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High-Performance Concrete: Applying Life-Cycle Cost Analysis and Developing Specifications

Arizona Department of Transportation Research Center

ADOT

High-Performance Concrete: Applying Life-Cycle Cost Analysis and Developing Specifications

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16. Abstract
Numerous studies and transportation agency experience across the nation have established that high-performance concrete (HPC) technology improves concrete quality and extends the service life of concrete structures at risk of chloride-induced corrosion. The feasibility and benefits of using HPC in Arizona bridges were demonstrated in ADOT's Sunshine Bridge project, after which ADOT wanted tools for determining when and how to use HPC in other bridge projects. One such tool would be life-cycle cost analysis (LCCA) software to help in selecting the optimum HPC solution. Another tool would be a set of draft HPC prescriptive specifications –for full deck replacement and for overlay repair – that contractors could use to incorporate HPC solutions in building and repairing ADOT bridges.

This project determined that, as LCCA software, the Life-365 Service Life Prediction Model™ was a viable option for estimating life-cycle costs of bridge decks where salt (chloride) is applied to control the accumulation of ice. Also developed for ADOT's use were draft specifications for using HPC on full bridge deck replacement and on overlay repair.

17. Key Words Life-Cycle Cost Analysis (LCCA), Service Life, Bridge Decks, Rate of Return, HPC, Silica Fume, Concrete Durability, Steel Corrosion, High-Performance Concrete, Chloride, Overlay and Repair, Prescriptive Specification		18. Distribution Statement This document is available to the US public through the National Technical Information Service, Springfield, Virginia 22161.	23. Registrant's Seal
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
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.
(Revised March 2003)

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LIST OF ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ADOT	Arizona Department of Transportation
ASTM	American Society for Testing and Materials
DOT	department of transportation
HPC	high performance concrete
LCCA	life-cycle cost analysis
SCM	supplementary cementitious materials
SF	silica fume
SHRP	Strategic Highway Research Program

NOTATIONS

C_t	critical chloride threshold, which is the chloride concentrations measured at the steel surface that initiate corrosion of steel
D	chloride diffusion coefficient is a measure of the capacity of concrete to resist chloride penetration
D_{28}	chloride diffusion coefficient D at 28 days
D_{ref}	chloride diffusion coefficient D at (*ref)* time in days
t_i	initiation period, the time (in years) to the onset of corrosion in the steel
t_p	propagation period, the time (in years) for steel corrosion to reach an unacceptable level
SL:	service life, the time (in years) when the structure can be in service
i:	inflation rate, the annual rate at which the prices of goods and services will increase over the future
r:	real discount rate, the annual rate at which future costs are discounted to current year dollars

EXECUTIVE SUMMARY

Numerous studies and public agency experience across the nation have established that high-performance concrete (HPC) technology improves concrete durability and extends the service life of concrete structures that would be at risk of chloride-induced corrosion. In 2004, the Arizona Department of Transportation (ADOT) initiated a program to investigate using HPC on specific ADOT bridge projects.

The feasibility and benefits of using HPC in Arizona bridges were confirmed in an ADOT demonstration project: SPR 538, *High-Performance Concrete for Bridge Structures in Arizona*. First, SPR-538 confirmed the feasibility and benefits of using HPC on Arizona bridges. Next, the project implemented the use of HPC in the full deck replacement of the “Sunshine” Bridge on Interstate 40 west of Winslow, Arizona. Finally, the project monitored the performance of the HPC placed on the Sunshine Bridge and confirmed its benefits (Jaber 2007; Jaber 2009). The results influenced the approach to this project and partially informed its conclusions.

Recognizing the benefits of HPC technology, ADOT needed decision-making tools for determining when and how to use HPC in other Arizona bridge projects. One such tool would be life-cycle cost analysis (LCCA) software that would help in selecting the optimum HPC solution for bridge projects.

Another tool would be a set of HPC prescriptive specifications – one for a full deck replacement, a second for overlay repair – that ADOT contractors could use to properly incorporate HPC solutions in building and repairing ADOT bridges. It was envisioned that drafting this set of specifications would be guided by information developed for special provision specifications from the Sunshine Bridge deck replacement project, and by survey information from transportation agencies already using HPC.

Recommendations

LCCA software that was developed by an industry consortium, the Life-365 Service Life Prediction Model™ (Life 365™), offered an approach for estimating life-cycle costs of bridge decks in situations where salt (chloride) is applied to control the accumulation of ice. Because the software focuses on concrete deterioration from chloride, Life 365™ is not useful in predicting bridge deck life-cycle costs in Arizona regions without seasonal ice.

Sufficient ADOT data for chloride concentrations (a crucial input for the analyses) were not available for the LCCA performed in this study. Assumptions and calculations were made as substitute inputs for the concentration level data. The lack of chloride concentration measurements may point to potential data needs in ADOT’s bridge deck evaluation program.

This project developed draft specifications (Appendix C and Appendix D) for full deck replacement and overlay repair using HPC. It is recommended that ADOT proceed by specifying and using HPC technology on selected bridges and monitoring the performance of those bridges, using these draft specifications as a basis for project-specific special provisions when HPC is required.

CHAPTER 1: INTRODUCTION

This project represents the second stage of a program to implement the use of high-performance concrete (HPC) technology on Arizona Department of Transportation (ADOT) bridges in regions where salt (chloride) is regularly applied to the deck to control ice. The stages are described below.

First Stage (2004 – 2009): The first stage was completed under ADOT project SPR-538, *High Performance Concrete for Bridge Structures in Arizona.* First, SPR-538 confirmed the feasibility and benefits of using HPC on Arizona bridges. Next, the project implemented the use of HPC in the full deck replacement of the Interstate 40 "Sunshine" Bridge over Burlington Northern Railway tracks approximately 20 miles west of Winslow, Arizona. Finally, the project monitored the performance of the HPC placed on the Sunshine Bridge and confirmed its benefits (Jaber 2007; Jaber 2009). The results of the SPR-538 project influenced the approach to this project and partially informed its conclusions.

After the project completion in 2009, ADOT needed decision-making tools for determining when and how to use HPC in Arizona bridge projects. One such tool would be life-cycle cost analysis (LCCA) software that would help in selecting the optimum HPC solution for specific bridge projects where chloride-induced corrosion would be a factor.

Another needed tool would be a set of HPC prescriptive specifications — one for a full deck replacement, a second for overlay repair — that ADOT contractors could use to properly incorporate HPC solutions in building and repairing ADOT bridges. It was envisioned that drafting this set of specifications would be guided by information developed for special provision specifications from the Sunshine Bridge deck replacement project, and by information from survey information from transportation agencies that have already used HPC.

