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In-Service Performance of High-Performance Concrete Bridge Decks

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The current statewide standard for New York State bridge decks is Class HP (high-performance) concrete. This mix was introduced in April 1996 to increase deck durability by reducing cracking and permeability. Since its introduction, more than 80 bridge decks have been built with Class HP concrete. To compare the performance of Class HP concrete with that of previously specified concrete, the decks were visually inspected. Results indicated that Class HP decks performed better than previously specified concrete in resisting both longitudinal and transverse cracking. Furthermore, of the 84 decks inspected, 49 percent exhibited no cracking at all, but of those that had cracked, 88 percent exhibited equal or less longitudinal cracking and 80 percent exhibited equal or less transverse cracking than previously specified concrete. A final result showed that average transverse crack density on Class HP decks, excluding uncracked decks, was 6.9 cm/m^2. This value is comparable with crack densities for other decks (not using HP mix) that were reported in recent literature.

The New York State Department of Transportation (NYSDOT) has developed specifications for portland cement concrete mixtures that are 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 that was 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 that were built with these concrete mixes was spalling caused by rebar corrosion, which was directly attributable to excessive permeability by such concrete-deteriorating solubles as deicing salts. To improve concrete durability, a bridge deck task force (composed of materials engineers, researchers, and structural engineers) was formed in fall 1994. The task force determined that significant improvement would result from a concrete mixture that reduced permeability and the potential for cracking (*2*).

The task force reviewed state-of-the-art mixes, conducted laboratory tests and statistical analysis of several mixes, and formulated a new concrete mixture by modifying Class H concrete. Designated as high-performance (HP) 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. According to an analytical model (R. J. Perry, unpublished data, February 1, 1996), it was estimated that corrosion might begin at 23 and 62 years of age for Class H and Class HP concrete mixes, respectively. The model assumes 3 in. of concrete cover and use of uncoated reinforcing steel.

Effective April 12, 1996 (*3*), Class HP concrete was implemented as the standard for all New York State bridge decks. By June 1998, more than 80 bridge decks had been constructed with HP concrete. With this number of Class HP decks in service, information could be collected and analyzed to compare the performance of Class HP concrete with that of previously specified concrete mixes.

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STUDY APPROACH

To quantify the performance of Class HP concrete, a statewide survey of decks that were built with this material was conducted. With NYSDOT's database, a list of decks that were completed from 1996 through early 1998 was produced. A survey questionnaire was drafted so as to obtain the most accurate and useful information possible without placing an undue burden on department resources. The questionnaire was then sent to construction engineers who were asked to complete the forms after visually inspecting each HP concrete bridge deck. They focused on the type of cracking that was not load-related. Information was requested on number, length, and plan location of all transverse cracks. The engineers were also asked to compare the performance of Class HP decks with that of those decks built with Class E and H concrete. The survey was intended to determine time of crack initiation as well as the effects (if any) of staged construction on deck cracking.

Survey responses were analyzed. Crack frequency was also analyzed and compared with data available from bridge decks that were built with Class E and H concrete. Survey results are summarized in the following section.

STATEWIDE SURVEY RESULTS

Table 2 summarizes survey results on deck cracking for the study population by year of construction. Figure 1 relates percentage of cracked decks with years in service. The two series of bars represent transverse and longitudinal cracking on decks that were built in each of the last 4 years. Table 3 summarizes transverse and longitudinal cracking by type of construction method used. Crack densities, estimated by dividing measured crack lengths by deck area, were obtained from the NYSDOT bridge inventory database. Table 4 contains the results of comparisons between Class HP and Class E and H decks. This table summarizes the responses given by inspectors in the field who were asked to qualitatively compare the number, width, and length of transverse and longitudinal cracks in Class HP decks with those cracks in Class E and H decks. Table 5 and Figure 2 give estimates of crack-initiation time. On the basis of the survey responses, seven general observations can be made.

