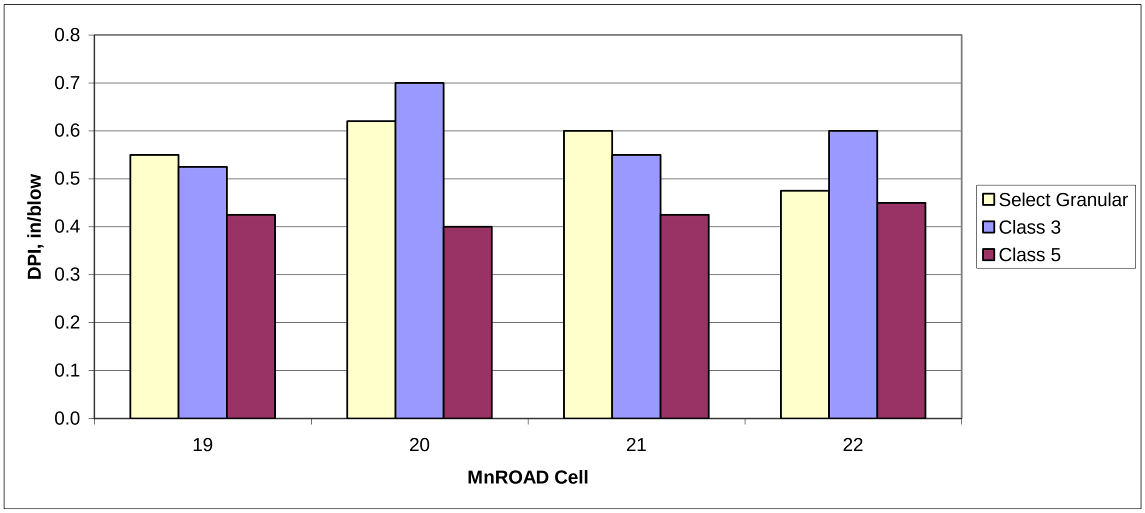

Figure 10 Average DPI for Cells 19 to 22.

Similar results exist for Cells 4, 15 – 18, 23 and 24 as part of the MnROAD Database, and are available by request. The following chart presents the average DPI for the materials and construction for Cells 16 to 23.

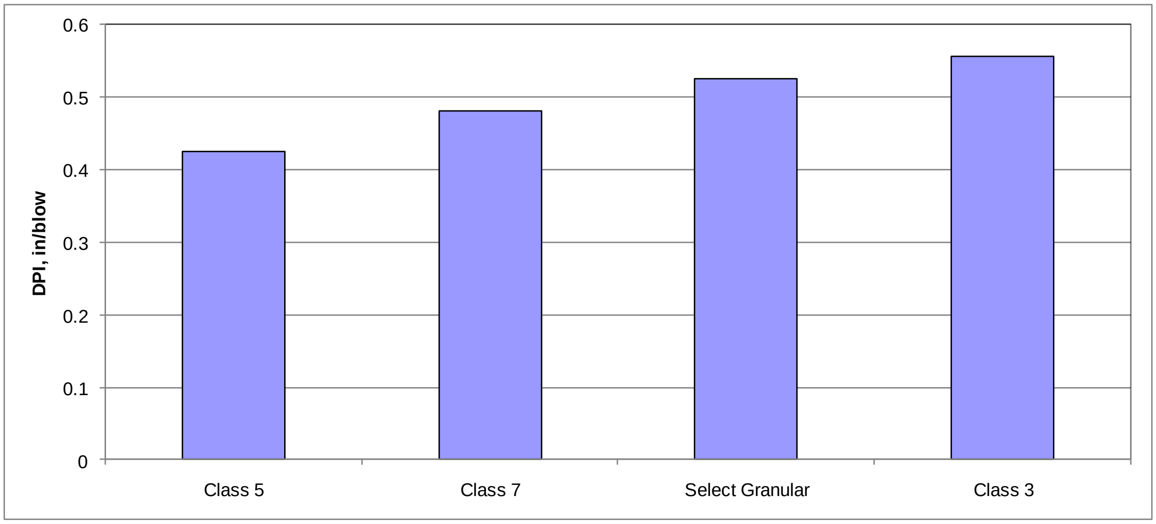

Figure 11 Average DPI for materials in Cells 16 to 23.

Hot Mix Materials

RAP Stockpiles

Three separate stockpiles of coarse, fine, and standard RAP were produced by the paving subcontractor. Sizing and separation of the coarse and fine fractions was accomplished by processing the standard RAP millings through a 1/4-in. screen. The three RAP stockpiles were sampled and tested prior to production of the FRAP mixtures, and the results are given in Table 7 and Figure 12. Interpolation of the unprocessed millings gradation shows that the amount of fine RAP was approximately 81 percent of the total.