Second Stage (2009-2015): The second stage of the ADOT HPC implementation program was this project, SPR-673, which consisted of developing and making available to ADOT the necessary tools and specifications to facilitate specifying and using HPC on bridge projects. First, the project was meant to provide a LCCA software tool to demonstrate the benefits of using HPC on bridge decks in Arizona. The project would also develop prescriptive HPC specifications for full bridge deck replacement. The specifications would be consistent with ADOT standard specifications for bridge decks. Finally, the project would develop prescriptive HPC specifications for repairing and replacing bridge deck overlays. The specifications would be consistent with ADOT standard specifications for bridge decks.

This report presents the methodology and results of the SPR-673 project.

CHAPTER 2: LIFE-CYCLE COST ANALYSIS FOR ADOT BRIDGE DECKS

Many life-cycle cost analysis (LCCA) programs are available for transportation structures, including roadways and buildings. This project focused on LCCA programs for concrete bridge decks. This chapter provides a brief summary of the LCCA concept and lists some available approaches and recommendations for LCCA software.

Corrosion of embedded steel reinforcement in concrete — due to the penetration of chloride from deicing salts, airborne salt, rain, or seawater — is the most prevalent form of concrete deterioration worldwide and costs billions of dollars every year in terms of infrastructure repair and replacement (Song Guangling 1998). Significant work has been done on chloride-induced corrosion in concrete that confirms it as the main cause of concrete deterioration (Glass and Buenfeld 1995; Merretz et al. 2003; Collepardi et al. 1972). The efforts by concrete researchers and the industry to measure the chloride levels of concentration during a structure's service life reflect the importance of this issue to the integrity of the concrete (Kirkpatrick et al. 2002; Maage et al. 1995; Mangat and Molloy 1994). Similarly, the search for reinforcing steel with improved corrosion resistance has resulted in promising alternatives (Brown et al. 2003; Ji et al. 2005).

Many strategies exist for increasing the service life of reinforced structures exposed to chloride salts, including the use of one or more of the following:

- Make concrete less permeable and reduce the travel of chlorides to the reinforcing steel by using low permeability, high-performance concrete that includes fly ash, silica fume, and other cementitious material.
- Protect the reinforcing steel by using chemical corrosion inhibitors that form a passivating layer around the steel.
- Reinforce with epoxy-coated reinforcement, galvanized steel, stainless steel, a low corrosion carbon steel, or fiber-reinforced composites and plastics.
- Apply waterproofing membranes or sealants to the concrete surface to shield the concrete and ultimately prevent or delay the penetration of chlorides.
- Install cathodic protection systems during initial construction or during the service life of the deck to prevent or slow down the steel corrosion process.

Each of these strategies has different technical merits and associated costs. Selecting the optimum strategy requires the means to weigh all associated costs against the potential to extend the structure's life. LCCA is being used more frequently for this purpose (Bentz 2003; Concrete Reinforcing Steel Institute 1998; Frohnsdorff 1999). LCCA uses estimated initial construction costs, protection costs, and future repair costs to compute the costs over the design life of the structure (Rushing and Fuller 2006). Corrosion protection strategies serve to reduce repair costs by reducing the frequency of future repairs.

While the implementation of such protection strategies may increase the initial structure cost, the strategy used may reduce life-cycle costs.

Selecting materials for reinforced concrete bridge decks is usually based on many factors, such as local availability, field performance, maintenance cost, and available funding. The need to provide the bridge design professionals with effective tools that help them select concrete materials and deck systems has expedited the development of easy-to-use interactive LCCA software.

A number of models have been developed for predicting the service life of concrete structures exposed to chloride environments and for estimating the life-cycle costs of different corrosion protection strategies. Some of these are available on a commercial basis (Bentz 2003; Concrete Reinforcing Steel Institute 1998; Ehlen et al. 2009; Frohnsdorff 1999). The approaches adopted by the different models (Violetta 2002; Weyers 1998) vary considerably; consequently, there can be significant variances between the solutions produced by individual models.

A service life model developed to predict the service life of reinforcing steel was found to provide the most accurate prediction of the deterioration mechanism of concrete bridge decks, (Tuutti 1982). This service life model is shown in Figure 1**.**

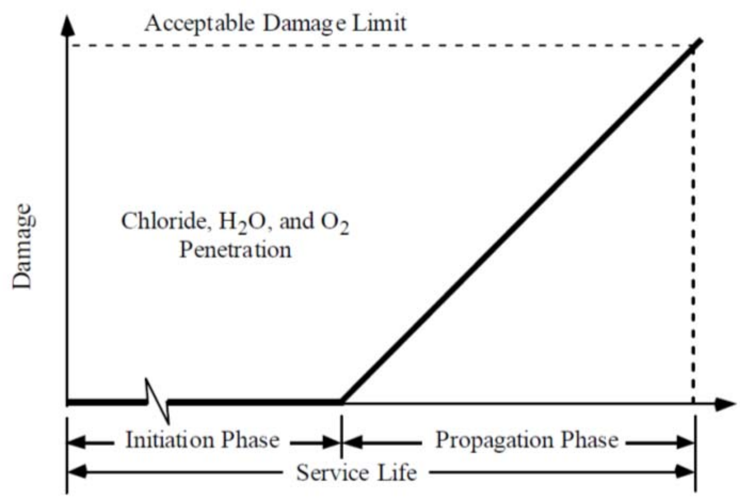


Figure 1. Service Life Prediction Model for Reinforced Concrete Bridges Exposed to Chloride (Source: Tuutti 1982)

In this model, the corrosion process is initiated by the diffusion of chloride ions to the edge of the reinforcing steel, or by carbonation reducing the pH of the concrete in contact with the steel, or by the combination of chloride ions and carbonation.

The structure service life is expressed in two phases, Initiation and Propagation. The model relies on chloride concrete diffusivity that governs the transport time of chloride ions through concrete as it makes its way to the reinforcing steel. The time it takes the chloride ions to travel through the concrete cover over the reinforcing steel, reach a threshold concentration, and start the corrosion process is called the Initiation Phase, or Initiation Period (IP). The Propagation Phase, or Propagation Period (PP), starts at the end of the IP, and ends when the structure is no longer structurally sound for its intended service. The IP is usually much longer than the PP (as much as five times longer).

Predicting Chloride Ingress Due to Diffusion

Tuutti's model predicts the IP assuming diffusion to be the dominant mechanism. Fick's second law is the governing differential equation:

$$\frac{dC}{dt} = D \bullet \frac{d^2C}{dx^2} \qquad \textbf{(Eq. 1)}$$

where C = chloride content,

D = apparent diffusion coefficient,

x = depth (from the exposed surface), and

t = time.

The chloride diffusion coefficient is a function of both time and temperature (Stanish 2000). Tuutti's model uses the following relationship to account for time-dependent changes in diffusion:

$$D(t) = D_{ref} \bullet \left(\frac{t_{ref}}{t}\right)^m \qquad \textbf{(Eq. 2)}$$

where $D(t)$ = diffusion coefficient at time t,

D_{ref} = diffusion coefficient at a reference time (t_{ref}), and

M = constant (depending on mix proportions).

