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In-Service Performance Of HP Concrete Bridge Decks

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ABSTRACT

Current Department specifications require Class HP (for "high-performance") concrete for bridge decks in New York State. In April 1996, Class HP replaced Classes E and H concretes as the statewide standard to increase deck durability by reducing cracking and permeability, but subsequently some cracking of HP decks was reported. Initially, no quantitative details were yet available, so that actual HP deck performance could not be evaluated. At the request of the Structures Design and Construction Division, Technical Services Division, Bridge Performance Committee, and Concrete Committee, the Transportation R&D Bureau initiated a survey of the NYSDOT Regions to record their experience with this mix and quantify the resulting information. By June 1998, more than 80 bridge decks had been built specifying HP concrete. These structures were visually inspected by regional engineers after opening to traffic, indicating that 1) HP decks performed better than Class E and H decks in resisting both longitudinal and transverse cracking, 2) of 84 decks inspected, 49 percent exhibited no cracking at all, but of those that had cracked 88 percent showed equal or less longitudinal cracking and 80 percent equal or less transverse cracking than the previously specified concretes, and 3) average transverse crack density on HP decks was 6.9 cm/m^2, a figure comparable to densities for other decks (not using HP mix) reported in the recent literature.

CONTENTS

I. INTRODUCTION

BACKGROUND

The New York State Department of Transportation develops specifications for portland-cement concrete mixtures used for all state projects (1). Several mix "classes" are available depending on application, and those required for various structural-concrete items are indicated on contract plans. Until 1996, NYSDOT Class E concrete was the standard used for structural slabs and structural-approach slabs. Class H concrete was an allowable substitution in pumping applications. Mix criteria are given in Table 1.

A very evident problem on bridge decks built with Classes E and H concretes had been spalling due to rebar corrosion, directly attributable to excessive permeability by such concrete-deteriorating solubles as de-icing salts. To improve concrete durability, a Bridge Deck Task Force (comprised of materials engineers, researchers, and structural engineers) was formed in the Fall of 1994. They determined that significant improvement would result from a concrete mixture that reduced permeability and potential for cracking (2).

The Task Force reviewed the state-of-the-art, conducted laboratory testing and statistical analysis of several mixes, and formulated a new concrete mixture by modifying Class H concrete. Designated "high-performance" or "Class HP" concrete, this mix has two pozzolanic substitutions for cement (Table 1). It has better handling and workability characteristics, lower permeability, and greater resistance to cracking. Note that increased strength was not the primary concern. Based on an analytical model (3), it was estimated that corrosion might be expected to commence at 23 and 62 years of age for Class H and Class HP concretes, respectively. This model assumes 3 in. of concrete cover and use of uncoated reinforcing steel. Effective April 12, 1996, through Engineering Instruction EI 96-024 (4), Class HP concrete was implemented as the standard for all New York State bridge decks. By June 1998, more than 80 decks had been constructed using HP concrete.

Table 1. Mix criteria for Class E, H, and HP concretes.

Property	Class E	Class H	Class HP
Cement Density, kg/m³	384	400	300
Sand, % of Total Aggregate*	35.8	40.0	40.0
Water/Cement Ratio (weight)	0.44	0.44	0.40
Air Content, %	6.5	6.5	6.5
Fly Ash Content, kg/m³	--	--	80
Microsilica Content, kg/m³	--	--	25
Slump Range, mm	75-100	75-100	75-100
Coarse Aggregate Gradation	CA2	CA2	CA2

*Solid volume.

After implementation of HP concrete, several reports were received regarding deck cracking, but evaluation of actual performance of HP concrete decks was impossible because no quantitative information was yet available. The Transportation R&D Bureau thus initiated a study to collect such data, at the request of the Structures Design and Construction Division, Technical Services Division, Bridge Performance Committee, and Concrete Committee. Results of that study are summarized here.

STUDY APPROACH

In consultation with the Concrete Engineering Unit of the Structures Division and members of the Bridge Performance Committee, it was decided to survey decks statewide where Class HP concrete had been used. A list of those completed from 1996 through early 1998 was produced using the Unit's own database and Materials Bureau staff records. A survey questionnaire was drafted and reviewed by the Structures Division, Bridge Performance Committee, and Region 1 Construction Engineer (Appendix A). It was modified based on comments received, and then sent to each region along with a list of that region's HP bridge decks. Regional Construction Engineers were asked to complete the forms after visually inspecting each HP concrete bridge deck. They were to focus on cracking that appeared to be unrelated to imposed loads. Information was requested on number, length, and plan location of all transverse cracks. Inspectors were also asked to compare performance of Class HP decks with those built using Class E and H concretes. The survey was also intended to determine time of crack initiation as well as the effects (if any) of staged construction on deck cracking.