Table 7 Laboratory versus Field Test Results – MnROAD RAP

	Lab Test			Field Test		
Sieve, mm	**Coarse RAP**	**RAP fines**	**MnROAD millings**	**Coarse RAP**	**RAP fines**	**MnROAD millings**
19	100	100	100	100	100	100
16	100	100	100	99	100	100
12.5	92	100	99	95	100	98
9.5	78	100	93	77		93
4.75	58	88	75	58	88	75
2.36	51	72	62	50	74	63
2	48	69	59	NA	NA	NA
1.18	42	59	52	42	61	53
0.6	32	45	39	33	46	40
0.425	26	36	32	NA	NA	NA
0.3	19	27	24	19	26	23
0.15	10	15	13	10	14	12
0.075	7	10.6	8.9	6.4	9.1	7.7
Avg %FAA	41	41	41			
% One face CR	77.85	69.05	75.6			
% Two face CR	77.25	68.3	75.09			
%AC Asphalt	5.33	5.92	5.86			
SpG	2.638	2.61	2.624			

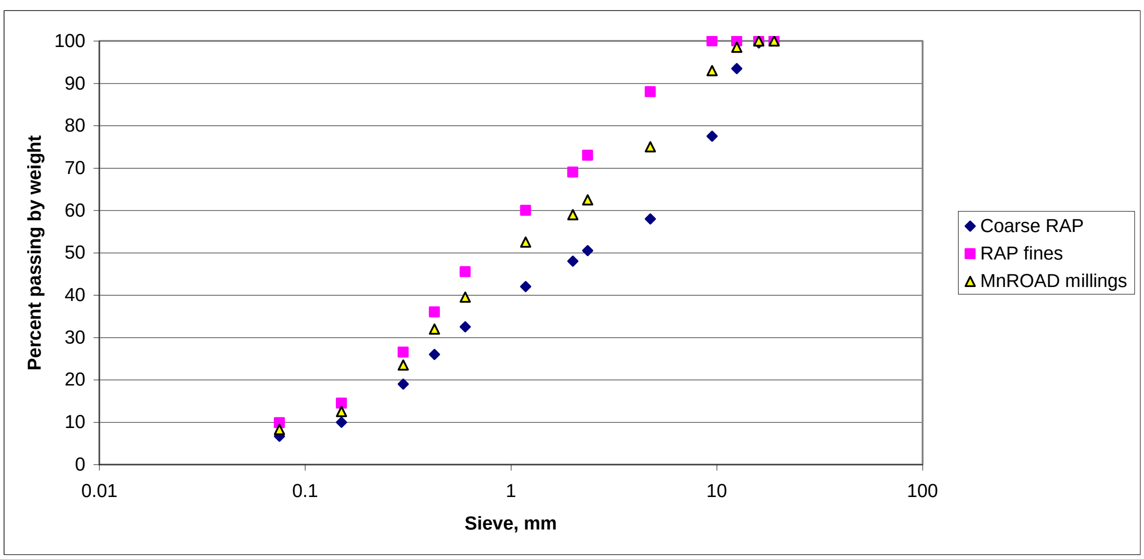

Figure 12 Average gradations of RAP stockpiles, Phase II.

The final aggregate gradation designs for Cells 20 – 22 are shown in Figure 13.

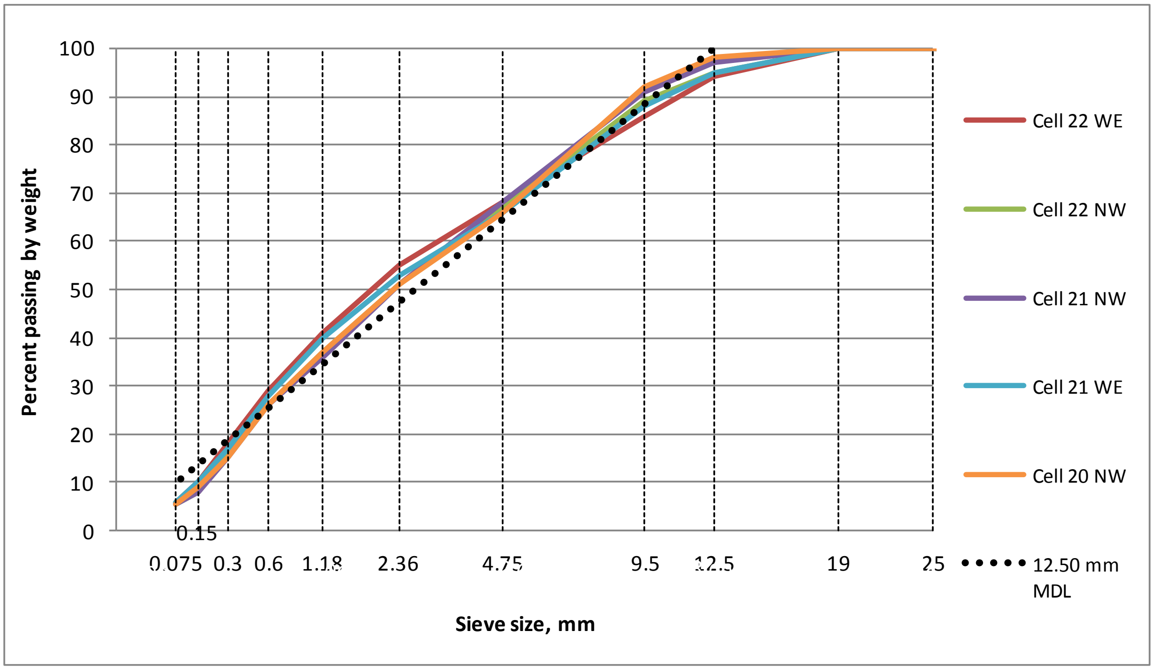

Figure 13 FRAP Mixture Gradations, Cells 20 – 22.