LCCA SOFTWARE

The literature search performed under this project found three research projects that produced software programs that were developed for performing LCCA on bridge structures:

Life-Cycle Cost Analysis for Protection and Rehabilitation of Concrete Bridges Relative to Reinforcement Corrosion-SHRP-S-377 (Purvis et al. 1994): This project's software program provides analysis of existing concrete bridges based on their existing conditions. The program offers repair options and strategies for the bridge structure as a whole. The program requires extensive field data from the bridge, including a condition index and traffic characteristics, to assess and predict the life cycle of the structure.

Bridge Life-Cycle Cost Analysis-NCHRP Report 483 (Hawk 2003)**:** This report and its accompanying software were developed under a research program funded by AASHTO. The LCCA is based primarily on parameters of design service life, obsolescence, condition-related reductions in load capacity, seismic vulnerability, scour vulnerability, and overloads.

Life-365 Service Life Prediction Model™ (Life 365™): Computer Program for Predicting the Service Life and Life Cycle Costs of Reinforced Concrete Exposed to Chlorides. This program uses the steel corrosion mechanism and concrete service life model developed by Tuutti as the basis for predicting the service life of concrete bridge decks (Ehlen et al. 2009). The program was developed by Life-365 Consortium II, which consists of the Concrete Corrosion Inhibitors Association, the National Ready Mix Concrete Association, the Slag Cement Association, and the Silica Fume Association. This free software program runs on both Microsoft Windows® and Apple® OS X operating systems and is geared mainly for bridge deck LCCA applications.

The first two software programs address LCCA for the entire bridge and are most appropriate for assessing repair options for an existing bridge based on traffic characteristics and other factors beyond the scope of this project. The third option is designed mainly to perform predictive LCCA on bridge decks. Based on extensive review of all three LCCA programs, the first two options do not offer LCCA for bridge decks based on materials options and deck components. The third program was found to be the most appropriate for performing LCCA consistent with the objectives of this project.

LCCA EXAMPLES

The Life 365™ software used in this project uses a mathematical model of chloride ingress due to diffusion represented by Equations (1) and (2) on the previous pages. The software uses the following information as input information for the analysis:

- Bridge Deck Information: Thickness, depth of reinforcement, and reinforcement percent of concrete volume
- Concrete Mix Design: Water/cementitious ratio, fly ash content, silica fume content, chloride diffusivity, and cost of concrete
- Steel Reinforcement: Black steel, epoxy coated, stainless steel and their costs
- Repair Information: Cost of repair per square foot, area to be repaired as a percent of the entire deck, and repair intervals
- Financial Parameters: Analysis year, analysis period, inflation rate, and discount rate
- Environmental Conditions: Average monthly temperature for the area
- Salt Application: Amount of salt on the bridge deck. (In the absence of actual chloride content, the following can be used: an estimate of salt application using records of salt added, an estimate of salt deposited by traveling vehicles, or default values provided by the software, which uses a national survey of salt concentration in the United States.)

To demonstrate the predictive approach of Life 365™ analysis and provide reference examples of the analysis, three representative Arizona areas — Flagstaff, Safford, and Virgin River Gorge — were selected based on their geography, elevations, weather conditions, and history of maintenance. The LCCA examples presented in this report used available ADOT records. Because ADOT data for chloride concentrations (a crucial input for the analyses) were not available for the LCCA performed in this study, assumptions and calculations were made to estimate concentration levels sufficient to test the software.

Fixed Input Data Across All Areas: The following fixed input data were used for all analyses in all three areas. The fixed data are presented in Table 1.

- Structural Data: Includes lane width, bridge deck length, slab thickness, reinforcement depth (concrete cover), and the amount of reinforcement in the concrete expressed as a percentage of the total volume. All analyses in the three areas use a typical bridge deck width of 50 feet, a deck length of 200 feet, a thickness of 8 inches and 2 inches of concrete cover over the reinforcement.
- Repair Parameters: Includes the cost of bridge deck repair per square foot, the area to be repaired (when needed) as a percent of the entire deck, and the time intervals between repairs

in years. The repair costs used for the example analyses are based on historical costs for ADOT bridge repair projects.

- Materials Cost: Includes the cost of black steel, epoxy-coated steel, and stainless steel reinforcement in Arizona at the time of the analysis.
- Financial Parameters: Includes the analysis year, the analysis period in years, the inflation rate, and the discount rate. These values were taken from the Arizona financial market at the time of the analysis.

Fixed Input Data within Each Area: These input data are specific to each area of analysis:

- Weather and Environmental Conditions: Average monthly temperature for each specific area.
- Salt Application: The analysis requires the actual concentrations of chloride salts from the concrete of the bridge deck under study. However, in the absence of this information, the analyses used one or a combination of the following:
    - ADOT records of salt application to the bridge deck
    - An estimate of salt deposited by passenger cars and trucks in cases where salt application records are not available
    - Default values provided by Life 365™ software, which uses a national survey of bridge deck salt concentrations in the United States

  Salt loads for the Virgin River Gorge area were calculated using an estimate of salt deposited by passenger cars and trucks on I-15.

  The salt application data and the calculation of the chloride concentration in the bridge deck should be confirmed using actual field measurement of chloride concentration.

Variable data includes concrete mix information. This includes water/cementitious ratio, fly ash content, silica fume content, and cost of concrete per cubic yard. These values are the same for all three areas, but they are varied within the analysis for each of the base solutions and the five alternatives.

For each area that was profiled, there is one base design option and five alternative design options (two of which use HPC) and the parameters are as follows:

Base Design Option — Represents ADOT Class S concrete with a water/cement ratio of 0.50 and black steel reinforcement.

Alternative 1 — Includes the base with 20 percent fly ash by weight of cementitious material.

Alternative 2 — Includes the base with epoxy steel reinforcement.

Alternative 3 — Includes the base with 20 percent fly ash by weight of cementitious material and epoxy steel reinforcement.

Alternative 4 — Includes HPC (the base with water/cementitious ratio of 0.40, 20 percent fly ash by weight of cementitious material, silica fume content of 6 percent by weight of cement) and epoxy steel reinforcement.

Alternative 5 — Includes HPC (the base with water/cementitious ratio of 0.40, 20 percent fly ash by weight of cementitious material, silica fume content of 6 percent by weight of cement) and stainless steel reinforcement.

The LCCA analyses for the Flagstaff area are presented and discussed on the following pages to help demonstrate the LCCA general approach. (The analyses result for the other two areas are presented in Appendix A.)