Survey responses received from the NYSDOT regions are discussed in Chapter II, summarized in Appendices B and C, and were analyzed to determine frequency and severity of transverse cracking. Crack frequency was also analyzed by region and compared with data available from bridge decks built using Class E and H concrete. Final conclusions and recommendations are presented in Chapter III.

II. STATEWIDE SURVEY RESULTS

Responses received by the end of September 1998 are summarized in Appendix B. Information on general use of the mix, construction problems encountered, ease in finishing decks using this mix, and effects of staged construction, as received from Regional Engineers, is summarized in Appendix C. Tables 2 and 3 summarize survey results by region and year of construction, respectively. Figure 1 shows occurrence of deck cracking in relation to years-in-service. The front two bars represent transverse and longitudinal cracking on decks built in each of four years. Table 4 summarizes longitudinal and transverse cracking reported by regions, and Table 5 covers transverse crack density reported by the regions. Crack densities were estimated by dividing measured crack lengths by deck area, as obtained from the NYSDOT bridge inventory database. Table 6 summarizes transverse crack

Figure 1. Occurrence of cracking in relation to year built.

A. PERCENT OF DECKS **B. NUMBER OF DECKS**

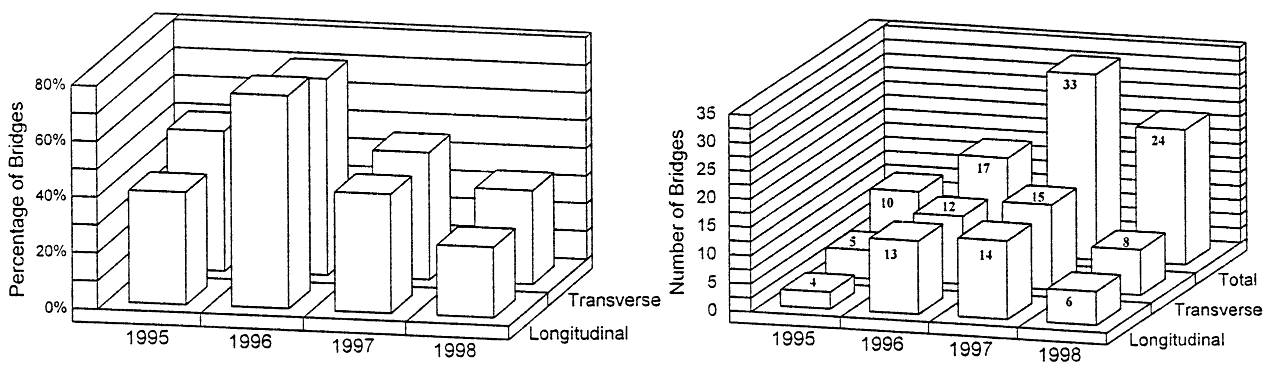


Table 2. Cracking by NYSDOT region.

NYSDOT Region*	Total Decks Inspected	Decks Cracked Total	Decks Cracked %	Decks Uncracked, %
1	14	11	78	22
2	12	11	92	8
3	1	0	0	100
4	5	0	0	100
5	15	8	53	47
7	7	4	57	43
8	7	3	43	57
9	10	3	30	70
10	13	3	23	77
Total	84	43	51	49

*Regions 6 and 11 did not respond.

Table 3. Cracking by year built.

Year Built	Total Decks Inspected	Decks with Transverse Cracking Total	Decks with Transverse Cracking %	Decks with Longitudinal Cracking Total	Decks with Longitudinal Cracking %
1995	10	5	50	4	40
1996	17	12	70	13	76
1997	33	15	45	14	42
1998	24*	8	33	6	25
Total	84	40	48	37	44

*Built through June 1998.

widths. Table 7 gives results of comparisons between Class HP and Class E and H decks, including number, width, and length of transverse and longitudinal cracks. Table 8 and Figure 2 give estimates of time that cracking began. Based on this information provided by the regions, six general observations can be made:

1. Field inspections were completed on 84 bridge decks built with the Class HP concrete adopted in EI 96-024. Table 2 shows that 41 (49 percent) of the inspected decks exhibited no cracking at all, but 43 decks (51 percent) showed some form of cracking.

2. Table 3 and Figure 1 show the relationship between years-in-service and transverse and longitudinal deck cracking. Transverse cracking was found on 40 (48 percent) of the inspected bridges and longitudinal cracking on 37 (44 percent). Thirty-four (40 percent) bridge decks exhibited both transverse and longitudinal cracking. All decks listed were built using Class HP concrete. Although it would be expected that years-in-service might have significant negative effect on deck condition within this study's time-frame, it appears to have no influence on deck cracking.