During construction the researchers visited the plant during construction of the FRAP Cells to observe production and collect additional samples from the RAP supply belt. As shown in Figure 14 to Figure 17, production of the FRAP mixtures was accomplished by setting up separate supply belts to carry the coarse and fine RAP fractions. The fractions were combined in a vibratory screen called a "RAP Gator" and then sent to the drum via a metered conveyor belt.

Figure 14 FRAP production: Loader at RAP feed bin.

Figure 15 FRAP production: Covered conveyer belt for fine RAP.

Figure 16 FRAP productions: Conveyers, drum, elevator, and silo.

Figure 17 FRAP production: Vibrating screen combining Fine and Coarse RAP.

Construction and Initial Performance Data

On September 5 and 10 paving operations occurred on the MnROAD mainline, including FRAP cells 20, 21, and 22. The approved mixture designs included the following components:

- 30 percent MnROAD millings
    - Non-fractionated mixture was designed to include approximately 24 percent fine plus 6 percent coarse (Cell 20). This was determined by the contractor, who evaluated trial mixes using FRAP.
    - Fractionated mixture was designed to include 20 percent fine plus 10 percent coarse (Cells 21 and 22). This was determined by the contractor.
- 35 percent washed manufactured sand
- 20 percent 0.5-in. chips
- 15 percent unwashed 0.75-in. rock

The final designs of each cell used identical percentages of RAP and aggregate material for the wear and non-wear mixtures. According to the final design records, the asphalt cement content of the non-fractionated mixture increased 0.3 percent between wear and non-wear designs, and the asphalt content increased 0.2 percent between mixtures for the fractionated designs.

Grading and base, as well as paving operations for cells 4, 15 – 19, 23 and 24 were also performed during the same general time frame as corresponding work to Cells 20 – 22. Additional details can be found in the MnROAD Phase II Construction Report (2).

Construction Observations

The following observations were made during the paving of FRAP Cells 20, 21, and 22 (Table 8 and Table 9). Densification was performed using an 8000 kg Vibratory Roller.

Table 8 Breakdown Roller Observations

Cell (Sta)	Lane	Frequency, rpm (*)	Distance,	Time, sec	= Roller

			ft		Impacts/ft
22	Passing	2900 pass 2	50	-	-
	Passing	3100	50	12.2	12.6
	Passing	2100, mini			
	Driving	2800 pass 1	50	15.8	14.7
	Driving	2900	50	15.2	14.7
22 (1236+60)	Passing	2800	40	15	17.5
22 (1235+60)	Passing	2800 pass 2	25	13	24.3
20 (1226+00)	Passing	2800	100	40	18.7
(*) Measured with Standco Tachometer (HH Sticht, NY, NY)					

An infrared camera was used to observe temperature conditions of the mix in the pave, immediately following the paver, and under the roller. Most of the thermal observations occurred during paver stops, when mix was not readily available. The effect on the material was such that thermal segregation was apparent in the newly placed material behind the paving machine. Figure 18, an area analysis of thermal image #05-29, shows intermingled mat temperatures occurred at station 1233+50 during a paver stop.

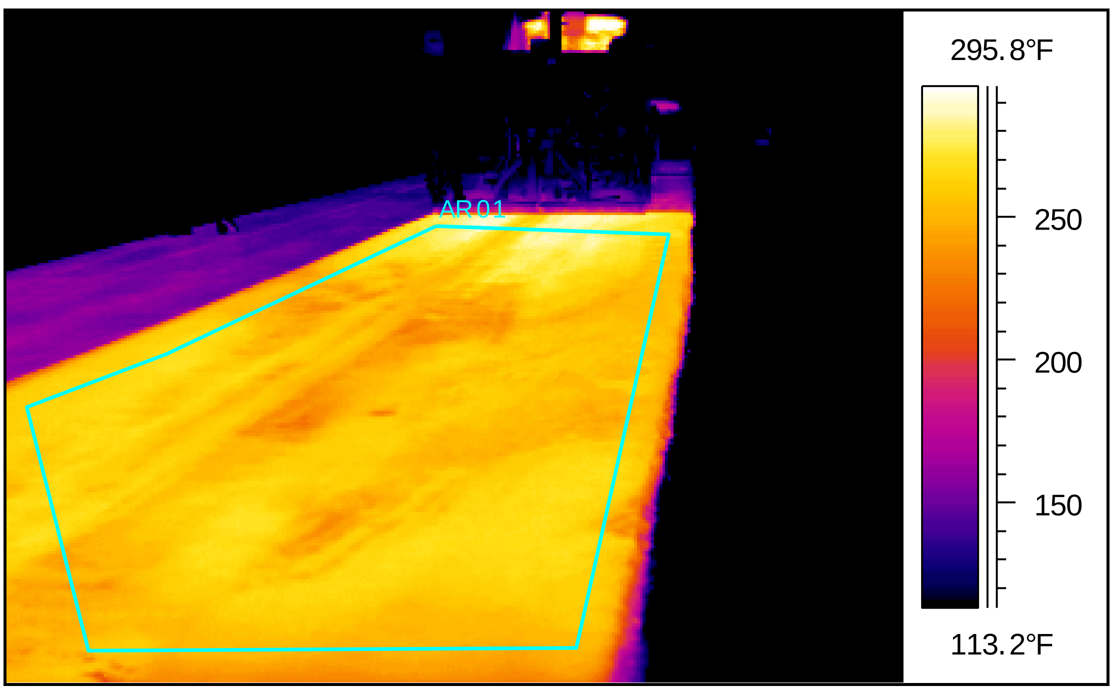

Figure 18 Image #05-29. Selection Max-Min: 291.6 and 225.1°F.

