PERFORMANCE TESTING OF HPC ON SUNSHINE BRIDGE

Final Report 658

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16. Abstract

The deck of the Sunshine Bridge overpass, located westbound on Interstate 40 (I-40) near Winslow, Arizona, was replaced on August 24, 2005. The original deteriorated concrete deck was replaced using high performance concrete (HPC), reinforced with low-carbon, low-corrosion reinforcing steel. HPC is a new technology in Arizona. This report documents the first survey of the deck's condition and recommends that ADOT embark on a monitoring program to evaluate the performance of HPC.

The ADOT monitoring program should consist of visual observation of the deck condition and concrete sampling and testing to measure and document HPC performance. The survey presented in this report was performed on December 18, 2007, which represents the first field survey since concrete deck placement.

Visual observation and test results show the following:

1. The concrete has a very low chloride permeability.
2. The concrete has significantly slowed down and/or prevented chloride penetration through the bridge deck.
3. The average air-void parameters of HPC do not meet the industry standards for frost resistant concrete.
4. The deck surface appears to have minimal wear from snow removal equipment and shows no signs of concrete cracking.

HPC appears to perform very well during the monitoring period despite the lower than recommended air void system. There were no signs of deterioration or adverse field conditions.

It is recommended that bridge deck monitoring and concrete testing be done annually or biennially throughout the bridge's estimated 50-year service life to confirm long-term performance of HPC. It is also recommend that the next monitoring survey be initiated and conducted before the end of the year 2009.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	Square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	Square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	Square meters	1.195	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	Cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	cubic meters	m^3	m^3	Cubic meters	1.308	cubic yards	yd^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.								
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or “metric ton”)	mg (or “t”)	Mg	megagrams (or “metric ton”)	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION					**ILLUMINATION**		
fc	foot candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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EXECUTIVE SUMMARY

The deck of the Sunshine Bridge overpass, located westbound on Interstate 40 (I-40) near Winslow, Arizona, was replaced on August 24, 2005. The original deteriorated concrete deck was replaced using high performance concrete (HPC), reinforced with low-carbon, low-corrosion reinforcing steel. HPC is a new technology in Arizona. This report documents the first survey of the deck's condition and recommends that ADOT embark on a monitoring program to evaluate the performance of HPC.

The ADOT monitoring program should consist of visual observation of the deck condition and concrete sampling and testing to measure and document HPC performance. The survey presented in this report was performed on December 18, 2007, which represents the first field survey since concrete deck placement.

Visual observation and test results show the following:

1. The concrete has a very low chloride permeability.
2. The concrete has significantly slowed down and/or prevented chloride penetration through the bridge deck.
3. The average air-void parameters of HPC do not meet the industry standards for frost resistant concrete.
4. The deck surface appears to have minimal wear from snow removal equipment and shows no signs of concrete cracking.

HPC appears to perform very well during the monitoring period despite the lower than recommended air void system. There were no signs of deterioration or adverse field conditions.

We recommend that bridge deck monitoring and concrete testing be done annually or biennially throughout the bridge's estimated 50-year service life to confirm long-term performance of HPC. We also recommend that the next monitoring survey be initiated and conducted before the end of the year 2009.

INTRODUCTION

The purpose of this work was to collect information on the performance of the high performance concrete (HPC), placed on the deck of the Sunshine Bridge overpass on I-40. The bridge deck was constructed on August 24, 2005, as a pilot project under ATRC Project SPR 538 to evaluate the feasibility of using HPC technology on bridges in Arizona.

PROJECT BACKGROUND

Work under SPR 538 consisted of replacing the deteriorated concrete deck slab with a durable cast-in-place HPC deck. The HPC was designed to achieve four main objectives:

- Higher durability under freeze-thaw exposure.
- Lower permeability to salt penetration.
- Lower shrinkage potential.
- Reduced steel corrosion.

Quality control and quality assurance programs were implemented during concrete placement to collect and document information regarding concrete properties at the time of placement. Concrete sampling and testing were performed during construction to measure the in-place properties of HPC. This work is a part of a long-term program to monitor the performance of HPC during service life to:

1. Establish a baseline for concrete properties in the field.
2. Compare the baseline of concrete properties against those measured during concrete placement.

The baseline established in this work will be used as a benchmark for evaluating concrete properties and performance during the service life of the concrete bridge deck.

