APPENDIX A

Test Matrix for Laboratory Mixtures

Concrete Mixture Proportions Prepared in Laboratory

Table A-1. Concrete mixture proportions for main body of experiments (lb/yd^3).

Concrete type	Cement (LA, HA, or TIL)	Fly ash	Natural pozzolan	Water	W/cm ratio	Aggregate		
						Natural sand	Manufactured fine	Coarse (limestone)
With natural sand and fly ash	452	113	-	237	0.42	1,389	-	1,841
With natural sand and natural pozzolan	508	-	57	237	0.42	1,389	-	1,841
Concrete with manufactured sand	452	113	-	237	0.42	969	646	1,615
With manufactured sand and natural pozzolan	508	-	57	237	0.42	969	646	1,615

Note: HA, LA, and TIL = high-alkali, low-alkali, and Type IL portland-limestone, respectively.

Table A-2. Concrete mixture proportions for clustering experiments (lb/yd^3).

Concrete type	Cement (LA, HA, or TIL)	SCM (FA 4 or FA 5)	Initial water	Retempering water	W/cm ratio	Aggregate	
						Fine (natural)	Coarse (limestone or gravel)
Control mixtures	439	110	230	-	0.42	1,347	1,785
Experimental mixtures	439	110	230	17	0.45	1,347	1,785

Note: HA, LA, and TIL = high-alkali, low-alkali, and Type IL portland-limestone, respectively; FA 4 and FA 5 =low-quality and high-quality fly ash, respectively.

Table A-3. Test matrix for the main body of laboratory mixtures (144 concrete mixtures).

Mix#	Cement	SCM	AEA	WRA	Air	Fine
1	LA	FA 4	S	C	L	N
2	LA	FA 4	S	C	H	N
3	LA	FA 4	S	C	L	M
4	LA	FA 4	S	C	H	M
5	LA	FA 4	S	I	L	N
6	LA	FA 4	S	I	H	N
7	LA	FA 4	S	I	L	M
8	LA	FA 4	S	I	H	M
9	LA	FA 4	U	C	L	N
10	LA	FA 4	U	C	H	N
11	LA	FA 4	U	C	L	M
12	LA	FA 4	U	C	H	M
13	LA	FA 4	U	I	L	N
14	LA	FA 4	U	I	H	N
15	LA	FA 4	U	I	L	M
16	LA	FA 4	U	I	H	M
17	LA	FA 5	S	C	L	N
18	LA	FA 5	S	C	H	N
19	LA	FA 5	S	C	L	M
20	LA	FA 5	S	C	H	M
21	LA	FA 5	S	I	L	N
22	LA	FA 5	S	I	H	N
23	LA	FA 5	S	I	L	M
24	LA	FA 5	S	I	H	M
25	LA	FA 5	U	C	L	N
26	LA	FA 5	U	C	H	N
27	LA	FA 5	U	C	L	M
28	LA	FA 5	U	C	H	M
29	LA	FA 5	U	I	L	N
30	LA	FA 5	U	I	H	N
31	LA	FA 5	U	I	L	M
32	LA	FA 5	U	I	H	M
33	LA	Nat.	S	C	L	N
34	LA	Nat.	S	C	H	N
35	LA	Nat.	S	C	L	M
36	LA	Nat.	S	C	H	M
37	LA	Nat.	S	I	L	N
38	LA	Nat.	S	I	H	N
39	LA	Nat.	S	I	L	M
40	LA	Nat.	S	I	H	M