Table 9 Locations Documented With Infrared Camera

Cell	Lane	Station	IR number	Remarks
22	Passing	1239+15		Paver stop

22	Passing	1239+15	05-03	Long paver stop
22	Passing	1239+29	05-04	Roller bump behind stopped roller
22	Passing	1239+29	05-05	
22	Passing	1239+29	05-06	
22	Passing	1239+29	05-07	
22	Passing	1239+29	05-08 to 10	Stopped 5 – 10 minutes
22	Passing	1237+53	05-11 to 17	Paver stop
	Passing		05-18	
	Passing		05-19	
21		1229+47		Paver runs into Passing CL when moving around sensors to pave Driving, just west of sensors.
21		1229+73		Paver runs into Passing CL when moving around sensors to pave Driving, just west of sensors.
21	Driving	1233+50	05-20 to 30	Paver stop, 33 minutes
			05-31	
			05-32	
20			05-33 to 40	Untarped trucks
21		1229+35		Paver stops for 8.5 min.

In April 2010 the University of Minnesota – Twin Cities (U of M) completed a report on the measurement of air voids at Mn/DOAD following the Phase II construction (4). The research produced much more data than was available through the LIMS database. Table 10 compares the U of M and LIMS data sets.

Table 10 Summary of Mn/DOT - U of M and LIMS Air Voids Data

Statistic	All void data	Averaged by material type	LIMS Field Voids
Minimum	2.6	3.8	4.0
First quartile	4.3	4.5	6.3
Median	5.4	5.9	8.2
Third quartile	6.8	6.7	9.0
Maximum	10.3	7.6	11.3
Count	180	30	37

Air voids test results are in

Table 11 and Figure 19. Results suggest that the greatest level of densification occurred in non-wear layers of the warm mix and FRAP cells. Except for Cell 21, void results for the FRAP wear course were greater, had relatively greater variation than the warm mix and FRAP non-wear.

Table 11 Voids by Material Type: Mn/DOT - U of M

Cell	Cores	Lift	Material	Mean	Stdev
4	4	Stabilized base	FDR	4.6	0.54
20	8	Nonwear	FRAP	4.4	0.62
21	8	Nonwear	FRAP	3.8	0.50
22	8	Nonwear	FRAP	3.9	0.62
20	8	Final wear	FRAP	6.5	0.55
21	8	Final wear	FRAP	5.2	0.92
22	8	Final wear	FRAP	5.8	0.83
20	8	Lower wear	FRAP	5.5	0.80
21	8	Lower wear	FRAP	3.8	0.84
22	8	Lower wear	FRAP	5.1	0.62
24	8	Final wear	HMA	5.9	1.63
4	4	Final wear	Superpave	6.3	0.67
4	4	Lower wear	Superpave	5.6	1.01
16	4	Nonwear	WMA	3.8	0.30
17	4	Nonwear	WMA	4.5	0.67
18	4	Nonwear	WMA	4.2	0.90
19	8	Nonwear	WMA	4.5	1.50
23	4	Nonwear	WMA	4.1	0.91
15	4	Final	WMA	6.1	1.81
16	4	Final	WMA	7.0	1.46
17	4	Final	WMA	7.3	1.38
18	4	Final	WMA	6.1	1.61
19	8	Final	WMA	7.3	2.54
23	4	Final	WMA	6.5	1.18
15	4	Lower wear	WMA	6.6	0.67
16	4	Lower wear	WMA	7.0	0.97
17	4	Lower wear	WMA	7.6	1.44
18	4	Lower wear	WMA	7.5	1.86
19	8	Lower wear	WMA	6.7	2.34
23	4	Lower wear	WMA	6.8	0.64

