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Experimental Use of Type K Cement Concrete in Wisconsin Highway Bridge Decks

FINAL REPORT

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16. Abstract

Type K cement is an expansive cement, as defined by ASTM C845. During the early stages of hydration, the expansive properties of the cement cause an increase in material volume in the paste. This volume increase compensates for drying shrinkage that occurs as the concrete hardens, thereby reducing or eliminating shrinkage cracking that is a problem with conventional (non-expansive) Type I portland cement concrete.

From 1990 to 1995, the Wisconsin Department of Transportation (WisDOT) constructed five experimental bridge decks using Type K cement concrete. Comparison bridge decks were constructed at four of these locations using conventional Type I cement. Shrinkage cracking did not occur in the Type K bridge decks. However, scaling was noted on the surface of these decks. Type I bridge decks exhibited shrinkage cracking, but no scaling. Laboratory testing showed that the chloride permeability of Type K cement concrete was approximately twice that of Type I cement concrete. The higher permeability was the most likely cause of the surface scaling noted in the Type K bridge decks.

Due to the surface scaling that occurred on Type K bridge decks, use of Type K cement was discontinued in Wisconsin. Construction. Further contributing to the decision not to specify Type K cement concrete were material costs 12 to 30 percent higher than conventional Type I portland cement concrete.

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Commonly Used Abbreviations

Initializations

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
BAD	Base aggregate dense
CABC	Crushed aggregate base course
CRCP	Continuously reinforced concrete pavement
CTH	County trunk highway
DOT	Department of Transportation
EBS	Excavation below subgrade
FDM	Facilities Development Manual
FWD	Falling weight deflectometer
HMA	Hot mix asphalt
IRI	International roughness index
JPCP	Jointed plain concrete pavement
JRCP	Jointed reinforced concrete pavement
M-E	Mechanistic-empirical
MEPDG	Mechanistic-empirical pavement design guide
NB	Northbound
PCC	Portland cement concrete
PCI	Pavement condition index
PDI	Pavement distress index
PDR	Pavement design report
SB	Southbound
SMA	Stone matrix asphalt
SN	Structural number
STH	State trunk highway
STN	State trunk network
TSR	Transportation Synthesis Report
USH	United States highway
WisDOT	Wisconsin Department of Transportation

Units

ksi	kips per square inch
in	inch/inches
psi	pounds per square inch
m/km	meters per kilometer
ft	foot/feet
ft^2	square feet
CY	cubic yards

1. Introduction and Background

1.1 Type K Cement

Crack development is a common problem encountered after a concrete bridge deck has cured and been put in service. Cracking is often caused by drying shrinkage, which occurs when concrete loses moisture as it cures. Even well-designed, properly cured concrete can experience so-called shrinkage cracking. The cracking is unsightly and can lead to leaching of deleterious materials into the bridge deck.

Type K cement is an expansive cement, as defined by ASTM C845. [*1*] Type K cement contains anhydrous calcium aluminate, which contributes to its expansive properties. [*2*] Compared to conventional Type I cement, Type K cement exhibits a greater increase in volume during hydration. This expansion compensates for the material volume lost during drying shrinkage. Cracking that normally results from the drying shrinkage can therefore be significantly reduced or eliminated by using an expansive cement.

1.2 Research Objective and Methodology

The objective of this research study was to evaluate the placement and performance of Type K cement concrete in Wisconsin bridge decks. Experimental bridge decks were constructed using Type K cement in five locations, as outlined in Section 2. Comparison bridge decks were placed with Type I cement at four of those locations. The decks were monitored for crack initiation and other distress development.

Material tests were performed using concrete samples taken when each bridge deck was constructed. Concrete slump was measured on site. Concrete specimens were also prepared for laboratory testing. Length change under restrained expansion was tested according ASTM C878, and concrete permeability was assessed using the rapid chloride permeability test according to AASHTO T277-831. [*3, 4*] These test results are discussed in Section 3.