Jaber Engineering Consulting, Inc. (JEC) has completed the work on this project according to the scope of work outlined in the project statement dated December 7, 2007.

SCOPE OF WORK

1. Visually examine the bridge deck and barriers and document any cracking. If cracking is found, identify the type and cause.
2. Obtain concrete cores from the deck and measure the following:
    a. ***Rapid chloride permeability*** (RCP) according to ASTM 1202 *Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*. (ASTM 2009)
    b. ***Air voids*** by performing an analysis according to ASTM C 457-06 *Method for Microscopical Determination of Parameters of the Air Void System in Hardened Concrete*. (ASTM 2006)
    c. ***Chloride ion content*** (CIC) according to ASTM 1218 *Method for Water-Soluble Chloride in Mortar and Concrete.* (ASTM 2002).
3. Measure the extent of chloride penetration through the concrete bridge deck.

WORK PERFORMED

1. *Field Sampling*

JEC retained Western Technologies, Inc. (WTI) to perform concrete coring. WTI used ground penetrating radar (GPR) instruments to locate the reinforcing steel. Concrete coring locations were selected to avoid any damage to the reinforcing steel during coring operations.

On December 18, 2007, concrete from the bridge deck was sampled at three locations and at least four cores were taken at each location. A schedule of the concrete core samples is presented in Table 1 and coring is shown in photos 1 through 5 in the Appendix. All concrete samples were less than 6 inches long to avoid penetration of the full depth of the deck. A non-shrink grout was used to patch all cored areas.

Table 1 - Cores Information

CORE INFORMATION			
AREA	CORE LOCATION	# CORES	DESIGNATION
A	14' S. of the north barrier and 23' W. of the E. end of the deck	5	A1, A2, A3, A4, A5[1]
B	12' S. of the north barrier and 94.5' E. of the W. end of the deck	4	B1, B2, B3, B4
C	12' S. of the north barrier and 23' E. of the W. end of the deck	4	C1, C2, C3, C4

[1] Core A5 was damaged during coring and was discarded

2. *Field Observation*

JEC made a visual observation of the concrete deck and its surface. There were no signs of deterioration, scaling, cracking, or similar adverse conditions. The deck surface showed light markings from snow removal blades and equipment.

3. *Laboratory Testing*

ADOT retained one sample from each location to perform an in-house RCP testing. ADOT samples were marked A1, B1, and C1. The remaining samples were sent to WTI and Construction Technology Laboratory (CTL) in Skokie, Illinois, for testing.

a. **Rapid chloride permeability** testing was performed by CTL using cores number A2, B2, and C2. For each core/location, (A, B, and C) the top ¾ inch of the concrete core was removed and discarded. A 2-inch thick sample was cut and labeled "TOP." Another 1-inch thick was cut and discarded and a 2-inch thick sample was cut and labeled

"BOTTOM." The top and bottom samples for each location were tested and their average represented the RCP value at that location. Results are presented in Table 2.

Table 2 - RCP Results

RCP TEST RESULTS ASTM C 1202, COULOMB				
SAMPLE	**CORE A2**	**CORE B2**	**CORE C2**	**AVERAGE**
TOP [1]	333	517	574	
BOTTOM [2]	204	273	193	
AVERAGE	**269**	**395**	**384**	**349**

[1] The top of this 2-inch sample is ¾ inch from the top of the corresponding core/deck surface.
[2] The top of this 2-inch sample is 3¾ inch from the top of the corresponding core/deck surface.

b. **Air void analysis** was performed by CTL using samples number A3, B3, and C3. Results are presented in Table 3.

Table 3 - Air Void Analysis Results

AIR VOID PARAMETERS ASTM C 457- 06						
LOCATION SAMPLE ID	**TOTAL AIR CONTENT (A)**	**SPACING FACTOR**	**SPECIFIC SURFACE**	**VOIDS PER INCH**	**LENGTH OF TRAVEL**	**NUMBER OF POINTS**
	(%)	(in)	in^2/in^3		(in)	
CORE A3	3.4	0.013	477	4.1	90	1351
CORE B3	6.2	0.012	378	5.8	90	1350
CORE C3	9.3	0.006	509	11.9	90	1351
AVERAGE	**6.3**	**0.010**	**455**	**7.3**	90	1351
RECOMMENDED(1)	6.5 ± 1.5	< 0.008	> 600	1.5 TIMES A	90	

[1] Fr. Ch. 4, Section 4.4, Table 4.4.1 of *Building Code Requirements for Structural Concrete.* (ACI 2002a)

c. **Chloride ion content** testing was performed by Motzz Laboratory of Tempe, Arizona, (a sub-consultant to WTI) using samples number A4, B4, and C4. Results are presented in Table 4.