   In Figure 1B the first two rows of bars allow comparisons of successive annual numbers of decks showing longitudinal and transverse cracking. The back row represents total bridges inspected. Although use of Class HP began in 1996, several experiemental decks had been built earlier, and were included in the inspection lists provided to the regions. No obvious correlation appears between years-in-service and cracking or cracking density, based on these data. Average cracking densities per year (in cm/m^2) are 9.0, 6.7, 4.2 and 5.0 for 1998, 1997, 1996 and 1995, respectively.

   In 1995, ten test decks were built under supervision of the Materials Bureau. By 1996, HP concrete was in wide use. The 1996 peak in percentage of decks that exhibited cracking (Figure 1B), probably reflects that manufacturers, engineers-in-charge, and construction tradesmen were all at the beginning of their "learning curves" for this material. By 1997, quality of the decks, measured here by lack of cracking, increased as these participants became more familiar with the material. Numbers for 1998 seem to illustrate a leveling of the amount of cracking observed.

3. To minimize disruption to traffic flow, staged construction is often used in New York State. The survey looked for effects, if any, of this construction method on deck cracking and for information on whether decks had been built using staged or continuous construction, as well as comments concerning possible consequences for deck cracking. Table 4 shows results of this portion of the survey and specific comments are given in Appendix C. Staged construction appears to have had no negative effects -- such decks actually cracked less than those built continuously.

4. Transverse crack density was estimated for each bridge, as listed by region in Table 5. Average density of transverse cracks on HP decks was 6.9 cm/m^2, with a maximum density of 26.8 cm/m^2. Table 5 displays transverse-crack information only. Cracking densities collected in this study were compared with those published in the recent literature. Research Report 161 (5) described a study of long-term serviceability of full-scale, lightly reinforced bridge deck slabs

Table 4. Cracking by NYSDOT Region and type of construction.

	Total Decks Cracked				% of Decks Cracked	
	Staged Construction		Continuous Construction		Staged	Continuous
Region*	Inspected	Cracked	Inspected	Cracked	Construction	Construction
A. TRANSVERSE CRACKING						
1	11	5	3	3	46	100
2	8	7	4	4	88	100
3	0	0	1	0	0	0
4	2	0	3	0	0	0
5	2	0	13	8	0	62
7	0	0	7	4	0	57
8	5	2	2	1	40	50
9	2	0	8	3	0	38
10	9	2	4	1	22	25
Total	39	16	45	24	41	53
B. LONGITUDINAL CRACKING						
1	11	8	3	2	72	67
2	8	5	4	3	63	75
3	0	0	1	0	0	0
4	2	0	3	0	0	0
5	2	0	13	7	0	54
7	0	0	7	4	0	57
8	5	1	2	1	20	50
9	2	0	8	3	0	38
10	9	2	4	1	22	25
Total	39	16	45	21	41	47

*No data from Regions 6 and 11.

Table 5. Transverse crack density by NYSDOT region.

Region*	Total Decks Inspected	Density, cm/m² Avg	Max	Min
1	14	6.9	26.8	0.6
2	12	5.5	12.7	0.5
3	1	–	–	–
4	5	–	–	–
5	15	5.0	12.1	0.9
7	7	8.4	8.6	8.2
8	7	11.1	11.1	11.1
9	10	1.2	2.4	0.2
10	13	10.6	21.0	0.4
Total	84	6.9	26.8	0.0

*No data from Regions 6 and 11.

Table 6. Transverse crack width by NYSDOT region.

Region*	Width, mm Avg	Max	Min
1	2.2	6.4	1.0
2	2.3	6.4	0.5
3	–	–	–
4	–	–	–
5	1.5	6.4	1.0
7	1.0	1.0	1.0
8	1.0	1.0	1.0
9	1.0	1.0	1.0
10	1.4	1.6	1.0
Total	1.5	6.4	0.5

*No data from Regions 6 and 11.

Table 7. Class HP deck performance compared with Class E and H decks*.