TABLE 1 Mix Criteria for Class E, H, and HP Concrete

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.

TABLE 2 Cracking by Year Deck Was Built

Year Built	Total Decks Inspected	Decks with Transverse Cracking Total	%	Decks with Longitudinal Cracking Total	%
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.

1. Field inspections were completed on 84 bridge decks that were built with the Class HP concrete. Forty-one (49 percent) of the inspected decks exhibited no cracking at all, but 43 decks (51 percent) showed some form of cracking.

2. Table 2 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 was found on 37 (44 percent). Thirty-four (40 percent) bridge decks exhibited both transverse and longitudinal cracking. All decks that were listed were built with Class HP concrete. Although it would be expected that years-in-service would have a significant negative effect on deck condition, no correlation appears to exist within the time frame of this study.

In Figure 1*b* the first two series of bars allow comparisons of successive annual totals of decks showing longitudinal and transverse cracking. The third series represents the total number of bridges inspected each year. Although NYSDOT mandated use of Class HP in 1996, several decks had been built earlier on an experimental basis and were included in the inspection list that was provided to the regions. No obvious correlation appears between years-in-service and cracking, or cracking density, according to these data. Average cracking densities per year (in cm/m²) are 9, 6.7, 4.2, and 5 for 1998, 1997, 1996, and 1995, respectively.

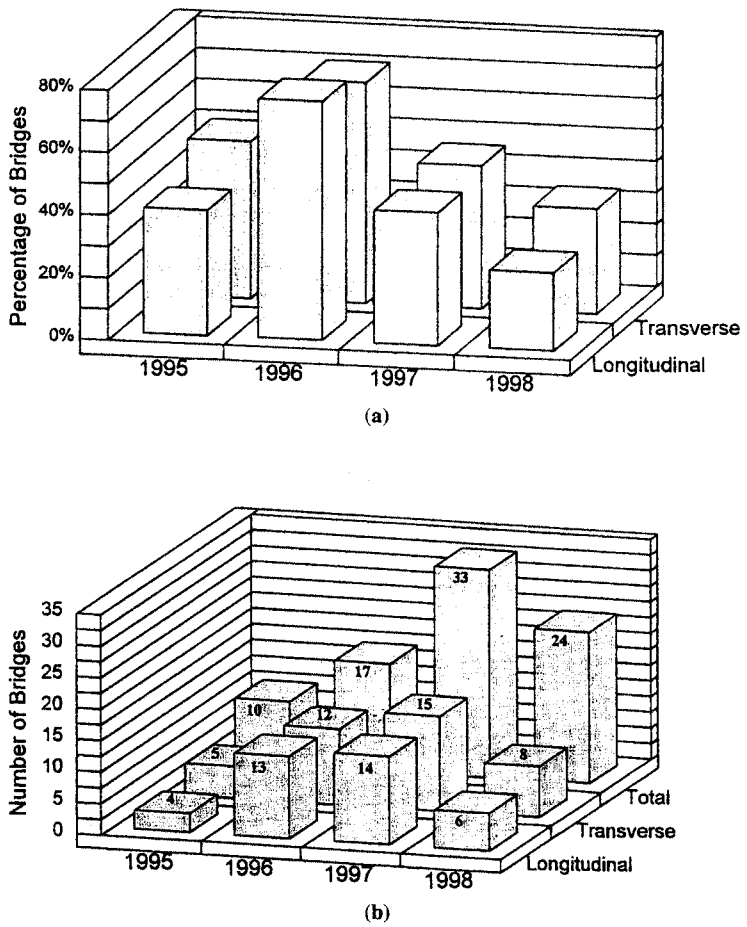

FIGURE 1 Effects of years-in-service on cracking: (*a*) percentage of decks and (*b*) number of decks.