The performance and material observations described above were used to compare Type I and Type K cement concretes. This report summarizes these research activities and describes the evolution of Type K cement use in Wisconsin.

2. Bridge Deck Evaluations

Five bridge decks constructed with Type K cement concrete were evaluated as part of this research study. These structures were built between 1990 and 1995. Comparison bridge decks constructed with Type I cement concrete were constructed at four of the five locations. The structures and identifying features are listed in Table 1. Sections 2.1 through 2.5 outline the performance histories of the experimental bridge decks, and a summary is provided in Section 2.6. A brief discussion of the impact on cost when using Type K cement concrete is provided in Section 2.7.

Table 1. Experimental Bridge Deck Locations

Structure ID	County	Feature On	Feature Under
B-53-153 & B-54-154	Rock	USH 51	Rock River & Soo Line Railroad
B-11-104 & B-11-01	Columbia	STH 13	Wisconsin River
B-67-234 & B-67-235	Waukesha	STH 164	I-94
B-13-409 & B-13-410	Dane	Locust Dr & CTH M	USH 18/151
B-14-116	Dodge	Soo Rd	USH 41

2.1 Structures B-53-153 and B-53-154, Rock County

Structure B-53-153 is located in the City of Janesville, on USH 51. It is part of the Monterey Bridge, which spans the Rock River. It was constructed in 1990 with a Type K cement concrete bridge deck. Comparison structure B-53-154, constructed in 1990 with Type I cement concrete, is located on USH 51 to the south, spanning the Soo Line railroad.

A five-year survey conducted in 1995 reported no shrinkage cracking on the bridge deck surface of structure B-53-153 (Type K). Moderate-severity scaling was noted along the outer edge of the roadway, which was likely a result of freeze-thaw action at the surface of the concrete. Shrinkage cracking was noted on the comparison deck made with Type I cement concrete. No scaling was noted on this bridge deck.

Routine bridge inspection reports were reviewed for these structures. The most recent inspection for structure B-53-153 took place on September 29, 2011. The report for the bridge deck noted "Type K concrete scaling in flow lines," where salt water from winter maintenance operations collected and led to degradation of the surface. One area of transverse cracking and a large spall at the north end of the deck were also noted.

The most recent inspection for structure B-53-154 took place on June 2, 2010. Diagonal cracking at the southwest corner and longitudinal cracks were noted on the bridge deck. Full depth transverse cracking with efflorescence was also recorded in the inspection report. It was recommended that the cracks on the deck surface be sealed.

2.2 Structures B-11-104 and B-11-1, Columbia County

These structures are located on STH 13, spanning the Wisconsin River at Wisconsin Dells. The eastbound bridge deck (B-11-104) was constructed with Type K cement concrete. The east quarter of the westbound deck (B-11-1) was also constructed with Type K cement; the remainder of the westbound deck was a comparison section that used Type I cement. The B-11-104 structure was newly constructed in 1991; the deck of B-11-1 was replaced concurrently.

A four-year inspection conducted in 1995 noted that no shrinkage cracking was present in the Type K concrete, while extensive cracking existed in the Type I concrete. However, extensive scaling distress

(moderate severity) was present on the deck surfaces constructed with Type K concrete. Scaling was noted along the gutter lines and also in the driving lanes. One patch had already been placed to correct an area of severe scaling.

Both bridge decks were reviewed during routine structure inspections on May 24, 2010. Notes for the B-11-104 bridge deck (Type K) included patches in the flow areas and a 40-ft^2 section in need of repair due to potholes and scaling 1 to 5 inches deep. Several moderate-sized transverse cracks were noted on the B-11-1 bridge deck (Type I).

2.3 Structures B-67-234 and B-67-235, Waukesha County

These structures, constructed in 1993, carry STH 164 (CTH J, Pewaukee Rd) over I-94 in the Town of Pewaukee. The bridge decks for structures B-67-234 and B-67-235 were constructed with Type K and Type I cement concrete, respectively.