FLAGSTAFF AREA LIFE-CYCLE COST ANALYSIS

Life 365™ software generates reports that can be tailored specifically to the user's needs. Table 1 shows the project information report for the Flagstaff area. It lists the fixed and variable data for the analysis alternatives under consideration. This includes a description of analyzed alternatives, bridge deck dimensions, concrete mix designs, reinforcement type, repair frequencies, material cost, repair cost, inflation rate, and discount rate. The Project Information report also includes:

The cost of the concrete mix taking into account any added supplementary cementitious materials (SCM) (Pun 1997) and admixtures (Miller and Miltenberger 2001)

The cost of the reinforcing steel (black, epoxy coated, and stainless steel)

The estimated repair cost, which represents the cost of repairing the structure starting when the concrete service life is reached, the area to be repaired as a percent of the total surface area, and frequency of repair at fixed time intervals

Financial parameters including the start of the analysis (year), analysis period (years), inflation rate, and discount rates (Rushing and Fuller 2006)

Table 1. Flagstaff Area Input Data for Life-Cycle Cost Analysis
(Project Information Report from Life 365™)

ALTERNATIVE	BASE	Alternative-1	Alternative-2	Alternative-3	Alternative-4	Alternative-5
		Base Plus Fly Ash	Base Plus Epoxy Steel	Base with Fly Ash and Epoxy Steel	HPC with Fly Ash, Epoxy Steel and Silica Fume	HPC with Fly Ash, Stainless Steel and Silica Fume
		Alt-1 (FA)	Alt-2 (ES)	Alt-3 (FA+ES)	Alt-4 (FA+ES+SF)	Alt-5 (FA+SS+SF)
Variable Data						
Concrete Mix and Materials						
Type	Class S ADOT	Class S ADOT	Class S ADOT	Class S ADOT	HPC	HPC
Water Cement Ratio (%)	0.50	0.50	0.50	0.50	0.40	0.40
Fly Ash (% of Cementitious)	-	20%	0%	20%	20%	20%
Silica Fume (% of Cement)	-	-	-	-	6%	6%
Concrete ($/cy)	$80.00	$85.00	$80.00	$85.00	$100.00	$100.00
Reinforcement						
Black Steel	YES	YES	-	-	-	-
Epoxy Steel	-	-	YES	YES	YES	-
Stainless Steel	-	-	-	-	-	YES

Fixed Data, All Alternatives	
Structural Data	
Bridge Element	Bridge Deck
Lane Width (ft)	50
Length (ft)	200
Analysis Area (sq. ft)	10,000
Slab Thickness (in)	8
Rein. Depth (in)	2
Rein. Percent of Concrete Volume (%)	1.20%
Repair	
Cost ($/sq. ft)	$37.16
Area to be repaired (%)	10%
Repair interval (yrs)	10
Material Cost	
Black Steel ($/lb)	$0.45
Epoxy-coated Steel ($/lb)	$0.60
Stainless Steel 316 ($/lb)	$3.00
Financial Parameters	
Base year	2011
Analysis Period (yrs)	100
Inflation Rate (%)	1.80%
Discount Rate (%)	3.00%

The life-cycle cost report contains the key results of the analyses and four of the most important graphs that demonstrate the analyses. The “Life-Cycle Costs” tabulation and the graph of “Life-Cycle Cost, by Alternative” list the construction cost, barrier cost, repair cost and the final life-cycle cost for each of the six analyses (base and five alternatives) performed for the Flagstaff area.

The report shows that Alternative Four has the lowest life-cycle cost of $12.62 per square foot of bridge deck area. A graphic presentation of the life-cycle cost for each of the six alternatives is shown in this report under “Graphs.” Although Alternative Five, which contains stainless steel, offers the best corrosion protection for the reinforcement steel, it does not offer the best life-cycle cost.

The “Cumulative Present Value” and “Cumulative Current Costs” graphs in Figure 2 show the number of repairs performed over the 100-year study period (service life) of the bridge deck along with the dollar cost associated with those repairs. Alternative Five has no maintenance events or cost resulting from steel corrosion during the study period, whereas Alternative Four has five maintenance events and Alternate Three has seven maintenance events. These results provide the design engineer with the information needed to select the alternative best suited for the bridge deck service conditions and costs.

Life365 v2.0 - Life-Cycle Costs

Project: SPR-673-Flagstaff

Description: Flagstaff area, (1 of 5)

Analyst: Tarif Jaber

Date: 04/15/2011

Life-Cycle Costs

Name	Construction Cost	Barrier Cost	Repair Cost	Life-Cycle Cost
Base case	$3.72 per sq. ft	$0.00 per sq. ft	$19.03 per sq. ft	$22.75 per sq. ft
Alt-1 FA	$3.85 per sq. ft	$0.00 per sq. ft	$18.37 per sq. ft	$22.21 per sq. ft
Alt-2 ES	$4.30 per sq. ft	$0.00 per sq. ft	$15.07 per sq. ft	$19.38 per sq. ft
Alt-3 FA+ES	$4.43 per sq. ft	$0.00 per sq. ft	$14.55 per sq. ft	$18.98 per sq. ft
Alt-4 FA+ES+SF	$4.80 per sq. ft	$0.00 per sq. ft	$7.82 per sq. ft	$12.62 per sq. ft
Alt-5 FA+SS+SF	$14.07 per sq. ft	$0.00 per sq. ft	$0.00 per sq. ft	$14.07 per sq. ft