Mix#	Cement	SCM	AEA	WRA	Air	Fine
41	LA	Nat.	U	C	L	N
42	LA	Nat.	U	C	H	N
43	LA	Nat.	U	C	L	M
44	LA	Nat.	U	C	H	M
45	LA	Nat.	U	I	L	N
46	LA	Nat.	U	I	H	N
47	LA	Nat.	U	I	L	M
48	LA	Nat.	U	I	H	M
49	HA	FA 4	S	C	L	N
50	HA	FA 4	S	C	H	N
51	HA	FA 4	S	C	L	M
52	HA	FA 4	S	C	H	M
53	HA	FA 4	S	I	L	N
54	HA	FA 4	S	I	H	N
55	HA	FA 4	S	I	L	M
56	HA	FA 4	S	I	H	M
57	HA	FA 4	U	C	L	N
58	HA	FA 4	U	C	H	N
59	HA	FA 4	U	C	L	M
60	HA	FA 4	U	C	H	M
61	HA	FA 4	U	I	L	N
62	HA	FA 4	U	I	H	N
63	HA	FA 4	U	I	L	M
64	HA	FA 4	U	I	H	M
65	HA	FA 5	S	C	L	N
66	HA	FA 5	S	C	H	N
67	HA	FA 5	S	C	L	M
68	HA	FA 5	S	C	H	M
69	HA	FA 5	S	I	L	N
70	HA	FA 5	S	I	H	N
71	HA	FA 5	S	I	L	M
72	HA	FA 5	S	I	H	M
73	HA	FA 5	U	C	L	N
74	HA	FA 5	U	C	H	N
75	HA	FA 5	U	C	L	M
76	HA	FA 5	U	C	H	M
77	HA	FA 5	U	I	L	N
78	HA	FA 5	U	I	H	N
79	HA	FA 5	U	I	L	M
80	HA	FA 5	U	I	H	M
81	HA	Nat.	S	C	L	N
82	HA	Nat.	S	C	H	N

Mix#	Cement	SCM	AEA	WRA	Air	Fine
83	HA	Nat.	S	C	L	M
84	HA	Nat.	S	C	H	M
85	HA	Nat.	S	I	L	N
86	HA	Nat.	S	I	H	N
87	HA	Nat.	S	I	L	M
88	HA	Nat.	S	I	H	M
89	HA	Nat.	U	C	L	N
90	HA	Nat.	U	C	H	N
91	HA	Nat.	U	C	L	M
92	HA	Nat.	U	C	H	M
93	HA	Nat.	U	I	L	N
94	HA	Nat.	U	I	H	N
95	HA	Nat.	U	I	L	M
96	HA	Nat.	U	I	H	M
97	TIL	FA 4	S	C	L	N
98	TIL	FA 4	S	C	H	N
99	TIL	FA 4	S	C	L	M
100	TIL	FA 4	S	C	H	M
101	TIL	FA 4	S	I	L	N
102	TIL	FA 4	S	I	H	N
103	TIL	FA 4	S	I	L	M
104	TIL	FA 4	S	I	H	M
105	TIL	FA 4	U	C	L	N
106	TIL	FA 4	U	C	H	N
107	TIL	FA 4	U	C	L	M
108	TIL	FA 4	U	C	H	M
109	TIL	FA 4	U	I	L	N
110	TIL	FA 4	U	I	H	N
111	TIL	FA 4	U	I	L	M
112	TIL	FA 4	U	I	H	M
113	TIL	FA 5	S	C	L	N
114	TIL	FA 5	S	C	H	N
115	TIL	FA 5	S	C	L	M
116	TIL	FA 5	S	C	H	M
117	TIL	FA 5	S	I	L	N
118	TIL	FA 5	S	I	H	N
119	TIL	FA 5	S	I	L	M
120	TIL	FA 5	S	I	H	M
121	TIL	FA 5	U	C	L	N
122	TIL	FA 5	U	C	H	N
123	TIL	FA 5	U	C	L	M
124	TIL	FA 5	U	C	H	M

Mix#	Cement	SCM	AEA	WRA	Air	Fine
125	TIL	FA 5	U	I	L	N
126	TIL	FA 5	U	I	H	N
127	TIL	FA 5	U	I	L	M
128	TIL	FA 5	U	I	H	M
129	TIL	Nat.	S	C	L	N
130	TIL	Nat.	S	C	H	N
131	TIL	Nat.	S	C	L	M
132	TIL	Nat.	S	C	H	M
133	TIL	Nat.	S	I	L	N
134	TIL	Nat.	S	I	H	N
135	TIL	Nat.	S	I	L	M
136	TIL	Nat.	S	I	H	M
137	TIL	Nat.	U	C	L	N
138	TIL	Nat.	U	C	H	N
139	TIL	Nat.	U	C	L	M
140	TIL	Nat.	U	C	H	M
141	TIL	Nat.	U	I	L	N
142	TIL	Nat.	U	I	H	N
143	TIL	Nat.	U	I	L	M
144	TIL	Nat.	U	I	H	M

Note: HA, LA, and TIL = high-alkali, low-alkali, and Type IL portland-limestone, respectively; FA 4 and FA 5 = low-quality fly ash and high-quality fly ash; U and S = unstable and stable AEAs; I and C = incompatible and compatible WRAs; L and G = limestone and gravel coarse aggregates.

Table A-4. Test matrix for clustering mixtures (61 concrete mixtures).