A 1995 inspection of the bridge decks after two years in service noted that the Type K deck had no shrinkage cracking, while the Type I deck had extensive shrinkage cracking. Minor surface scaling was present on the Type K deck. The scaling was primarily along the gutter lines and parapets.

The most recent structure inspection reports for these structures (May 10, 2010) did not note any significant cracking or scaling on the Type K bridge deck. Transverse cracks were noted on the surface and underside of the Type I deck.

2.4 Structures B-13-409 and B-13-410, Dane County

Structure B-13-410 carries CTH M over USH 18/151 in the Town of Verona. Its bridge deck was constructed with Type K cement concrete. Structure B-13-409, located just to the west, carries Locust Drive over USH 18/151. It was constructed with Type I cement concrete. Both structures were constructed in 1994.

An inspection of the Type K bridge deck after one year in service noted no shrinkage cracking, nor any other distress. No cracks were noted during routine structure inspections until 2000, when the bridge had been in service for six years. From the 2000 inspection forward, transverse cracks were noted on the surface and underside of the bridge deck. No scaling was recorded through the most recent inspection in 2010, when the bridge had been in service for 16 years.

The most recent inspection of the Type I bridge deck was in 2011. Diagonal cracks were noted on both the surface and underside of the deck.

2.5 Structure B-14-116, Dodge County

This structure was constructed in 1995 on Soo Road over USH 41 in Dodge County. The bridge deck was constructed with Type K cement concrete. No Type I comparison structure was designated.

Scaling was noted in the flow lines of the bridge deck surface in 1996, after one year in service. Scaling was also noted in all subsequent routine bridge inspections through 2010. No cracking on the bridge deck surface was observed during the routine inspections.

2.6 Performance Summary

A performance summary for the trial bridge decks is presented in Table 2. Type K bridge decks did not have shrinkage cracking, but four of the five decks had surface scaling. Shrinkage cracking was present on the Type I bridge decks, but no scaling was observed. Most distress occurred during the first five years in service.

Table 2. Bridge Deck Performance Summary

Structure ID	**County**	**Type K**		**Type I**	
		Cracking	***Scaling***	***Cracking***	***Scaling***
B-53-153 & B-54-154	Rock	None	Moderate	Present	None
B-11-104 & B-11-01	Columbia	None	Extensive	Extensive	None
B-67-234 & B-67-235	Waukesha	None	Minor	Extensive	None
B-13-409 & B-13-410	Dane	Transverse*	None	Diagonal	None
B-14-116	Dodge	None	Minor	N/A	N/A

* Transverse cracks developed after six years in service

2.7 Cost Discussion

For WisDOT's first trial structure constructed in 1990 with Type K cement concrete, the materials and construction cost for the bridge deck was 12 percent higher than for the conventional bridge deck made with Type I cement concrete. The cost increase for subsequent trial bridge decks was 25 to 30 percent.

The higher cost associated with Type K cement was due to several factors. The Type K cement was a specialty material and only available from selected sources. In addition, the mixture design required 715 pounds of Type K cement per cubic yard of concrete, which is 20 to 25 percent more than the Type I cement requirement for bridge deck concrete. Finally, maintaining the seven-day continuous wet cure under burlap for the Type K bridge decks was noted as an additional cost. [*5*]

3. Material Testing

Material tests were conducted at the WisDOT Truax Materials Laboratory to compare properties of the Type I and Type K cement concrete. Laboratory testing included permeability and expansion of the concrete. Concrete slump was measured in the field during construction. Results of these tests are shown in Table 3 and discussed below.