Graphs

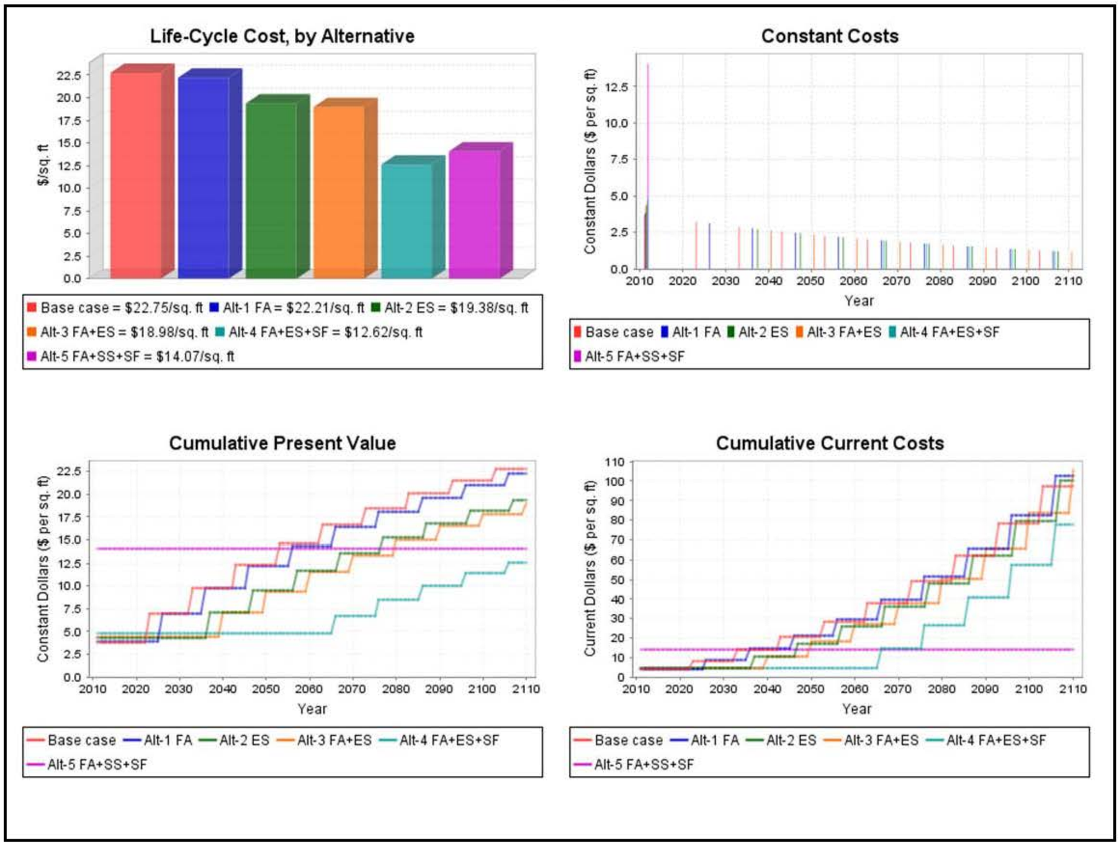


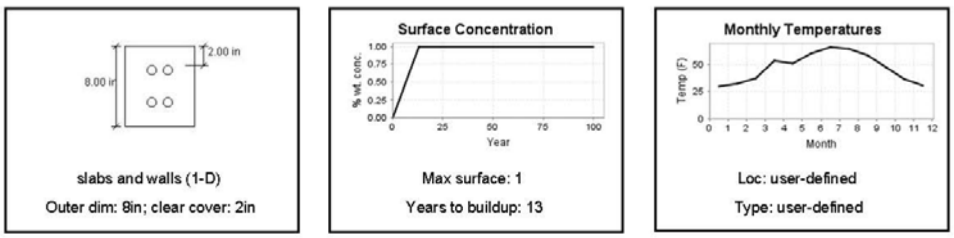
Figure 2. Flagstaff, Life-Cycle Costs

Figure 3 shows the fixed and variable data assumed for the analyses. The “Service Life” column under the “Diffusion Properties and Service Lives” table lists the number of years until the first repair and maintenance is required. The “Initiation and Propagation Periods” are also listed under the same table for each of the six analyses for the Flagstaff area. Life-365™ assumes that grade 316 stainless steel has a corrosion threshold of Ct = 0.50% (i.e., 10 times black steel).

Life365 v2.0 - Concrete Mixes and Service Lives

Project: SPR-673-Flagstaff | Description: Flagstaff area, (1 of 5)

Analyst: Tarif Jaber | Date: 04/15/2011



Concrete Mixes

Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
Base case		0.5				Black Steel
Alt-1 FA		0.5	Class F Fly Ash (20%);			Black Steel
Alt-2 ES		0.5				Epoxy Coated
Alt-3 FA+ES		0.5	Class F Fly Ash (20%);			Epoxy Coated
Alt-4 FA+ES+SF		0.4	Class F Fly Ash (20%); Silica Fume (6%);			Epoxy Coated
Alt-5 FA+SS+SF		0.4	Class F Fly Ash (20%); Silica Fume (6%);			316 Stainless

"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
Base case	2.14E-8 in*in/sec	0.2	0.05 % wt. conc.	6 yrs	6 yrs	**12 yrs**
Alt-1 FA	2.14E-8 in*in/sec	0.36	0.05 % wt. conc.	9.2 yrs	6 yrs	**15.2 yrs**
Alt-2 ES	2.14E-8 in*in/sec	0.2	0.05 % wt. conc.	6 yrs	20 yrs	**26 yrs**
Alt-3 FA+ES	2.14E-8 in*in/sec	0.36	0.05 % wt. conc.	9.2 yrs	20 yrs	**29.2 yrs**
Alt-4 FA+ES+SF	4.57E-9 in*in/sec	0.36	0.05 % wt. conc.	35.5 yrs	20 yrs	**55.5 yrs**
Alt-5 FA+SS+SF	4.57E-9 in*in/sec	0.36	0.5 % wt. conc.	100+ yrs	6 yrs	**106+ yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.

Figure 3. Flagstaff, Concrete Mixes and Service Lives

The software also generates the following separate reports (see Appendix A):

- Life Cycle Cost, by Alternative: Compares all alternatives graphically and lists the cost of each for the study period.
- Constant Costs: Displays the sum of all costs that occur each year, where this sum is inflated to account for increases in construction prices over the study period using the inflation rate listed in the project information graph, and is deflated to the present year of study using the discount rate listed in the project information.
- Current Costs: Displays the sum of all costs that occur in each year, where this sum is inflated to account for increases in construction prices over the study period using the inflation rate listed in project information report. This represents the actual dollars expended for each alternative, i.e., "cash flow."
- Cumulative Present Value: Shows the cumulative or total constant dollars expended over the project, where "constant dollars" in each year is the sum of all costs inflated each year in the study period using the inflation rate in the project information graph and then deflated to the present year of the study period using the discount rate listed in the project information.
- Cumulative Current Costs: Shows the cumulative or total current dollars expended over the life of the bridge deck, where "current dollars" in each year is the sum of all costs, inflated each year in the study period using the inflation rate in the project information report. Current dollars specifically take into account the change in construction prices over the study period, and are then an estimate of the actual dollars to be expended.
- Chloride Concentration versus Depth: Graphs the concentration of chlorides (on the vertical axis) at each depth of the structure, at the time of initiation.
- Chloride Concentration versus Time at Reinforcement Depth (2 inches): Graphs the level of chlorides at the reinforcing steel (on the vertical axis) at each point in time up to the time of initiation. Each curve will terminate at the point of initiation and reach a concentration level equal to the 'C_t' for the prospective alternative. (C_t is the chloride concentration at the steel's perimeter that initiates corrosion of the steel).
- Surface Concentration versus Time: Graphs the change in chloride concentration on the surface of the concrete structure over time for all alternatives.
- Diffusivity versus Time: Graphs changes in concrete diffusivity over time. Diffusivity of concrete generally exhibits two basic characteristics: A decline as the concrete hardens, and an annual oscillation caused by annual changes in temperature. A large annual variation in temperature in a particular region will cause a larger annual variation in concrete diffusivity.
- Initiation and Propagation Periods: Graphically charts the comparison between the initiation and propagation periods for all six alternatives.