Mix#	Cement	SCM	Initial w/cm	Retempering	AEA	WRA	Coarse	Temperature
1	TIL	FA 4	0.42	Yes	S	C	L	70
2	TIL	FA 4	0.42	Yes	S	C	L	90
3	TIL	FA 4	0.42	Yes	S	C	G	70
4	TIL	FA 4	0.42	Yes	S	C	G	90
5	TIL	FA 4	0.42	Yes	U	I	L	70
6	TIL	FA 4	0.42	Yes	U	I	L	90
7	TIL	FA 4	0.42	Yes	U	I	G	70
8	TIL	FA 4	0.42	Yes	U	I	G	90
9	TIL	FA 5	0.42	Yes	S	C	L	70
10	TIL	FA 5	0.42	Yes	S	C	L	90
11	TIL	FA 5	0.42	Yes	S	C	G	70
12	TIL	FA 5	0.42	Yes	S	C	G	90
13	TIL	FA 5	0.42	Yes	U	I	L	70
14	TIL	FA 5	0.42	Yes	U	I	L	90
15	TIL	FA 5	0.42	Yes	U	I	G	70
16	TIL	FA 5	0.42	Yes	U	I	G	90
17	LA	FA 4	0.42	Yes	S	C	L	70
18	LA	FA 4	0.42	Yes	S	C	L	90
19	LA	FA 4	0.42	Yes	S	C	G	70
20	LA	FA 4	0.42	Yes	S	C	G	90
21	LA	FA 4	0.42	Yes	U	I	L	70
22	LA	FA 4	0.42	Yes	U	I	L	90
23	LA	FA 4	0.42	Yes	U	I	G	70
24	LA	FA 4	0.42	Yes	U	I	G	90
25	LA	FA 5	0.42	Yes	S	C	L	70
26	LA	FA 5	0.42	Yes	S	C	L	90
27	LA	FA 5	0.42	Yes	S	C	G	70
28	LA	FA 5	0.42	Yes	S	C	G	90
29	LA	FA 5	0.42	Yes	U	I	L	70
30	LA	FA 5	0.42	Yes	U	I	L	90
31	LA	FA 5	0.42	Yes	U	I	G	70
32	LA	FA 5	0.42	Yes	U	I	G	90
33	HA	FA 4	0.42	Yes	S	C	L	70
34	HA	FA 4	0.42	Yes	S	C	L	90
35	HA	FA 4	0.42	Yes	S	C	G	70
36	HA	FA 4	0.42	Yes	S	C	G	90
37	HA	FA 4	0.42	Yes	U	I	L	70
38	HA	FA 4	0.42	Yes	U	I	L	90
39	HA	FA 4	0.42	Yes	U	I	G	70
40	HA	FA 4	0.42	Yes	U	I	G	90
41	HA	FA 5	0.42	Yes	S	C	L	70

Mix#	Cement	SCM	Initial w/cm	Retempering	AEA	WRA	Coarse	Temperature
42	HA	FA 5	0.42	Yes	S	C	L	90
43	HA	FA 5	0.42	Yes	S	C	G	70
44	HA	FA 5	0.42	Yes	S	C	G	90
45	HA	FA 5	0.42	Yes	U	I	L	70
46	HA	FA 5	0.42	Yes	U	I	L	90
47	HA	FA 5	0.42	Yes	U	I	G	70
48	HA	FA 5	0.42	Yes	U	I	G	90
49	TIL	FA 4	0.45	No	U	I	G	70
50	TIL	FA 4	0.45	No	U	I	G	90
51	LA	FA 4	0.45	No	U	I	G	70
52	LA	FA 4	0.45	No	U	I	G	90
53	HA	FA 4	0.45	No	U	I	G	70
54	HA	FA 4	0.45	No	U	I	G	90
55	TIL	FA 4	0.42	Yes	U	I	L	90*
56	LA	FA 4	0.42	Yes	U	I	L	90*
57	HA	FA 4	0.42	Yes	U	I	L	90*
58	HA	FA 4	0.42	Yes	S	C	L	90*
59	HA	FA 5	0.42	Yes	S	C	L	90*
60	LA	FA 4	0.45	No	U	I	L	90*
61	HA	FA 4	0.45	No	U	I	L	90*

Note: *Concrete temperature at the time of mixing. HA, LA, and TIL = high-alkali, low-alkali, and Type IL portland-limestone, respectively; FA 4 and FA 5 = low-quality fly ash and high-quality fly ash; U and S = unstable and stable AEAs; I and C = incompatible and compatible WRAs; L and G = limestone and gravel coarse aggregates.