Table 4 - Chloride Ion Content Results

CHLORIDE ION CONTENT ASTM C 1218 - 02								
REGION FROM SURFACE (IN)	**CORE A4**		**CORE B4**		**CORE C4**		**AVERAGE**	
	(%)	(LB)	(%)	(LB)	(%)	(LB)	(%)	(LB)
0 TO 1	0.1800	0.2700	0.2100	0.3150	0.2000	0.3000	**0.1967**	**0.2950**
1 TO 2	0.0120	0.0180	0.0140	0.0210	0.0074	0.0111	**0.1113**	**0.1670**
2 TO 3	0.0086	0.0129	0.0096	0.0144	0.0062	0.0093	**0.0081**	**0.0122**
3 TO 4	0.0096	0.0144	0.0096	0.0144	0.0087	0.0131	**0.0093**	**0.0014**
4 TO 5	0.0089	0.0134	0.0080	0.0120	0.0060	0.0090	**0.0076**	**0.0115**
5 TO 6	0.0092	0.0138	0.0065	0.0098	-	-	**0.0079**	**0.0118**
BASE CONCRETE*	0.0087	0.0131	0.0087	0.0131	0.0087	0.0131	**0.0087**	**0.0131**
ACI THRESHOLD(1)	**1.3**	**2 LBS**	**1.3**	**2 LBS**	**1.3**	**2 LBS**	**1.3**	**2 LBS**

*Base concrete values were measured during concrete deck placement - August 24, 2005
[1] Fr. *Guide for Concrete Highway Bridge Deck Construction.* (ACI 2002b).

FINDINGS

The average RCP value for concrete at all three locations was 349 coulombs. The average RCP for the concrete at the time of placement was 984 coulombs. This indicates that the concrete has gained significant resistance to chloride permeability since placement. This is attributed mainly to the effect of fly ash and silica fume on concrete. The concrete is currently considered to have very low chloride penetrability as shown in Table 5.

Table 5 - ASTM C1202[(1)]

Charge Passed (coulomb)	Chloride Penetrability
> 4000	High
2000 - 4000	Moderate
1000 - 2000	Low
100 - 1000	Very Low
< 100	Negligible

[1]Fr *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.* (ASTM 2009).

The air void analysis indicates that air void parameters do not meet recommended criteria by the American Concrete Institute in *Guide to Durable Concrete* (ACI 2008) and industry standards for frost resistant concrete. The lower air content is the result of the higher than expected concrete air loss during pumping.

The chloride levels measured in three locations at varying deck depths indicate that the concrete has significantly prevented or slowed the penetration of chloride into the bridge deck. This correlates very well with the RCP test results measured, as shown in Table 2.

RECOMMENDATIONS

We recommend that a biennial monitoring program (visual observation, sampling, and testing of the concrete) be continued to monitor the development of HPC properties and confirm its performance in the field. Monitoring programs should continue for a minimum of 10 years, with intervals extended by one year each time until there is no significant change in concrete properties measured in the field.

REFERENCES

1. American Concrete Institute. 2002a. *Building Code Requirements for Structural Concrete.* ACI 318. Detroit, Michigan: American Concrete Institute. Chapter 4, Section 4.4, Table 4.4.1.

2. American Concrete Institute. 2002b. *Guide for Concrete Highway Bridge Deck Construction.* ACI 345. Detroit, Michigan: American Concrete Institute. Chapter 7, Section 7.3.4.

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4. American Society for Testing and Materials. 2002. *Method for Water-Soluble Chloride in Mortar and Concrete.* ASTM 1218-02. West Conshohocken, Pennsylvania: American Society for Testing and Materials.

5. American Society for Testing and Materials. 2006. *Method for Microscopical Determination of Parameters of the Air Void System in Hardened Concrete.* ASTM C457-06. West Conshohocken, Pennsylvania: American Society for Testing and Materials. .