FINDINGS

Life 365™ offers a simple tool for estimating life cycle costs of some bridge decks in Arizona by focusing on concrete deterioration from chloride. In those areas where deicing chemicals or chlorides are not introduced on bridge decks, Life 365™ is not useful in predicting service life of concrete bridge decks.

Because ADOT data for chloride concentrations (a crucial input for the analyses) were not available for the LCCA performed in this study, assumptions and calculations were made to estimate concentration levels sufficient to test the software.

CHAPTER 3: DRAFTING HPC SPECIFICATIONS

When first implementing HPC for bridge decks, it is common for state departments of transportation (DOTs) to adopt a prescriptive approach to the HPC specifications. Performance specifications are usually more effective when the DOT and the local bridge design and construction market have gained significant knowledge and direct experience building bridge decks using HPC technology.

STATE-OF-THE-PRACTICE SURVEY

A survey was conducted of state DOTs to gather information about the current state of the practice in implementing HPC on bridges. A total of 26 state DOTs responded, and the responses are presented in Appendix B.

Of the 26 DOT respondents, 19 used HPC on their projects. Of those with standalone HPC specifications, four respondents used HPC prescriptive specifications, and four used HPC performance specifications. Eighteen respondents used chloride permeability as one of the acceptance criteria for HPC. Additional analysis results are presented in Table 4 and the individual survey responses in Appendix B.

The survey responses did not significantly influence the project's development of draft HPC specifications and did not provide information beyond what was already available to ADOT. Most of the state DOTs did not have fully developed or standalone specifications that could be used as a source for the specifications developed under this research project. The survey responses showed that most of the respondents considered the use of HPC to be adding specific materials to the concrete, such as silica fume and other cementitious material, without fully implementing HPC technology.

From the survey responses, it can be concluded that the state of practice for HPC is at significantly different stages of implementation nationally. At the time of the survey, some states had developed full HPC specifications and were well into implementing the HPC technology, while others continued to use standard bridge deck mixes.

The states that had developed HPC specifications used prescriptive-based specifications. Only a few state DOTs had started to specify performance requirements, such as chloride permeability, as an acceptance criterion for concrete. Some state DOTs had developed payment schedules implementing incentives and disincentives based on performance criteria.

DRAFTING ARIZONA HPC SPECIFICATIONS

Because ADOT is in the early stages of implementing HPC technology on bridge decks, this project drafted prescriptive specifications. As ADOT uses HPC on Arizona bridge decks, data should be collected for HPC performance, construction practices, and lessons learned. This data would be used to update ADOT's specifications. As more HPC practice and experience is gained — by ADOT and by Arizona's bridge construction industry — ADOT may develop performance-based specifications.

Full Deck Replacement Specifications

The HPC full deck replacement specifications presented in this report (Appendix C) can be used as the basis for an independent set of special provisions for bridge deck construction using HPC. The prescriptive specifications for HPC bridge deck replacement were developed using two sources:

- ADOT special provisions for the I-40 Sunshine Bridge deck replacement (2005)
- ADOT Standard Specifications (2008), Sections 601 and 1006

As ADOT begins to implement HPC on bridge decks, the specification should be updated based on lessons learned and data collected for short- and long-term HPC performance.

Overlay and Repair Specifications

The prescriptive specification for HPC bridge deck overlays (Appendix D) was developed using two sources:

- ADOT special provisions used for bridge deck overlay projects. These special provisions are generally incomplete. They include the addition of microsilica, also known as silica fume, to the concrete mixture as one of the cementitious materials, but they lack essential components of HPC technology that provide the improved durability, quality improvements, and extended service life realized when HPC is fully implemented.
- ADOT Standard Specifications (2008), Sections and 601 and 1006

CHAPTER 4: RECOMMENDATIONS

LIFE CYCLE COST ANALYSES

Life 365™ software could be used to predict the life cycle cost of bridge decks exposed to chlorides in service, and to design the decks for minimum life cycle costs. Life 365™ offers a simple LCCA tool for bridges where chlorides are the primary cause of concrete deterioration, but is not an appropriate LCCA tool for bridge decks that are not exposed to chlorides. The software is readily available, but it requires users to have specific software training and a basic knowledge of concrete technology and bridge deck design parameters.

It is recommended that actual measured values of chloride concentrations, a crucial input for this software, be used in the LCCA analyses. However, for the LCCAs performed in this study (Appendix A), ADOT data for chloride concentrations were not available. Assumptions of chloride concentration levels were made based on the limited information available at the time, making it difficult to use this particular LCCA tool. For new bridge deck projects in regions of the state that have seasonal ice, it is recommended that sufficient chloride measurements be taken for existing bridge decks in the same regions.

DRAFT HPC SPECIFICATIONS

The survey responses collected for this study indicated that the state of practice for HPC is at significantly different stages of implementation nationally. Some states had developed full HPC specifications and were well into implementing the HPC technology, while others continued to use standard bridge deck mixes. The states using HPC specifications had prescriptive-based specifications.

Because ADOT is in the early stages of implementing HPC technology on bridge decks, this project drafted prescriptive specifications. The draft specifications presented in this report (Appendix C and Appendix D) are recommended as a basis for developing project-specific special provisions and stored specifications.

As ADOT implements HPC on Arizona bridge decks, it would be valuable to collect data on HPC performance, construction practices, and lessons learned. This data would be used to update ADOT's specifications. Field data and HPC performance test results can ultimately be used to support the transition from prescriptive specifications to performance specifications. Performance-based HPC specifications can be developed when ADOT staff and the Arizona construction industry have gained sufficient experience with HPC technology and implementation.

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APPENDIX A:
DEMONSTRATION LIFE-CYCLE COST ANALYSIS SUPPORTING DATA AND SAMPLE ANALYSES

FLAGSTAFF AREA LIFE-CYCLE COST ANALYSIS

Table A-1. Life Cycle Cost Analysis - Flagstaff Area

ALTERNATIVE	BASE	Alternative-1	Alternative-2	Alternative-3	Alternative-4	Alternative-5
		Base Plus Fly Ash	Base Plus Epoxy Steel	Base with Fly Ash and Epoxy Steel	HPC with Fly Ash, Epoxy Steel and Silica Fume	HPC with Fly Ash, Stainless Steel and Silica Fume
		Alt-1 (FA)	Alt-2 (ES)	Alt-3 (FA+ES)	Alt-4 (FA+ES+SF)	Alt-5 (FA+SS+SF)
Variable Data						
Concrete Mix and Materials						
Type	Class S ADOT	Class S ADOT	Class S ADOT	Class S ADOT	HPC	HPC
Water Cement Ratio (%)	0.50	0.50	0.50	0.50	0.40	0.40
Fly Ash (% of Cementitious)	-	20%	0%	20%	20%	20%
Silica Fume (% of Cement)	-	-	-	-	6%	6%
Concrete ($/cy)	$80.00	$85.00	$80.00	$85.00	$100.00	$100.00
Reinforcement						
Black Steel	YES	YES	-	-	-	-
Epoxy Steel	-	-	YES	YES	YES	-
Stainless Steel	-	-	-	-	-	YES