Table 3. Material Testing Results

County	Structure ID	Cement	Permeability *AASHTO T277* (Total charge passed, coulombs)	Restrained Expansion *ASTM C878* (Percent expansion)	Slump (in)
Rock	B-53-154	Type I	5,498	†	*
	B-53-153	Type K	11,312	0.014%	6.3
Columbia	B-11-1	Type I	3,221	†	3.9
	B-11-104	Type K	7,487	0.060%	*
Waukesha	B-67-235	Type I	†	†	*
	B-67-234	Type K	†	0.079%	4.25 to 6
Dane	B-13-409	Type I	3,020	†	2.75
	B-13-410	Type K	5,471	0.057%	5.5
Dodge	B-14-116	Type K	†	-0.027%	6

† - Not tested

* - Not available

Concrete permeability was tested using the procedures outlined in AASHTO test method T277-831 for the determination of the chloride permeability of concrete. In this test, a concrete specimen with one end immersed in a sodium chloride solution is subjected to a potential difference of 60 V. Measurements are taken for six hours to determine the total charge passed through the specimen. This value is related to the chloride permeability as follows: [*4*]

Total charge passed (coulombs)	Chloride permeability
> 4,000	High
2,000 to 4,000	Moderate
1,000 to 2,000	Low
100 to 1,000	Very low
< 100	Negligible

Chloride permeability was measured for three of the research locations. The average permeability value was calculated using three to six specimens; these average values are reported in Table 3. The Type K specimens had a permeability that was approximately twice that of the Type I specimens. At the Dane and Columbia County locations, the Type K specimens had a "high" permeability, while the Type I specimens were in the "moderate" permeability interval. At the Rock County location, concrete from both Type I and Type K bridge decks had "high" permeability.

The expansion of Type K cement concrete was tested using ASTM C878 for restrained expansion of shrinkage-compensating concrete. In this test, the length change of a concrete specimen is measured

after a seven-day curing period in lime-saturated water. [*3*] The Type K specimens had measurable expansion at four of the test locations. At the Dodge county location, the Type K specimens demonstrated shrinkage (Table 3).

Concrete slump, which measures the consistency and workability of fresh concrete, was measured in the field at the time of deck construction. Slump values for Type K cement concrete were typically higher than for concrete incorporating Type I cement. This observation was verified in additional field notes recorded by project staff and concrete contractors. The target slump specified by WisDOT for Type K cement concrete was 5 inches ± 1 inch, per manufacturer recommendations. After scaling was noted on the first trial bridge decks, it was recommended that less water be used in the mixture, thus targeting a slump at the lower end of the range. However, slump continued to measure on the high side, averaging 5 to 6 inches (Table 3).

4. Summary and Conclusions

Type K cement concrete was used for construction of experimental bridge decks at five Wisconsin highway locations. Comparison bridge decks were built using conventional Type I cement concrete. These bridge decks were constructed in the early 1990s and subsequently evaluated for cracking and surface distress. Expansion and permeability tests were also conducted in the laboratory.

Bridge decks constructed with Type K cement had little or no shrinkage cracking. The expansive properties of the Type K cement successfully reduced the concrete shrinkage; this material property was verified in laboratory testing for restrained expansion. However, nearly all of the trial decks exhibited surface scaling, while the Type I cement concrete decks did not scale. Laboratory testing showed that the Type K cement had higher chloride permeability than Type I cement, which was the most likely cause of the scaling noted early in the life of Type K bridge decks.

Use of Type K cement was more costly than conventional Type I cement. Type K cement concrete for the trial bridge decks cost 12 to 30 percent more than the Type I concrete. This was due to increased cement requirements of a limited-supply specialty cement, and also due to construction costs entailed with Type K cement concrete.

Because of the surface scaling issues and high cost associated with Type K cement concrete, further use of this material was not recommended. Furthermore, the material became unavailable to the Wisconsin market after the regional Type K cement supplier went out of business in the late 1990s. After the final trial bridge deck was constructed in 1995, Type K cement concrete was not used in bridge decks on the Wisconsin State Trunk Network. [*6*]

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