Mixing Sequences

Procedure for 144 Main Mixtures

A drum mixer with 3-ft^3 capacity was used. Two mixing procedures were considered during the study. The first procedure, used in the main body of experiments, i.e., the 144 concrete mixtures, consisted of the following:

1. Mix the coarse aggregate and the water needed for saturating the aggregate to saturated surface dry (SSD) condition for 1 minute.

2. Add the AEA diluted in one-third of the mixing water and mix for 1 minute.

3. Add the fine aggregate along with one-third of the mixing water and mix for 1 minute.

4. Introduce the cementitious materials and mix for 0.5 minute.

5. Add the WRA diluted with the remainder of the water and mix for 2.5 minutes.

6. Rest the mixture for 3 minutes with the mixer covered with a wet towel.

7. Remove the wet towel and resume mixing for 2 minutes.

8. Sample and test for air content in fresh state and SAM number.

Procedure for Clustering Study

Additional steps were necessary for the clustering study. The second procedure, used for clustering experiments, consisted of the following additional steps after the first sampling:

1. Rest the remaining concrete in the mixer for 15 minutes with no cover.

2. Add additional water used for retempering to the mixer and mix for 2 minutes.

3. Sample and test for air content in fresh state and SAM number.

Field Investigation Sites

Pennsylvania

Source: © 2018 Google

Figure A-1. Aerial view of coring locations in Dauphin, Pennsylvania.

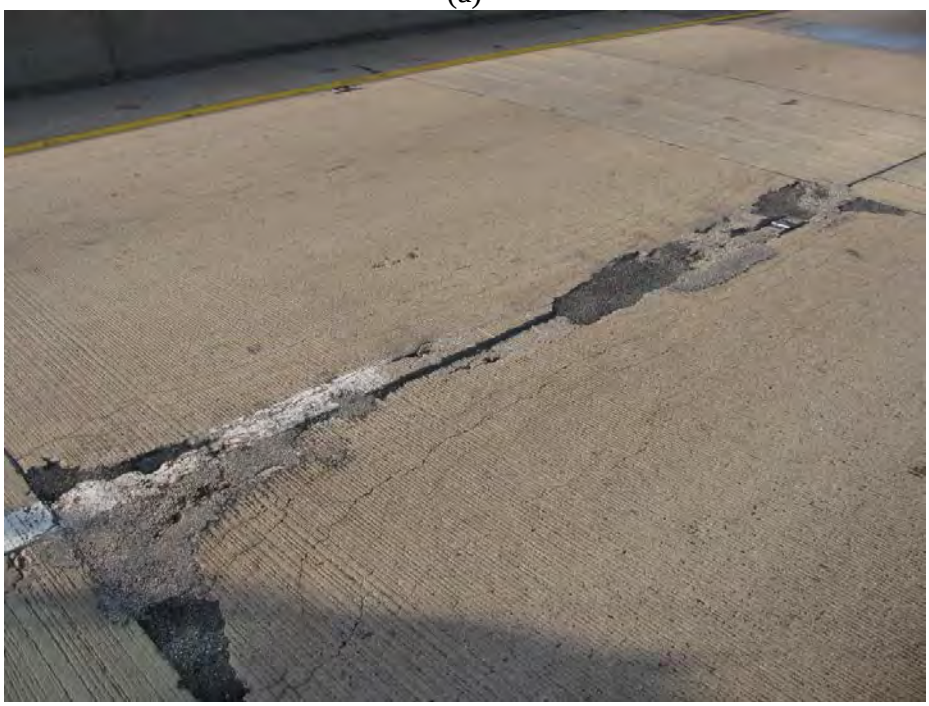
(a)

(b)

Source: PennDOT.

Figure A-2. Coring locations in Dauphin, Pennsylvania, with (a) sound concrete and (b) distressed pavement.

(a)



(b)

Source: National CP Tech Center.

Figure A-3. Dauphin, Pennsylvania, with (a) high concentration of cracks and (b) D-cracking and longitudinal cracking at distressed section.

(a)

(b)

Source: National CP Tech Center.

Figure A-4. Sound concrete/control section surface condition, Dauphin, Pennsylvania, with (a) no cracking but some signs of scaling and abrasion in panels and (b) no joint damage.

New York

(a) (b) (c)

Source: NYSDOT.