TABLE 3 NYSDOT Bridge Deck Cracking by Type of Construction

Total Decks Cracked				% of Decks Cracked	
Staged Construction		Continuous Construction		Staged	Continuous
Inspected	Cracked	Inspected	Cracked	Construction	Construction
A. TRANSVERSE CRACKING					
39	16	45	24	41	53
B. LONGITUDINAL CRACKING					
39	16	45	21	41	47

In 1995, 10 test decks were built under supervision of the Materials Bureau. By 1996, HP concrete was in wide use. The peak in 1996, in percentage of decks that exhibited cracking (Figure 1*b*), was probably due to the fact that manufacturers, engineers-in-charge, and construction tradesmen were all at the beginning of their "learning curves" for this material. In 1997, the quality of the decks, measured here by lack of cracking, increased as the participants became more familiar with the material. Numbers for 1998 appear 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 staged construction on deck cracking. The survey sought information on whether decks had been built with staged or continuous construction and comments about possible effects on deck cracking. Table 3 shows results of this portion of the survey. Staged construction appears to have no negative effects; decks that were built with staged construction actually cracked less than those built continuously.

4. Transverse crack density was estimated for every bridge that exhibited cracking. Average cracking density of transverse cracks on HP decks was 6.9 cm/m^2, with a maximum density of 26.8 cm/m^2.

Cracking densities collected for this study were compared with those published in recent literature. A NYSDOT research report (*4*) described a study of long-term serviceability of full-scale, lightly reinforced bridge deck slabs in New York State. In the report, crack densities for 13 AASHTO decks that were built between 1982 and 1988 were obtained. Maximum crack density was 27.3 cm/m^2. A NYSDOT special report (*5*) examined the effectiveness of a new curing procedure that was issued in Engineering Instruction 86-24 (*6*). 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; 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.

TABLE 4 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 5 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

Average, maximum, and minimum crack widths are 1.5, 6.4, and 0.5 mm, respectively. Many survey responses stated crack widths of <1 mm, which were recorded as 1 mm; thus, these results are conservative. It should also be noted that widths were not measured at crack roots but were measured rather at crack tips, which may be worn from traffic.

5. Inspectors were asked to compare Class HP decks with Class E and H decks. Thirty-two of 40 (80 percent) responses 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 (88 percent) responses stated that Class HP concrete decks performed as well as or better than Class E and H concrete decks in resisting longitudinal cracking. These numbers correspond to the italicized values in Table 4, which lists percentages of responses that compare cracking on HP decks with cracking on Class E and H decks.

6. The amount of time until first appearance of cracking was also surveyed. It was found that most deck cracks appeared within 14 days after the concrete pour, as shown in Table 5 and Figure 2.

7. Information on span length, superstructure type (stringers, slabs, trusses, box beams, and tee beams), superstructure material (steel, concrete, and prestressed concrete), number of spans, and span type (simply supported or continuous) was obtained for all the inspected bridges from the Bridge Inventory and Inspection System database.

A large percentage of the bridges (81 percent) were steel stringer superstructures. Cracking data were analyzed to evaluate performance of these bridge details. Statistical methods were used, as necessary, to investigate effects of various attributes in a rational format to supplement visual observations. Analysis-of-variance methods (with 95 percent confidence limits) were used to determine attributes that significantly influenced bridge performance. The results from the analysis revealed that cracking densities were independent

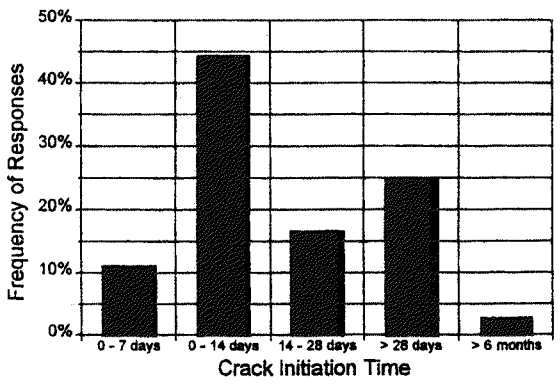

FIGURE 2 Estimates of crack-initiation time.