6. American Society for Testing and Materials. 2009. *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.* ASTM C1202 – 09. West Conshohocken, Pennsylvania: American Society for Testing and Materials. Table 5.

APPENDIX

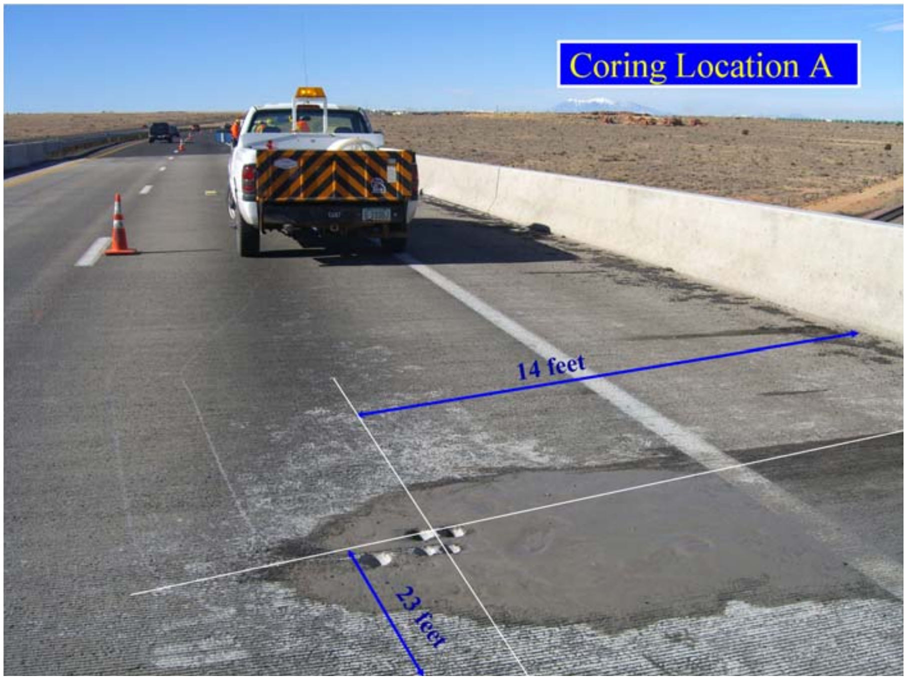