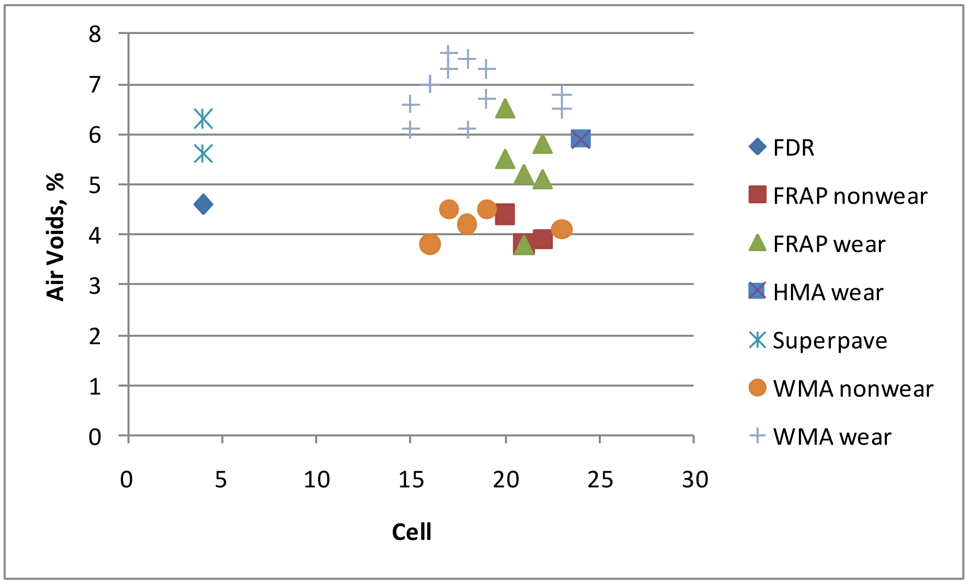

Figure 19 Average Air Voids: Mn/DOT - U of M

Figure 20 MnROAD Station 1233+00, Cell 21.

Figure 21 Longitudinal view of rolling patterns over non-wear mix.

Figure 22 View of rolled non-wear mixture.

Bituminous mixture samples were acquired at the time of construction from the uncompacted mat behind the paving machine. The samples were evaluated in the laboratory for conformance to volumetric design parameters and asphalt content by ignition oven (I.O.). Results of the laboratory analysis,

Table 12, show that FRAP mixtures contained relatively more asphalt when compared to normal RAP mixtures.

Table 12 Production Quality Tests on Bituminous Mixture Samples

Cell	Total RAP	Method	Binder	Layer	MDR	Sample ID	VMA	VFA	Rice Voids	I.O. AC%	Design AC	I.O. - Design AC, %
4	0	HMA	64-34	WE	2008-183	MT-BM08-0745	14.2	82.4	2.5	5.5	5.4	0.1
15	20	WMA	58-34	WE	2008-210	MT-BM08-0749	15.9	72.3	4.4	5.4	5.2	0.2
16	20	WMA	58-34	NW	2008-211	MT-BM08-0744	13.9	92.1	1.1	5.7	5.5	0.2
16	20	WMA	58-34	WE	2008-210	MT-BM08-0751	14.7	74.1	3.8	5.2	5.2	0
17	20	WMA	58-34	WE	2008-210	MT-BM08-0905	14.4	77.2	3.3	5.3	5.2	0.1
20	30	HMA	58-28	NW	2008-194	MT-BM08-0685	14.8	87.2	1.9	5.7	5.5	0.2
20	30	HMA	58-28	WE	2008-193	MT-BM08-0707	14.7	73.5	3.9	5.2	5.2	0
21*	30	HMA	58-28	NW	2008-199	MT-BM08-0684	14.7	79.6	3	5.6	5.5	0.1
21*	30	HMA	58-28	WE	2008-197	MT-BM08-0706	13.9	78.4	3	5.6	5.2	0.4
22*	30	HMA	58-34	NW	2008-200	MT-BM08-0686	14.5	86.2	2	5.8	5.5	0.3
22*	30	HMA	58-34	WE	2008-198	MT-BM08-0708	14.4	77.7	3.2	5.6	5.2	0.4
(*) Fractionated RAP mixture.												

FWD Approach

FWD data was collected on all of the bituminous cells in the months following construction. It is well documented that FWD results for bituminous pavements are influenced by base condition (saturated, frozen, unfrozen) and temperature. Because of this, the following comparisons will use only FWD data collected in the late summer and fall months, when base materials are likely to be stable and surface temperatures are relatively moderate. Applicable data includes FWD data collected between August and October 2009. The normalized Area Factor was used to draw conclusions about performance similarities of the bituminous cells following construction.

$$AreaFactor = 6\left(1 + 2\left(\frac{D_{12}}{D_0} + \frac{D_{24}}{D_0}\right) + \frac{D_{36}}{D_0}\right) \qquad \text{Equation 1}$$

Where:
D_0 = Deflection measured at the center of FWD load plate
D_{12} = Deflection measured 12 in. (305 mm) from the center of FWD load plate
D_{24} = Deflection measured 24 in. (610 mm) from the center of FWD load plate
D_{36} = Deflection measured 36 in. (914 mm) from the center of FWD load plate

Note that MnROAD FWD testing procedure calls for variation in the intensity of the applied load at a given location. For example, Figure 23 shows the load intensity (normalized to 40.5 kN) versus percentile. The MnROAD FWD load history since 2007 was used to create the figure.