Figure A-5. Distressed concrete pavement, Albany, New York, with (a) scaling and (b and c) wide-open cracks that can be due to traffic loading.

Source: NYSDOT.

Figure A-6. Coring conducted by NYSDOT staff on Alternate Route 7, Albany, New York.

Nevada

(a)

(b)

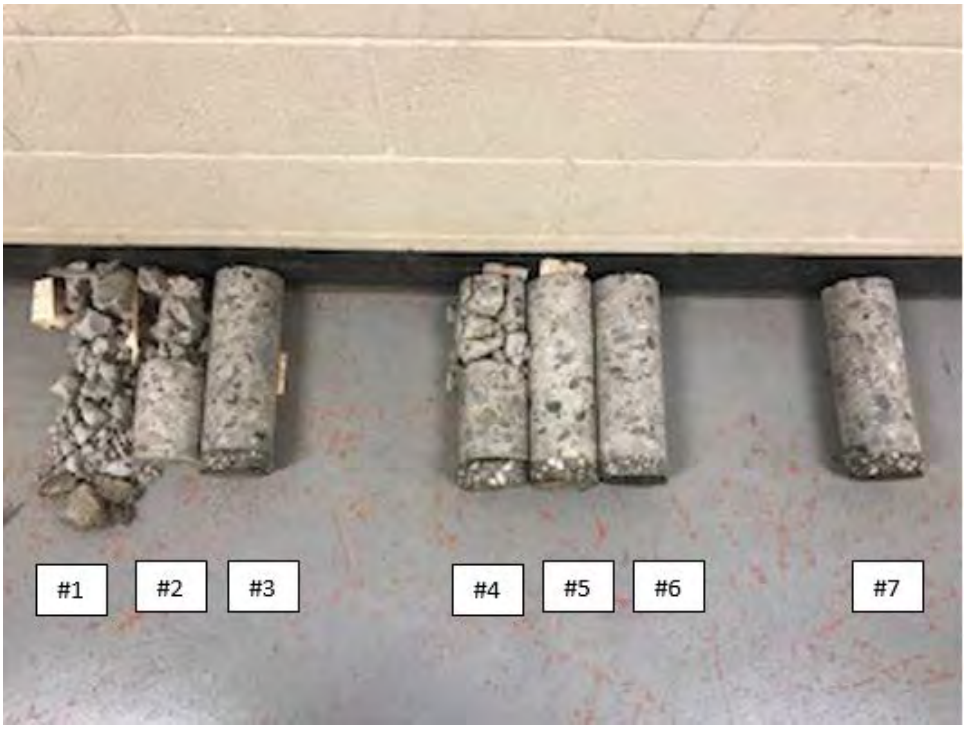
Source: Nevada DOT.

Figure A-7. Panels in Valmy, Nevada, exhibiting (a) moderate distress and (b) severe distress.

Source: Nevada DOT.

Figure A-8. Panels exhibiting slight or no distress, Valmy, Nevada.

Seven cores were extracted from this pavement, as shown in Figure A-9.



Source: Nevada DOT.

Figure A-9. Extracted cores, I-80, Valmy, Nevada.

Missouri

Source: National CP Tech Center.

Figure A-10. Panel with severe distress, US-63, Moberly, Missouri.

Source: National CP Tech Center.

Figure A-11. Panel with moderate distress, US-63, Moberly, Missouri.

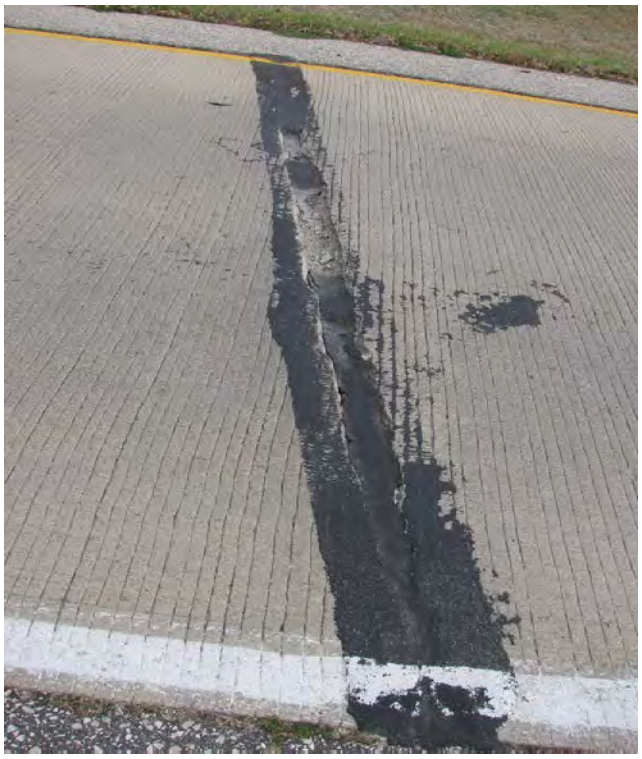
Source: National CP Tech Center.