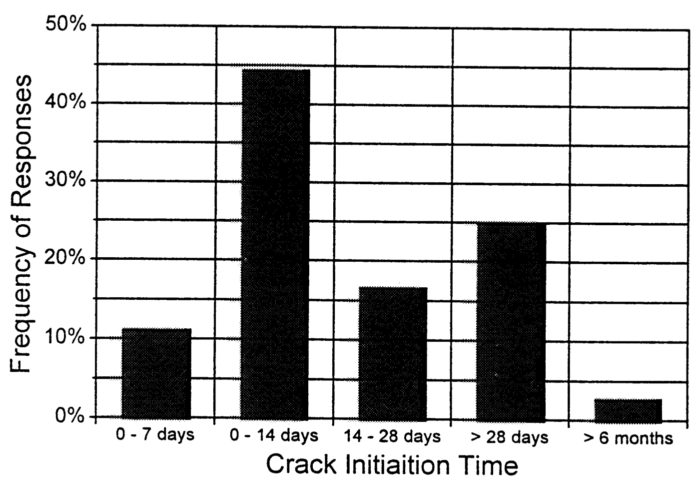
	Transverse Cracking			Longitudinal Cracking		
Cracking Amount	Total Cracks	Avg Width	Total Length	Total Cracks	Avg Width	Total Length
Significantly less	*22.5%*	20.0%	22.5%	*6.0%*	9.7%	6.5%
Less than before	*22.5%*	10.0%	22.5%	*39.0%*	35.5%	38.7%
About the same	*35.0%*	57.5%	45.0%	*42.0%*	54.8%	51.6%
More than before	*20.0%*	10.0%	10.0%	*9.0%*	0.0%	0.0%
Significantly more	*0.0%*	2.5%	0.0%	*3.0%*	0.0%	3.2%

*Table omits decks with no cracking

Table 8. Initiation of cracking.

Cracking Began	Total Responses	% of Responses
During curing	0	0
0-7 days after pour	4	11
0-14 days after pour	16	44
14-28 days after pour	6	17
More than 28 days	9	25
More than 6 months	1	3

Figure 2. Initiation of cracking.



in New York State. In that report, crack densities were recorded for 13 AASHTO decks built between 1982 and 1988. Maximum crack density was 27.3 cm/m^2. Special Report 117 (6) examined effectiveness of a new curing procedure issued in EI 86-24 (7). A very controlled crack survey was conducted, in which randomly selected decks were sectioned into grids and inspected for cracking. Stress-related cracking was ignored, but transverse, longitudinal, and diagonal cracks were included. The decks were often sprayed with water to enhance visibility of cracking. The maximum crack density reported was 655 cm/m^2.

5 Crack widths are detailed in Table 6, where average, maximum, and minimum measurements are 1.5, 6.4, and 0.5 mm, respectively. Many regions reported crack widths of "< 1mm", which were listed as 1 mm, and results in Table 6 thus are probably conservative. It should also be noted that widths were not measured at crack roots but rather at crack tips, which may be worn from traffic.

6. Inspectors were asked to compare Class HP decks to Class E and H decks. Thirty-two of 40 responses (80 percent) reported that Class HP concrete decks performed about the same or better than Class E or H decks in transverse cracking. Twenty-nine out of 33 responses (88 percent) stated that Class HP concrete decks performed as well or better than Class E and H concrete decks in resisting longitudinal cracking. These numbers correspond to the italicized values in Table 7, which lists percentages of responses that compared cracking on HP decks to Class E and H decks. A breakdown of actual numbers by region is given in Appendix B.

7. Time to first appearance of cracking was also surveyed -- most deck cracks appeared within two weeks after the concrete pour, as shown in Table 8 and Figure 2.

III. CONCLUSIONS AND RECOMMENDATIONS

Results of this survey indicate that since publication of Engineering Instruction 96-024 and introduction of Class HP concrete for New York State bridge decks, performance of deck material has improved. "Performance" is measured here in terms of increased crack resistance without compromise in workability, construction practices, or both. Class HP deck performance was compared to Class E and H decks. (Construction practices for Class HP decks were relatively unchanged from those for Class E and H decks.)

Quantitative data were obtained for transverse cracking, but only qualitative information for longitudinal cracking. Nearly half the bridges inspected had no cracking at all. Of Class HP decks inspected, 80 percent were reported to perform as well as or better than Class E and H decks. Within the service period covered, no correlation appeared between deck year-in-service and either crack density or amount of cracking. Crack densities have been comparable to those reported in the recent literature for other concrete decks. Most cracks occurred within two weeks of the deck pour, and were not influenced by staged construction.

ACKNOWLEDGMENTS

Several Department of Transportation personnel contributed to the success of this study. Special thanks are extended to Dr. R.J. Perry, Director of Transportation Research and Development, the Structural Support Services Unit, the Bridge Inventory and Inspection Unit of the Structures Design and Construction Division, and Regional Construction Groups who inspected the bridge decks.

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6. Lorini, R.A., and Hossain, M.M. *Effects of Curing on Bridge-Deck Concrete Shrinkage Cracking.* Special Report 117, Transportation Research and Development Bureau, New York State Department of Transportation, March 1995.

7. "Structural Slab Concrete and Overlay Curing Procedures." Engineering Instruction 86-24, New York State Department of Transportation, May 23, 1986.