Photo 1- Coring location A

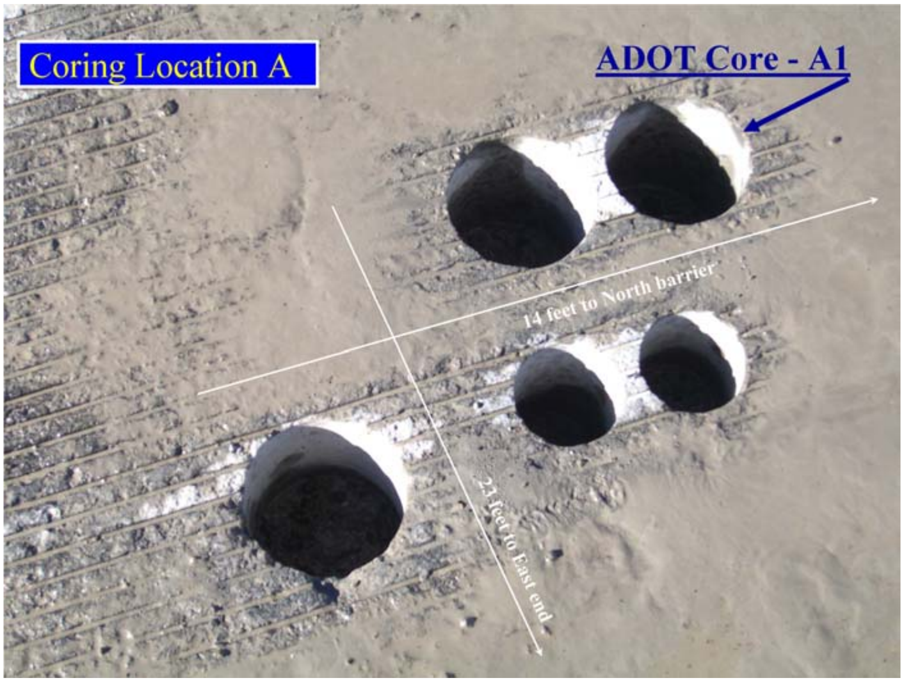

Photo 2- Coring location A

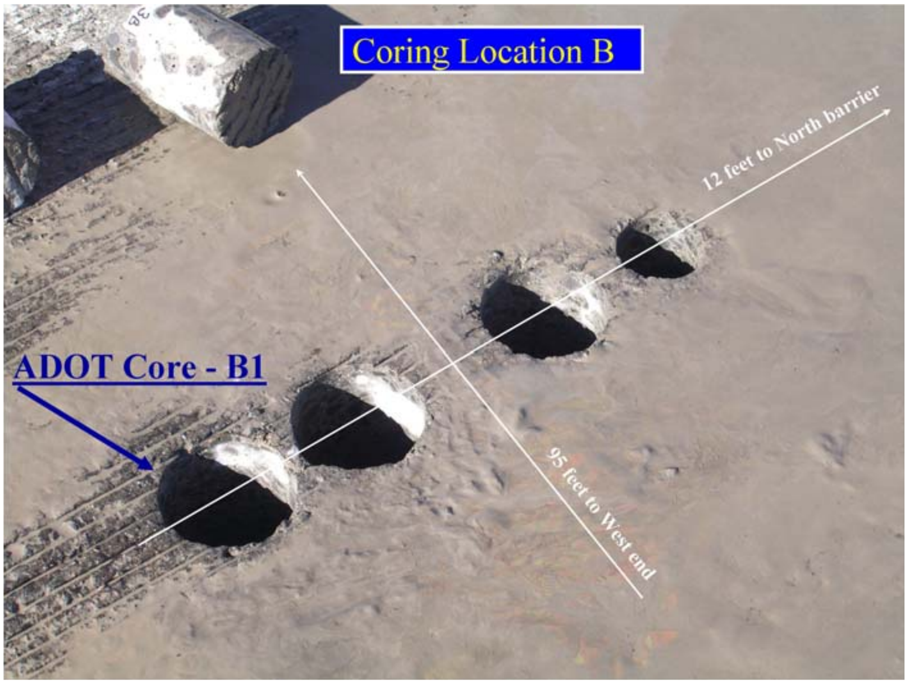

Photo 3- Coring location B

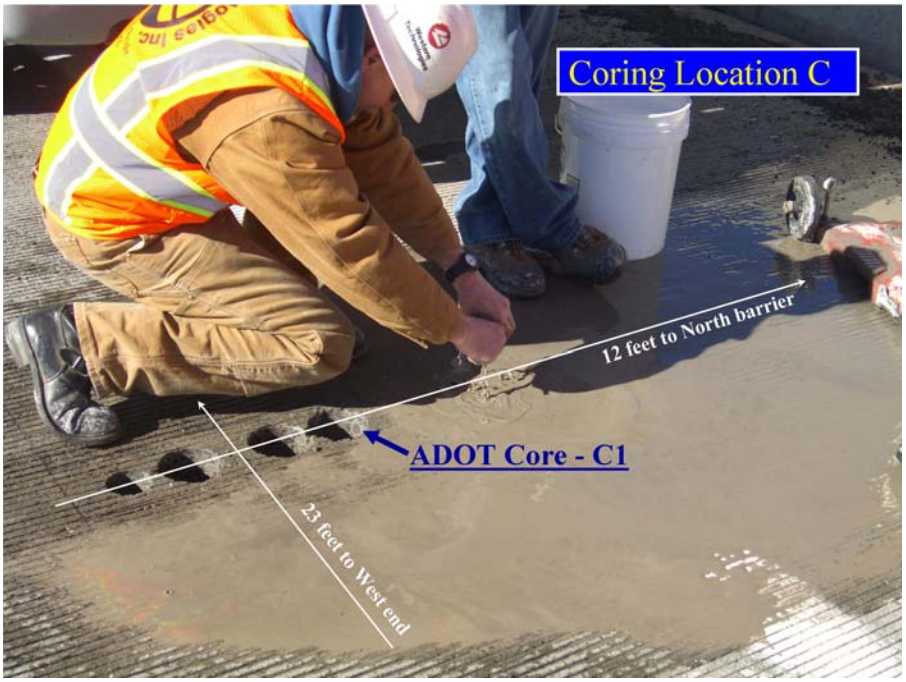

Photo 4- Coring location C

Photo 5- Concrete cores