Figure A-12. Extracting a core from a panel with slight or no distress, US-63, Moberly, Missouri.

Minnesota US-52

Source: National CP Tech Center.

Figure A-13. Panel with no distress, US-52, Rochester, Minnesota.



Source: National CP Tech Center.

Figure A-14. No mid-panel distress but severe joint damage, US-52, Rochester, Minnesota.

Minnesota MnROAD Research Facility

Source: Janssen 2006.

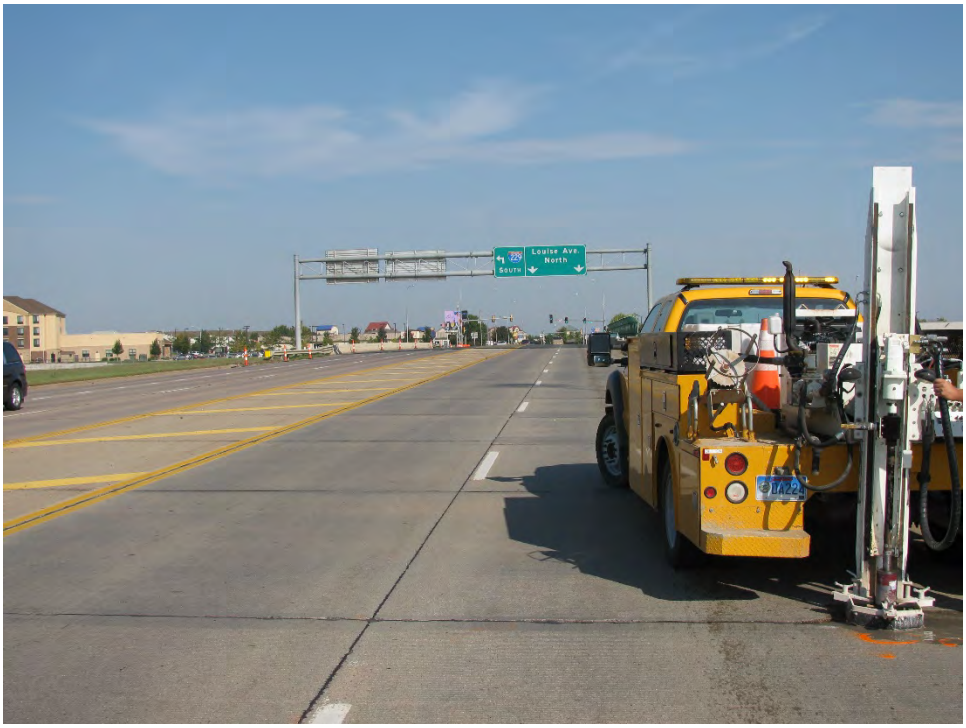
(a)

Source: Minnesota MnROAD Research Facility.

(b)

Figure A-15. MnROAD maintenance yard condition of panels in (a) 1994 and (b) 2018.

South Dakota



Source: National CP Tech Center.

Figure A-16. First test section in Sioux Falls, South Dakota.

(a)

(b)

Source: National CP Tech Center.

Figure A-17. First test section, Sioux Falls, South Dakota, with (a) severe joint damage and (b) acceptable mid-panel pavement performance.

(a)

(b)

Source: National CP Tech Center.

Figure A-18. Second test section, Sioux Falls, South Dakota, with (a) D-cracking patterns close to the joints and (b) joint staining.

Michigan

Source: National CP Tech Center.

Figure A-19. Severe joint damage, M-6 freeway, Grand Rapids, Michigan.

Source: National CP Tech Center.

Figure A-20. Damage-free concrete at mid-panels, M-6 freeway, Grand Rapids, Michigan.