APPENDICES

A. SURVEY QUESTIONNAIRE ON HP CONCRETE-DECK PERFORMANCE
B. SURVEY RESPONSES FROM NYSDOT REGIONS
C. REGIONAL COMMENTS ON HP CONCRETE PERFORMANCE

APPENDIX A. SURVEY QUESTIONNAIRE ON HP CONCRETE-DECK PERFORMANCE

This questionnaire concerns performance of bridge decks using HP concrete. As you are aware, current Department standards call for HP concrete for bridge decks, introduced to increase durability by reducing cracking and permeability. Several complaints have been received concerning HP concrete decks cracking. But, quantitative information is lacking in this regard to evaluate the true performance of HP concrete decks. At present, the Bridge Performance Committee, the Concrete Committee, Structures Construction and Design Division, and Technical Services Division are all examining this issue and we are conducting this survey on behalf of them. Thus, we ask you to provide the following information for **each bridge deck** built in your region using HP concrete. After receiving the survey responses, we will send you a copy of the summary. For further explanation, contact Sreenivas Alampalli or Frank Owens of Transportation Research & Development Bureau at (518) 457-5826.

DECK INFORMATION

BIN	PIN	Contract No.	Region	County

Q1. Month and year of deck placement: ______________________________
Was this a continuous pour? ______________________________
Month and year opened to traffic: ______________________________

Q2. Are there any cracks on the deck? If, possible please provide photographs.

If no cracks, go to question 10 directly.

If cracks are present, please provide the following details **with a map of the cracking**:
1. Total number of transverse cracks: ____________________
2. Total length of the transverse cracks: ____________________
3. Average transverse crack width: ____________________

Q3. Based on your experience, how do you compare **this deck** cracking to decks built with concrete used by the Department before HP concrete was introduced (choose one of the following).

	LONGITUDINAL. CRACKS			TRANSVERSE CRACKS		
	Number of Cracks	Average Crack Width	Total Crack Length	Number of Cracks	Average Crack Width	Total crack Length
Significantly less than before						
Less than before						
About the same						
More than before						
Significantly more than before						

Q4. Have you any information as to when cracking began?

1. Within 24 hours of deck pour
2. Within 48 hours of deck pour
3. Within 7 days of deck pour
4. Within 14 days of deck pour
5. After 28 days
6. As soon the deck was opened for the traffic (____ days after last deck pour).
7. During Stage II construction (if applicable)
8. Other ____

Q5. If staged construction was used, in your opinion how did this affect deck cracking?

Q6. Please provide any other comments on construction issues you may have, relating to use of HP concrete in decks (also include EIC or inspector comments, if available).

Q7. Your contact information:

Name:
Title:
Region:
Work Location:
Address:

Telephone No:
Fax No:
e-mail (if available):

Mail the completed questionnaire to the following address.
Sreenivas Alampalli
Transportation R&D Bureau
New York State Department of Transportation
Albany, NY 12232-0869
Tel/Fax: (518) 457-5826/7535
e-mail: salampalli@gw.dot.state.ny.us

APPENDIX B. SURVEY RESPONSES FROM NYSDOT REGIONS

NOTE 1

Comparison between Class HP and E

Class HP Exhibits ___ Transverse/Longitudinal Cracking.

1	Significantly les
2	Less
3	About the same
4	More
5	Significantly more

NOTE 2

Cracks were first noticed...

1	Within 24 hours of deck pour
2	Within 48 hours of deck pour
3	Within 7 days of deck pour
4	Within 14 days of deck pour
5	After 28 days
6	Upon deck opening
7	During stage II
8	Other