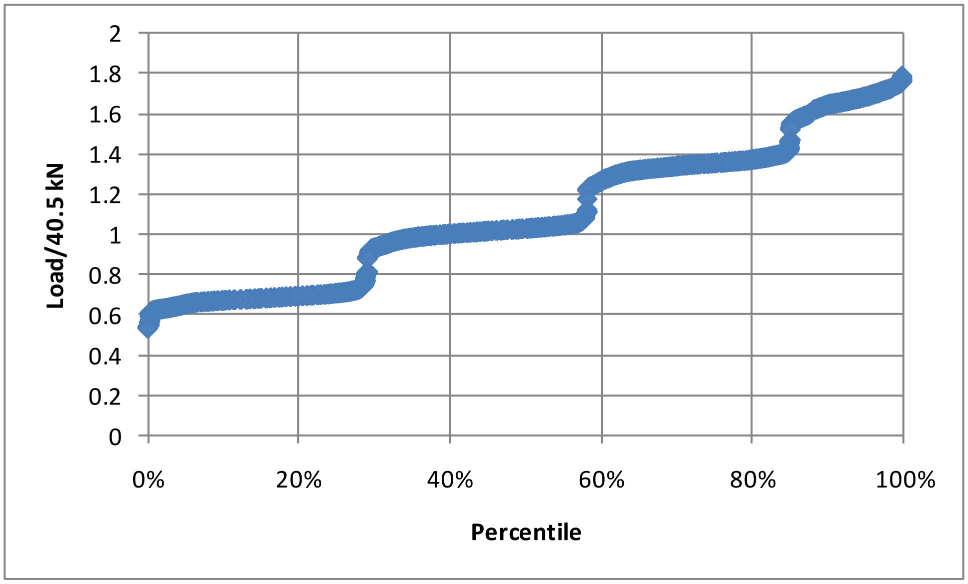

Figure 23 MnROAD FWD load intensity.

The Area Factor approach is a convenient analysis tool because it is not necessary to perform a manipulation to normalize the deflection to any standardized load intensity. This is so because the normalizing load ratios cancel algebraically when dividing by the load-normalized divided at the center of the load plate.

FWD Data Comparison

FWD data was unavailable for the timeframe between 2008 construction and April 2009 because of scheduling priorities at MnROAD. Data gathered from April to July 2009 was ignored because of base thaw-recovery issues. Therefore, the "initial" structural comparison was based on the FWD dataset collected from August to October 2009. Figure 24 and Table 13 show the FWD data.

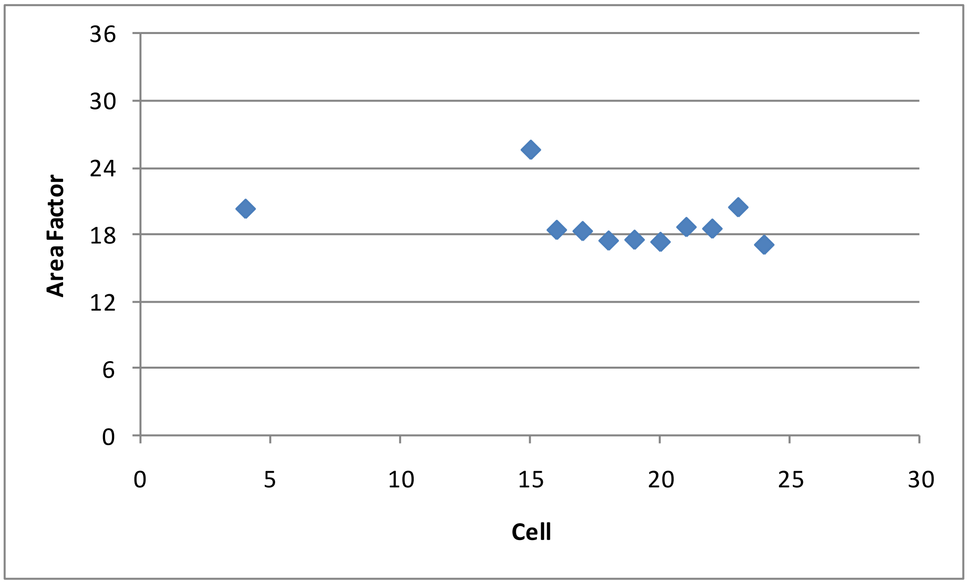

Figure 24 Average Area Factor from MnROAD driving lane, outer wheel path – Fall 2009.

Table 13 shows that the average Area Factor for the Phase II bituminous cells was 19.0. All but two of the cells had Area Factors within 10 percent of the average. Cell 15 produced the maximum Area Factor (25.6), indicating that the values of D_{12}, D_{24}, and D_{36}were somewhat similar to D_0. The FRAP, hot, and warm mix asphalt cells produced similar Area Factors. Based on the Area Factor, these cells initially performed in a structurally equivalent manner. Cells 4 and 23 produced slightly larger Area Factors, possibly due to the stabilized and railroad ballast base materials.

Table 13 Comparison of Average Area Factors, MnROAD- Fall 2009

Timeframe	Cell	Lane	Wheel path	Area Factor	Stdev	Count	% above average
8, 9,10/2009	4	driving	outer	20.3	0.110243	60	6.6%
9,10/2009	15	driving	outer	25.6	0.085049	30	34.4%
9,10/2009	16	driving	outer	18.4	0.076929	30	-3.4%
9,10/2009	17	driving	outer	18.3	0.080147	30	-4.0%
9,10/2009	18	driving	outer	17.4	0.126378	30	-8.5%
9,10/2009	19	driving	outer	17.5	0.103328	30	-8.1%
9,10/2009	20	driving	outer	17.3	0.142738	45	-9.1%
9,10/2009	21	driving	outer	18.6	0.139525	60	-2.1%
9,10/2009	22	driving	outer	18.5	0.080528	30	-2.8%
9,10/2009	23	driving	outer	20.4	0.097806	30	7.3%
9,10/2009	24	Inside	outer	17.0	0.172172	30	-10.4%
				Avg = 19.0			

Figure 25 compares the average FWD deflection basins for Cells 4, 15, 21, 23, and 24. The figure supports the conclusion from the Area Factor analysis since Cells 23, 4, and 15 produced relatively lower deflections for D_0 and D_{12}. Note the deflection similarity that occurs for D_{24} and D_{36}.