Manitoba, Canada

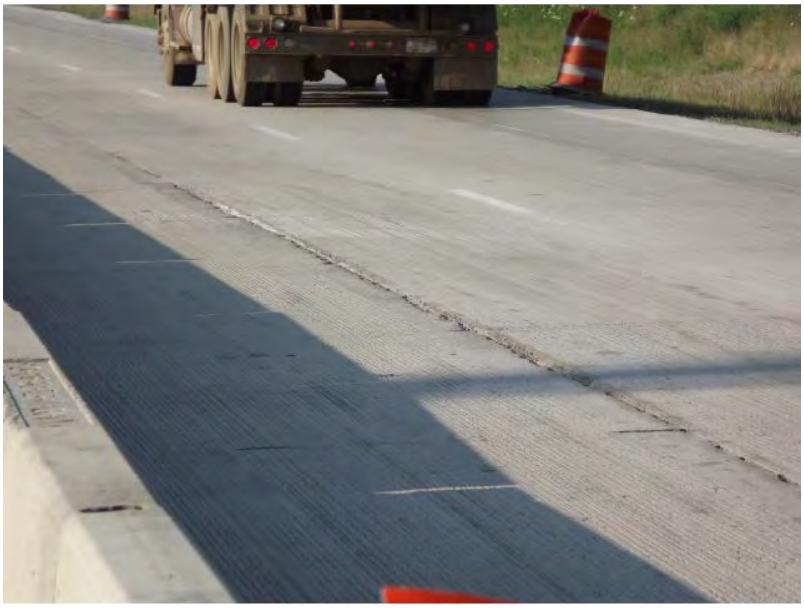
Source: Manitoba Infrastructure Department.

Figure A-21. Observed joint damage, PTH-30, Manitoba, Canada.

Source: Manitoba Infrastructure Department.

Figure A-22. Observed surface distress, PTH-30, Manitoba, Canada.

Ohio



(a)

(b)

Source: Ohio DOT.

Figure A-23. Panels in Allen County, Ohio with (a) premature distress and (b) coring.

Ontario, Canada

Source: Ontario Ministry of Transportation.

Figure A-24. Joint distress observed in ON-417, Ontario, Canada.

(a)

(b)

Source: Ontario Ministry of Transportation.

Figure A-25. Sound mid-panel concrete (both a and b) sampled on ON-417 in Ontario, Canada.

Table A-5. Summary of observations from investigated sites.

Geographic Location	Core #	W/cm	Observed Properties			Expected Performance		
			Air (%)	S.F. (in.)	S.S. (in.$^{-1}$)	Air	S.F.	S.S.
Pennsylvania	1-E	0.47	2.46	0.011	634	Poor	Poor	Poor
	3-E		4.03	0.015	382	Poor	Poor	Poor
	4-E		2.5	0.013	513	Poor	Poor	Marginal
	5-E		2.39	0.013	531	Poor	Poor	Marginal
	1-C		2.75	0.011	624	Poor	Poor	Good
	2-C		1.96	0.023	345	Poor	Poor	Poor
	4-C		2.3	0.011	615	Poor	Poor	Good
	5-C		3.99	0.012	470	Poor	Poor	Marginal
New York	5	0.44	4.47	0.007	796	Marginal	Good	Good
	6		3.82	0.009	618	Poor	Marginal	Good
	7		6.74	0.008	511	Good	Good	Marginal
	8		5.69	0.009	538	Marginal	Marginal	Marginal
	9		7.13	0.009	467	Good	Marginal	Marginal
Nevada	3	0.44	4.52	0.013	408	Marginal	Poor	Marginal
	3		7.40	0.010	430	Good	Marginal	Marginal
	5		3.00	0.013	513	Poor	Poor	Marginal
	6		4.63	0.014	375	Marginal	Poor	Poor
	6		7.6	0.009	381	Good	Marginal	Poor
	7		1.93	0.018	432	Poor	Poor	Marginal
Missouri	1	0.38	4.70	0.007	635	Marginal	Good	Good
	2		1.61	0.010	833	Poor	Marginal	Good
	3		2.50	0.009	769	Poor	Marginal	Good
	4		3.06	0.019	333	Poor	Poor	Poor
	5		1.73	0.014	589	Poor	Poor	Marginal
	6		4.38	0.014	390	Marginal	Poor	Poor
	7		1.90	0.017	457	Poor	Poor	Marginal
	8		1.11	0.016	633	Poor	Poor	Good