DNR = Did not report

BIN	PIN	REG	STG	CRK	TRAN	LONG	STG TVS CRK	STG LNG CRK	AGE	TRANSVERSE NUM	TRANSVERSE LENGTH (m)	TRANSVERSE WIDTH (mm)	LONGITUDINAL NUM NOTE 1	LONGITUDINAL WIDTH	LONGITUDINAL LENGT	TRANSVERSE NUM NOTE 1	TRANSVERSE LENGTH	TRANSVERSE WIDTH	CRK STRT NOTE 2	DECK AREA (m^2)	CRK DENS (cm / m^2)
D256566		1	Y	N																	
D257195	175355	1	Y	N																	
100422	175297	1	N	Y	Y	Y	N	N	98	11	33	Hairline	2	2	2	3	2	3	4	668.9	4.933473
1033500	102708	1	N	Y	Y	N	N	N	98	10	20	Hairline	DNR	DNR	DNR	3	3	3	6	1096.2	1.824485
2202240	175323	1	Y	Y	Y	Y	Y	Y	98	9	27.4	Hairline	3	3	3	3	3	3	4	102.1	26.83643
D257229	172164(I)	1	Y	Y	Y	Y	Y	Y	98	MANY	MANY	Hairline	2	2	2	4	3	4	6		NA
	172164(II)	1	Y	N																	
D257302	175319(I)	1	Y	Y	Y	Y	Y	Y	97	5	DNR	Hairline	3	3	3	3	3	3	5		
	175319(II)	1	Y	Y	Y	Y	Y	Y	97	10	DNR	Hairline	3	3	3	3	3	3	5		
1062850	180485(I)	1	Y	Y	N	Y	N	Y	96	DNR	DNR	DNR	Long. cracks only. Aro			DNR	DNR	DNR	5	8905.7	
1074940	180485(IA)	1	Y	Y	N	Y	N	Y	96	DNR	DNR	DNR	Joints & piers. Could n			DNR	DNR	DNR	3	3887.7	
1074940	180485(II)	1	Y	Y	N	Y	N	Y	96	DNR	DNR	DNR	Comapare. (Lack of Ex			DNR	DNR	DNR	5	3887.7	
D256471	103414(I)	1	Y	Y	Y	Y	Y	Y	96	2	6.1	6.4	2	2	2	2	2	2	DNR	1137.1	0.536452
1002579	103414(II)	1	N	Y	Y	Y	N	N	96	3	6.1	4.8	2	2	2	2	2	2	DNR	1137.1	0.536452
TOTAL		**14**	**11**	**11**	**8**	**10**	**5**	**8**													**6.9**
1018861	204223	2	N	Y	Y	Y	N	N	97	9	64	Hairline	3	3	3	2	2	3	8	1093.7	5.851696
1018862	204223	2	Y	Y	Y	Y	Y	Y	96	13	110	0.5	3	3	3	2	2	3	8	1093.7	10.0576
4018872	204223	2	N	Y	Y	Y	N	N	96	7	16.8	0.5	3	3	3	2	2	3	8	2113.5	0.79489
4018871	204223	2	Y	Y	Y	Y	Y	Y	97	3	18.3	Hairline	3	3	3	2	2	3	8	2033.2	0.900059
1020130	201872(I)	2	Y	Y	Y	Y	Y	Y	97	12	8.5	6.4	3	3	3	3	3	3	DNR	196.7	4.321301
1020130	201872(II)	2	N	Y	Y	Y	N	N	97	12	8.5	6.4	3	3	3	3	3	3	DNR	196.7	4.321301
4020060	201855	2	N	Y	Y	N	N	N	97	23	478.4	Hairline	DNR	DNR	DNR	4	4	5	4	3781.8	12.65006
1004760	205661	2	Y	Y	Y	Y	Y	Y	97	12	31.7	Hairline	2	DNR	DNR	1	3	2	8	1222.2	2.593684
1004740	205668	2	Y	Y	Y	Y	Y	Y	97	4	3.4	Hairline	3	3	3	2	2	2	8	732.8	0.463974
1004750	205661	2	Y	N																	
1053740	201865	2	Y	Y	Y	N	Y	N	96	32	107	3.2	DNR	DNR	DNR	4	4	4	4	1170.5	9.141393
1053740	201865(II)	2	Y	Y	Y	N	Y	N	96	38	107	3.2	DNR	DNR	DNR	4	4	4	4	1170.5	9.141393
TOTAL		**12**	**8**	**11**	**11**	**8**	**7**	**5**													**5.5**
4435080	375215	3	N	N																	
D256505		4	N	N																	
D256520		4	N	N																	
D256544		4	Y	N																	
D256531		4	Y	N	N	N	N	N		Stress related cracking only											
D256405		4	N	N	N	N	N	N		Stress related cracking only											
TOTAL		**5**	**2**	**0**	**0**	**0**	**0**	**0**													