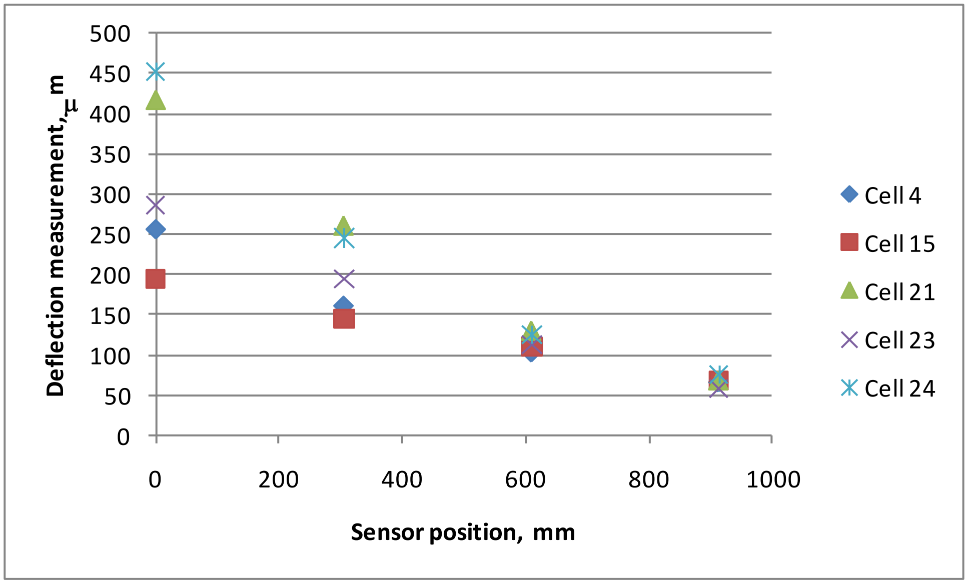

Figure 25 Deflection basin averages from MnROAD driving lane - Fall 2009.

Ride, Noise and Friction

The ride quality of the bituminous test cells was evaluated in the fall of 2008 using a lightweight inertial profiler, and was reported in terms of International Roughness Index (IRI). With the exception of Cells 4 and 23, the bituminous cells had initial average IRI values near or below 1.0 m/km in the driving lane.

Tire-pavement noise was measured using the On Board Sound Intensity (OBSI) method. Initial OBSI was collected in November 2008 in the passing lane only because it was assumed that the new construction would differ little between lanes. The average value for MnROAD bituminous cells was found to be 101.0 dB(A). In contrast to IRI results, the FRAP Cells along with Cells 4 and 23 produced above average OBSI values, while the warm mix cells were all below the average. The low volume HMA on Cell 24 was not evaluated at that time.

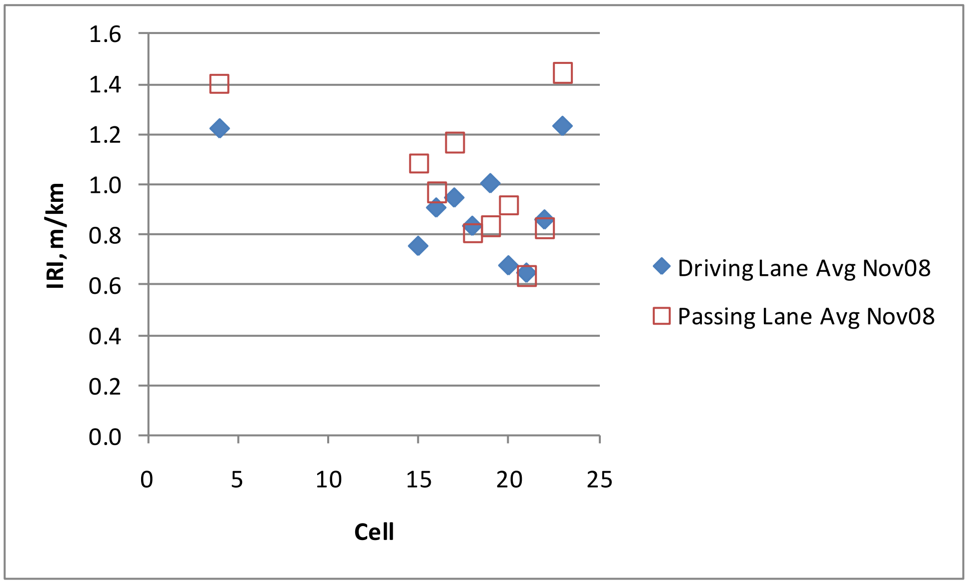

Figure 26 Initial IRI measurements.