Fixed Data, All Alternatives	
Structural Data	
Bridge Element	Bridge Deck
Lane Width (ft)	50
Length (ft)	200
Analysis Area (sq. ft)	10,000
Slab Thickness (in)	8
Rein. Depth (in)	2
Rein. Percent of Concrete Volume (%)	1.20%
Repair	
Cost ($/sq. ft)	$37.16
Area to be repaired (%)	10%
Repair interval (yrs)	10
Material Cost	
Black Steel ($/lb)	$0.45
Epoxy-coated Steel ($/lb)	$0.60
Stainless Steel 316 ($/lb)	$3.00
Financial Parameters	
Base year	2011
Analysis Period (yrs)	100
Inflation Rate (%)	1.80%
Discount Rate (%)	3.00%

Table A-2. Environmental Data - Flagstaff Area

Environmental Data	
Chloride Exposure	
Max. Surface Content. (% by wt. conc.)	1
Time to build to max (yrs)	13
Temperature History	
Month	**Mean Temperature (^oF)**
January	29.7
February	32.2
March	36.6
April	53.2
May	50.8
June	60.1
July	66.1
August	64.4
September	57.8
October	47.1
November	36.5
December	30.2

Table A-3. Salt Load Calculations - Flagstaff Area

Salt Applications	**Area**
	1-Flagstaff
Salt Data	
Rate of Application (tons per mile)	300
No of Applications per year	3
Annual Salt Application (tons per mile)	900
Annual Salt Application (pounds per feet)	376
Annual Salt Application (% of concrete weight)	8%
Years to reach threshold	13
Fixed Assumptions for all areas	
Bridge Element	Bridge Deck
Lane Width (ft)	50
Slab Thickness (in)	8
Salt Analysis Area (sq. ft)	1
Concrete Weight (pcf)	150
Analyzed area weight (psf)	100
Concrete Concentration (% of weight of concrete)	1

Table A-4. Weather Data for -Flagstaff Area — Temperature

(U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000)

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: FLAGSTAFF PULLIAM AP, AZ **COOP ID: 023010**

Climate Division: AZ 2 **NWS Call Sign: FLG** **Elevation: 7,003 Feet** **Lat: 35°08N** **Lon: 111°40W**

Temperature (°F)																					
Mean (1)				Extremes										Degree Days (1) Base Temp 65		Mean Number of Days (3)					
Month	Daily Max	Daily Min	Mean	Highest Daily(2)	Year	Day	Highest Month(1) Mean	Year	Lowest Daily(2)	Year	Day	Lowest Month(1) Mean	Year	Heating	Cooling	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
Jan	42.9	16.5	29.7	66	1971	30	37.0	1986	-22	1971	4	22.6	1979	1099	0	.0	.0	8.1	4.0	30.5	2.2
Feb	45.6	18.8	32.2	71	1986	26	37.2	1995	-23	1985	1	25.9	1979	930	0	.0	.0	10.2	2.5	27.7	1.0
Mar	50.3	22.8	36.6	73+	1988	26	41.8	1989	-16	1966	4	26.8	1973	880	0	.0	.0	16.9	1.0	29.5	.3
Apr	58.4	27.3	42.9	80+	1992	28	50.4	1989	-2	1975	2	36.2	1975	668	0	.0	.0	24.1	.4	24.6	@
May	67.6	34.0	50.8	87+	1974	27	56.8	1984	14	1975	6	45.6	1980	446	0	.0	.0	30.1	.0	13.0	.0
Jun	78.7	41.4	60.1	96	1970	26	66.5	1974	22+	1955	2	55.0	1998	174	23	.0	1.7	29.9	.0	2.7	.0
Jul	82.2	49.9	66.1	97	1973	5	69.0	1980	32+	1955	8	62.8	1987	33	64	.0	2.1	31.0	.0	.0	.0
Aug	79.7	49.1	64.4	92+	1978	7	66.9	1995	24	1968	23	60.5	1979	56	36	.0	.6	31.0	.0	.0	.0
Sep	73.8	41.7	57.8	90	1950	1	60.7	1983	23+	1971	20	53.0	1986	224	3	.0	.0	29.9	.0	2.3	.0
Oct	63.1	31.1	47.1	85	1980	1	52.5	1988	-2	1971	30	38.6	1971	554	0	.0	.0	27.8	.1	18.2	@
Nov	50.8	22.1	36.5	74+	1977	3	42.3	1995	-13	1958	18	29.6	1972	850	0	.0	.0	16.5	1.1	28.0	.3
Dec	43.7	16.6	30.2	68	1950	11	39.9	1980	-23+	1990	23	21.9	1972	1085	0	.0	.0	9.5	4.1	30.0	1.8
Ann	61.4	30.9	46.2	97	Jul 1973	5	69.0	Jul 1980	-23+	Dec 1990	23	21.9	Dec 1972	6999	126	.0	4.4	265.0	13.2	206.5	5.6

+ Also occurred on an earlier date(s)

@ Denotes mean number of days greater than 0 but less than .05

Complete documentation available from: www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

Issue Date: February 2004 035-A

(1) From the 1971-2000 Monthly Normals

(2) Derived from station's available digital record: 1950-2001

(3) Derived from 1971-2000 serially complete daily data

Source: U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000

Table A–5. Weather Data for 1-Flagstaff Area — Precipitation

(U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000)

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data,
and Information Service

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: FLAGSTAFF PULLIAM AP, AZ **COOP ID: 023010**

Climate Division: AZ 2 **NWS Call Sign: FLG** **Elevation: 7,003 Feet** **Lat: 35°08N** **Lon: 111°40W**

Precipitation (inches)