BIN	PIN	REG	STG	CRK	TRAN	LONG	STG TVS CRK	STG LNG CRK	AGE	TRANSVERSE NUM	TRANSVERSE LENGTH (m)	TRANSVERSE WIDTH (mm)	LONGITUDINAL NUM NOTE 1	LONGITUDINAL WIDTH	LONGITUDINAL LENGT	TRANSVERSE NUM NOTE 1	TRANSVERSE LENGTH	TRANSVERSE WIDTH	CRK STRT NOTE 2	DECK AREA (m^2)	CRK DENS (cm / m^2)
1030780	520929	5	N	Y	Y	N	N	N	95	6	76.8	6.4	DNR	DNR	DNR	4	3	3	3	636	12.07547
1071441	500647	5	N	Y	Y	Y	N	N	96	20	24.4	1	2	2	2	1	1	1	4	483.8	5.043406
1071451	500647	5	N	Y	Y	Y	N	N	96	MAP	MAP	1	2	2	2	1	1	1	4	487.7	NA
1071471	500647	5	N	Y	Y	Y	N	N	95	3	3.7	1	2	2	2	1	1	1	4	417.5	0.886228
1071481	5006472	5	N	Y	Y	Y	N	N	95	MAP	MAP	1	2	2	2	1	1	1	4	409.7	NA
1071501	500647	5	N	Y	Y	Y	N	N	95	MANY	1 EACH	1	2	2	2	1	1	1	4	557.9	NA
3329270	575401	5	N	N																	
1062550	530778	5	N	Y	Y	Y	N	N	95	23	14	1	3	3	3	3	3	3	DNR	326.5	4.287902
1046551	503311	5	N	N																	
1046552	503311	5	N	N																	
1027780		5	N	N																	
1011659		5	N	N																	
332829	575387	5	Y	N																	
3326930	575411	5	Y	N																	
1044230	513119	5	N	Y	Y	Y	N	N	95	2	31.6	1	4	DNR	DNR	2	2	3	3	1141.5	2.768287
TOTAL		**15**	**2**	**8**	**8**	**7**	**0**	**0**													**5**
3340810	705219	7	N	Y	Y	Y	N	N	95	DNR	DNR	DNR	5	2	5	3	3	3	5	156.7	NA
3337950	775189	7	N	Y	Y	Y	N	N	97	DNR	DNR	DNR	1	3	1	2	3	3	5	141.4	NA
3337370	715253	7	N	Y	Y	Y	N	N	97	16	37.5	Hariline	2	3	2	3	3	3	5	435.9	8.602891
1021340	704424	7	N	Y	Y	Y	N	N	97	6	6.1	Hariline	2	3	2	1	3	1	8	74.3	8.20996
3369170	775195	7	N	N																	
1032120	750062	7	N	N																	
1044890	703002	7	N	N																	
TOTAL		**7**	**0**	**4**	**4**	**4**	**0**	**0**													**8.4**
3222020	875504	8	Y	N												1	1	1	DNR		
1022300	846043	8	Y	Y	Y	N	Y	N	98	10	90	0.5	DNR	DNR	DNR	3	3	3	3	808.2	11.13586
1044579	872938	8	Y	N																	
1044659	872938	8	N	N																	
3348160	875517	8	Y	N																	
1005201	804085	8	Y	Y	Y	Y	Y	Y	98	Many	Short	Hariline	4	1	3	4	1	3	4	483	NA
1005202	804085	8	N	Y	Y	Y	N	N	98	Many	Short	Hariline	4	1	3	4	1	3	4	492.3	NA
TOTAL		**7**	**5**	**3**	**3**	**2**	**2**	**1**													

BIN	PIN	REG	STG	CRK	TRAN	LONG	STG	STG	AGE	TRANSVERSE			LONGITUDINAL			TRANSVERSE			CRK	DECK	CRK
							TVS	LNG		NUM	LENGTH	WIDTH	NUM	WIDTH	LENGT	NUM	LENGTH	WIDTH	STRT	AREA	DENS
							CRK	CRK			(m)	(mm)	*NOTE 1*			*NOTE 1*			*NOTE 2*	(m^2)	(cm / m^2)
1030710	916617	9	N	N																	
1003820	930666	9	N	N																	
1030530	921316	9	N	Y	Y	Y	N	N	97	MANY	10.1	Hairline	2	2	2	4	4	4	5	1168.9	0.86406
1003711	935755	9	N	N																	
1030720	916617	9	N	N																	
1021360	912504	9	N	Y	Y	Y	N	N	96	2	17	1	1	1	1	1	1	1	DNR	721.2	2.357182
1021390	912504	9	Y	N																	
1045660	975170	9	N	N																	
1026390	912026	9	N	Y	Y	Y	N	N	96	3	1.8	Hairline	3	3	3	3	3	3	DNR	743	0.242261
1017540	912026	9	Y	N									3	3	3	3	3	3	DNR	332.2	NA
TOTAL		**10**	**2**	**3**	**3**	**3**	**0**	**0**													**1.2**
1019439	5886(I)	10	Y	N																	
1019439	5886(II)	10	Y	Y	Y	Y	Y	Y	98	11	13.9	Hairline	3	3	3	3	3	3	5	3112.2	0.446629
1019439	5886(III)	10	Y	N																	
1019439	5886(IV)	10	N	N																	
1049491	22860	10	Y	N																	
1049441	22860	10	Y	N																	
1049461	22860	10	Y	N																	
1049471	22860	10	Y	N																	
1056779	5289264	10	Y	N																	
1073260	18801	10	Y	Y	Y	Y	Y	Y	97	41	187	1.6	EIC's state that they lack the experience in bridg						8	1806	10.35437
1073250	18801	10	N	Y	Y	Y	N	N	97	113	633	1.6	necessary to make this comparison.						8	3008.4	21.04108
1073282	18801	10	N	N																	
1073281	18801	10	N	N																	
TOTAL		**13**	**9**	**3**	**3**	**3**	**2**	**2**													**10.6**
====================																			====================		
TOTALS		**84**	**39**	**43**	**40**	**37**	**16**	**16**						**29**			**32**				**6.9**