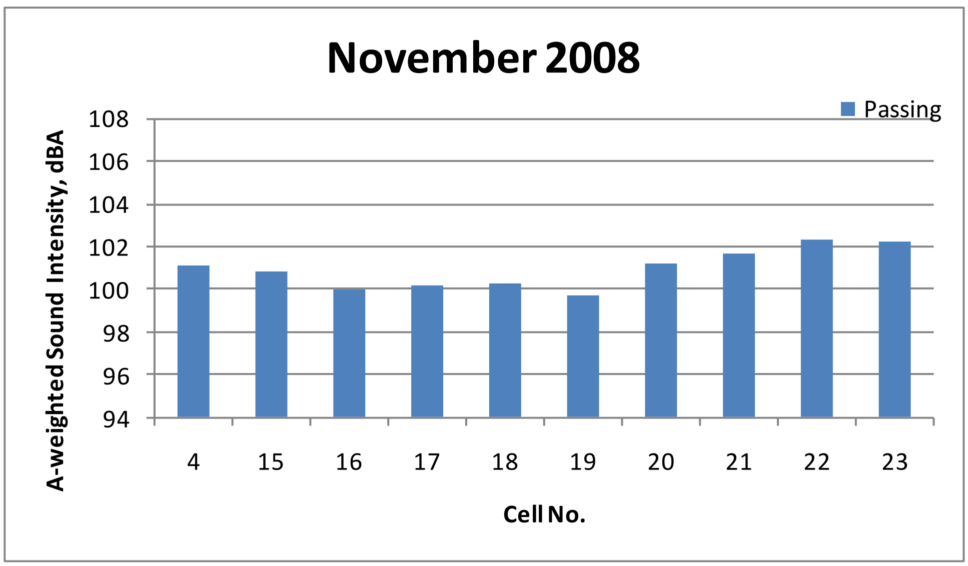

Figure 27 Noise data measured with the OBSI method, passing lane average 101.0.

Tire-pavement friction was evaluated at 40 mph in the driving and passing lanes using a Dynatest Locked-Wheel Trailer configured with a ribbed-tire. In October 2008 the average MnROAD bituminous friction number was found to be 57.5. All bituminous cells produced initial friction number (FN 40R) readings at or above 50.

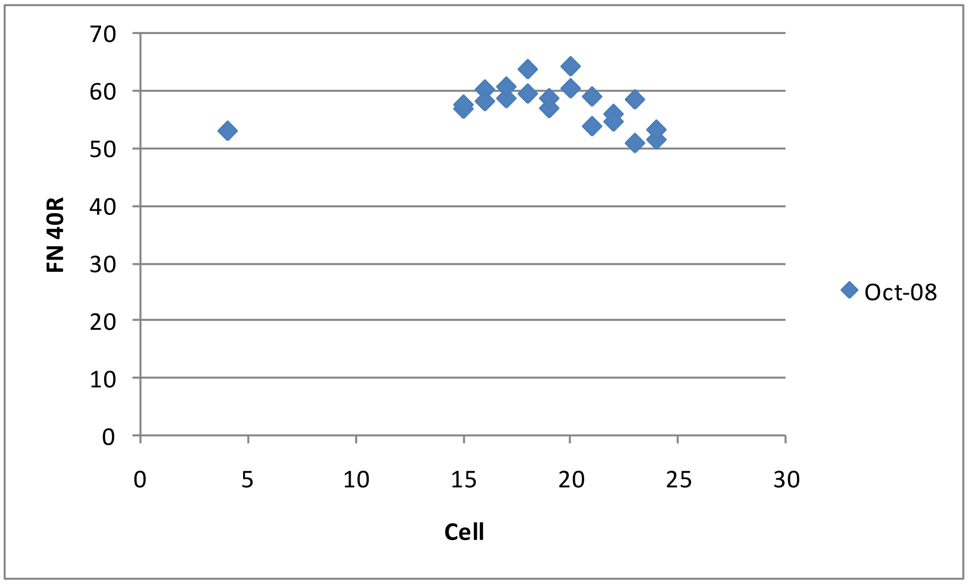

Figure 28 Dynamic friction test results, average of 57.5.

Conclusions

This report describes eleven bituminous test cells constructed during the Phase II MnROAD Reconstruction that occurred in 2008. The cells material components were selected to include a number of variables useful to asphalt pavement research as well as aggregate base research. The asphalt structures were designed for a 5-year life.

Construction monitoring activities were performed on the granular and bituminous layers. DCP tests of the granular materials showed that Class 5, Class 7, Class 3, and Select Granular sections exhibited similar performance. Analysis of as-built asphalt content showed the contractor met or exceeded the minimum required asphalt content. FRAP mixtures averaged 0.3 % excess asphalt compared to the design values.

New bituminous cells in the Phase II reconstruction had similar friction performance. Tire-pavement noise was more variable, with an average of 101 dB[A]. Cells 21 through 23 were the loudest, and will be checked in future monitoring activities. Ride quality was between 0.6 and 1.2 m/km (38 and 53 in/mi) for all cells except Cell 4 and Cell 23, which were rougher. This trend will also be checked in future monitoring activities.

FWD data showed that the test cells performed in a similar manner, and substructure could potentially be ignored in future bituminous performance analyses. The only exception to this generalization was the full-depth asphalt cell, whose Area factor fell 34 percent above the average.

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