Geographic Location	Core #	W/cm	Observed Properties			Expected Performance		
			Air (%)	S.F. (in.)	S.S. (in.$^{-1}$)	Air	S.F.	S.S.
Minnesota US 52	1	0.42	4.70	0.006	727	Marginal	Good	Good
	2		4.15	0.012	472	Poor	Poor	Marginal
	3		4.53	0.011	492	Marginal	Poor	Marginal
	4		4.70	0.007	690	Marginal	Good	Good
	5		2.58	0.015	451	Poor	Poor	Marginal
	6		4.49	0.015	357	Marginal	Poor	Poor
	8		4.96	0.014	353	Marginal	Poor	Poor
	9		2.00	0.013	595	Poor	Poor	Marginal
	10		3.78	0.014	396	Poor	Poor	Marginal
	11		6.59	0.012	372	Good	Poor	Poor
Minnesota, MnROAD	2		3.66	0.012	503	Poor	Poor	Marginal
	3		3.94	0.014	363	Poor	Poor	Poor
	4		4.34	0.014	373	Marginal	Poor	Poor
	6		3.99	0.010	531	Poor	Marginal	Marginal
	7		3.07	0.009	703	Poor	Marginal	Good
South Dakota	2	0.38	2.86	0.014	456	Poor	Poor	Marginal
	3		1.13	0.022	440	Poor	Poor	Marginal
	5		4.00	0.007	816	Poor	Good	Good
	6		5.30	0.009	556	Marginal	Marginal	Marginal
	6		2.83	0.014	479	Poor	Poor	Marginal
	8		7.59	0.008	456	Good	Good	Marginal
Michigan	1	0.45	4.48	0.013	418	Marginal	Poor	Marginal
	2		3.97	0.012	467	Poor	Poor	Marginal
	7		4.14	0.009	589	Poor	Marginal	Marginal
	8		3.27	0.010	619	Poor	Marginal	Good
Manitoba, Canada	1	0.45	5.14	0.013	391	Marginal	Poor	Marginal
	2		3.49	0.013	442	Poor	Poor	Marginal
	3		4.05	0.011	487	Poor	Poor	Marginal
	5		10.00	0.007	417	Good	Good	Marginal

Geographic Location	Core #	W/cm	Observed Properties			Expected Performance		
			Air (%)	S.F. (in.)	S.S. (in.$^{-1}$)	Air	S.F.	S.S.
Ohio	1	0.44	2.75	0.006	1,061	Poor	Good	Good
	2		4.19	0.005	1,031	Poor	Good	Good
	3		5.13	0.005	946	Marginal	Good	Good
	4		5.17	0.005	882	Marginal	Good	Good
	5		3.55	0.004	1,281	Poor	Good	Good
	6		2.70	0.005	1,263	Poor	Good	Good
	7		4.88	0.006	867	Marginal	Good	Good
	8		2.46	0.005	1,280	Poor	Good	Good
	9		4.11	0.005	959	Poor	Good	Good
	10		2.08	0.004	1,446	Poor	Good	Good
	11		4.89	0.007	658	Marginal	Good	Good
	12		4.76	0.005	1,011	Marginal	Good	Good
	13		5.16	0.004	1,237	Marginal	Good	Good
	14		6.15	0.003	1,115	Marginal	Good	Good
	15		5.15	0.004	1,101	Marginal	Good	Good
	16		4.50	0.004	1,090	Marginal	Good	Good
	17		3.49	0.005	1,221	Poor	Good	Good
	18		2.45	0.005	1,238	Poor	Good	Good
	19		4.02	0.005	932	Poor	Good	Good
	20		2.24	0.005	1,453	Poor	Good	Good
	21		2.82	0.004	1,458	Poor	Good	Good
	22		2.33	0.005	1,387	Poor	Good	Good
	23		2.92	0.006	943	Poor	Good	Good
Ontario, Canada	5	0.45	5.1	0.009	432	Marginal	Marginal	Marginal
	14		5.5	0.007	685	Marginal	Good	Good
	20		5.1	0.005	838	Marginal	Good	Good
	24		6.0	0.005	584	Marginal	Good	Marginal
	35		2.3	0.006	914	Poor	Good	Good
	44		3.1	0.006	1,016	Poor	Good	Good
	C2T	0.40	6.2	0.006	513	Marginal	Good	Marginal
	C4T		4.7	0.006	592	Marginal	Good	Marginal
	2C		5.0	0.004	810	Marginal	Good	Good
	5C		5.7	0.004	1,054	Marginal	Good	Good

Note: S.F. = spacing factor, S.S. = specific surface.