APPENDIX C. REGIONAL COMMENTS ON HP CONCRETE PERFORMANCE

Workability

- If the slump requirement was less strict, it might be easier to finish.
- Spalling and flaking were problems on a number of decks.
- Slump was very critical to the quality of the finish.
- Class HP was more difficult to seal than Class H.
- Finish of the deck was "terrible" and prompted investigation into other decks.
- Sealing was easier when water was added at the site. (Max slump of 4.5")
- Finish was excellent.
- Was finished easier with a broom than with astro-turf.
- When contractor tried to apply astro turf finish, the concrete started to tear or pull apart.

Cracking

- Cracking slowly increased while crews were working at the site.
- HP pours of substructure elements exhibited cracking. These pours were of significant volume. The deck did not exhibit problematic cracking.
- Cracks seem to generate over floor beams of truss superstructures.
- Vibrations from traffic on Stage 1 decks causes Stage 2 decks to crack.

Material

- Material is very sensitive to the environment, particularly sun, wind, and heat.
- Concrete needs extra time to set up.

Construction

- Pour went very slowly
- Make closure pours mandatory in staged projects.
- There should be some investigation of the benefits of saw cutting a control joint over piers or places of zero deflection.
- The contract should specify a quantity of time and labor to smooth the approach pavement for phase 2 detours to reduce vibration from 18-wheel loads.

Live Load

- Much less superstructure deflection after closure pour.
- HP produces a very hard, stiff deck. Bracing needed to hold the deck forms is more than the EIC is used to. The steel may be too flexible for the deck.
- Girders were observed to deflect excessively under live load.
- Girders vibrate during deck pour.

Summary of EIC Comments by Contract Number

D257460
Staged construction was used in this project. Longitudinal and transverse cracks were about the same or less than with Class H concrete. There was less vibration in the bridge deck once the closure pour was complete. There should be investigation of placing a control joint over piers or locations of zero deflection.

D256757
HP concrete produces a very hard, stiff deck. Structural steel may be too flexible for the bridge deck's increased stiffness. No data were given for this deck as to whether is was more resistant to cracking than previous decks.

D257081, D257087 & D257236
HP concrete was more difficult to finish. Cracking in these decks was about the same or less than Class H decks. At D257081 bad finish of the bridge deck prompted investigation into other decks, but further information was not available. D257236 was reported to have excessive scaling and flaking with some difficulty finishing. Most cracks were observed in the tension zone.

D257234
Transverse cracks appeared directly over each floor beam of the truss system. These cracks did not appear to be any worse than those observed with Class H concrete. Staged construction did not negatively affect cracking. Cracking could have been caused by traffic vibration during concrete curing. The HP deck had an excellent finish.

Cracks that were worse or significantly worse using HP

D257229
Cracks in this deck were reported to be greater in number and length than on Class H decks. Staged construction was used. Girder vibration was observed during deck pour. Once live load was allowed on the new deck, girders appeared to experience "excessive deflection". HP concrete needs more time to set up. The other main concern was that bridge girders apparently not stiff enough.

D257236
Longitudinal and transverse cracks were more numerous than before. The number and length seemed to be growing over time. This was a continuous pour. Two parts of the project (EB & WB) were done a month apart. The only live load on or near the bridge was during contractor operations.

D256581

In this deck, number and total length of longitudinal cracks were significantly greater than before. The deck was continuously poured. The bridge is a single-span prestressed-concrete voided-slab bridge. This deck was one of the first using HP concrete. There were no problems with the deck finish.

D256448

This bridge deck was a non-continuous pour, and had more longitudinal cracks than with previous standard mixes. Staged construction was not believed to affect cracking. Cracks followed through Stages 1 and 2 over piers.

D256070

This bridge had a continuously poured HP deck, steel plate-girder superstructure, and integral abutments. Staged construction was not used. The cracking is isolated to the control joint area and ends of the slab. The transverse number, width, and length are all worse than Class H decks. There were large deflections (6") of girders at midspan. Cracking appeared to be due to superstructure rotation/movement of the integral design. HP requires less hand finishing but more mixing time for a consistent mix.