	Precipitation Totals									Mean Number of Days (3)				Precipitation Probabilities (1) Probability that the monthly/annual precipitation will be equal to or less than the indicated amount										
	Means/ Medians(1)		Extremes							Daily Precipitation				Monthly/Annual Precipitation vs Probability Levels These values were determined from the incomplete gamma distribution										
Month	Mean	Med-ian	Highest Daily(2)	Year	Day	Highest Monthly(1)	Year	Lowest Monthly(1)	Year	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.05	.10	.20	.30	.40	.50	.60	.70	.80	.90	.95
Jan	2.18	1.76	1.83	1979	17	9.55	1993	.00	1972	8.0	5.0	1.4	.3	.04	.17	.43	.74	1.08	1.49	1.99	2.64	3.55	5.09	6.64
Feb	2.56	1.99	3.93	1993	19	10.05	1993	.02	1972	8.1	5.2	1.4	.5	.18	.34	.67	1.02	1.41	1.86	2.41	3.10	4.07	5.69	7.30
Mar	2.62	2.53	2.81	1970	1	6.18	1973	.00	1972	9.4	6.1	1.6	.3	.08	.28	.64	1.02	1.44	1.92	2.49	3.21	4.21	5.89	7.55
Apr	1.29	1.21	1.70	1985	21	3.83	1988	.00	1991	5.8	3.1	.8	.1	.03	.10	.26	.44	.65	.89	1.19	1.57	2.10	3.01	3.92
May	.80	.71	1.11	1965	24	4.14	1992	.00+	1996	5.4	2.4	.4	.0	.00	.04	.15	.27	.40	.56	.75	.98	1.32	1.88	2.44
Jun	.43	.24	2.40	1956	29	1.93	1972	.00+	1998	2.7	1.4	.2	.0	.00	.00	.00	.07	.15	.25	.37	.53	.75	1.13	1.51
Jul	2.40	2.26	2.55	1964	15	6.62	1986	.00	1993	11.3	5.5	1.3	.4	.29	.59	.99	1.34	1.68	2.05	2.46	2.96	3.61	4.66	5.65
Aug	2.89	2.82	3.04	1986	13	8.06	1986	.58	1976	12.8	6.7	1.7	.5	.73	1.00	1.42	1.79	2.16	2.54	2.98	3.49	4.16	5.22	6.21
Sep	2.12	1.67	2.84	1970	5	6.75	1983	.00+	1992	7.7	4.3	1.3	.5	.00	.11	.42	.74	1.09	1.50	1.99	2.60	3.47	4.93	6.38
Oct	1.93	1.19	2.42	1992	24	9.86	1972	.00	1999	5.7	3.6	1.3	.4	.03	.12	.35	.61	.91	1.28	1.73	2.32	3.16	4.60	6.05
Nov	1.86	1.27	3.21	1978	11	6.64	1985	.00+	1999	5.1	3.5	1.2	.4	.00	.00	.39	.71	1.03	1.39	1.82	2.34	3.04	4.21	5.35
Dec	1.83	1.28	2.95	1951	30	6.78	1992	.00	1999	6.6	4.1	.9	.3	.05	.16	.40	.66	.95	1.29	1.70	2.22	2.95	4.19	5.41
Ann	22.91	21.76	3.93	Feb 1993	19	10.05	Feb 1993	.00+	Dec 1999	88.6	50.9	13.5	3.7	13.35	15.06	17.33	19.11	20.72	22.30	23.96	25.83	28.14	31.56	34.57

+ Also occurred on an earlier date(s)
# Denotes amounts of a trace
@ Denotes mean number of days greater than 0 but less than .05
** Statistics not computed because less than six years out of thirty had measurable precipitation

(1) From the 1971-2000 Monthly Normals
(2) Derived from station's available digital record: 1950-2001
(3) Derived from 1971-2000 serially complete daily data
Complete documentation available from:
www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

035-B

Table A–6. Weather Data for 1-Flagstaff Area — Snow

(U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000)

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data,
and Information Services

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: FLAGSTAFF PULLIAM AP, AZ **COOP ID: 023010**

Climate Division: AZ 2 **NWS Call Sign: FLG** **Elevation: 7,003 Feet** **Lat: 35°08N** **Lon: 111°40W**

Snow (inches)																							
Snow Totals															Mean Number of Days (1)								
Means/Medians (1)					Extremes (2)										Snow Fall >= Thresholds					Snow Depth >= Thresholds			
Month	Snow Fall Mean	Snow Fall Median	Snow Depth Mean	Snow Depth Median	Highest Daily Snow Fall	Year	Day	Highest Monthly Snow Fall	Year	Highest Daily Snow Depth	Year	Day	Highest Monthly Mean Snow Depth	Year	0.1	1.0	3.0	5.0	10.0	1	3	5	10
Jan	23.0	21.1	4	3	15.6	1982	21	63.4	1980	34+	1979	30	12	1979	7.4	4.8	2.9	1.9	.3	19.0	15.5	12.1	5.2
Feb	22.2	23.0	5	3	21.1	1987	24	45.5	1990	40+	1979	3	22	1979	7.3	4.7	2.6	1.4	.3	17.4	13.6	10.9	6.1
Mar	25.4	23.7	3	1	18.1	1991	1	79.4	1991	36+	1973	30	21	1973	8.3	5.7	3.2	1.5	.4	10.7	7.7	5.5	2.5
Apr	10.1	5.3	1	1	11.1	1988	21	33.1	1988	31	1973	1	9	1973	3.9	2.3	1.2	.7	.2	3.5	2.1	1.5	.8
May	1.3	.4	#	0	4.7	1975	21	8.2	1975	4	1975	21	#	1994	1.1	.5	.1	.0	.0	.2	@	.0	.0
Jun	#	.0	#	0	#	1993	6	#+	1993	0	0	0	#	1979	.0	.0	.0	.0	.0	.0	.0	.0	.0
Jul	.0	.0	#	0	.0	0	0	.0	0	0	0	0	#	1985	.0	.0	.0	.0	.0	.0	.0	.0	.0
Aug	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Sep	.0	.0	0	0	.9	1986	24	.9	1986	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Oct	3.1	.0	#	0	9.5	1974	30	24.7	1971	11+	1974	30	1+	1974	1.2	.6	.3	.3	.0	.8	.5	.3	.1
Nov	13.8	9.6	1	1	18.4	1985	12	40.7	1985	23	1975	30	4	1973	3.8	2.7	1.5	1.0	.4	5.6	4.1	2.9	.9
Dec	15.8	15.6	3	2	14.6	1992	4	41.7	1992	22	1975	1	11	1992	6.2	4.0	1.7	.9	.2	13.5	10.8	7.6	2.5
Ann	114.7	98.7	N/A	N/A	21.1	Feb 1987	24	79.4	Mar 1991	40+	Feb 1979	3	22	Feb 1979	39.2	25.3	13.5	7.7	1.8	70.7	54.3	40.8	18.1

+ Also occurred on an earlier date(s) #Denotes trace amounts

@ Denotes mean number of days greater than 0 but less than .05

-9/-9.9 represents missing values
Annual statistics for Mean/Median snow depths are not appropriate

(1) Derived from Snow Climatology and 1971-2000 daily data

(2) Derived from 1971-2000 daily data

Complete documentation available from:
www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

035-C

Table A–7. Weather Data for 1-Flagstaff Area — Freeze Data
(U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000)

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: FLAGSTAFF PULLIAM AP, AZ **COOP ID: 023010**

Climate Division: AZ 2 **NWS Call Sign: FLG** **Elevation: 7,003 Feet** **Lat: 35°08N** **Lon: 111°40W**

Freeze Data									
Spring Freeze Dates (Month/Day)									
Temp (F)	Probability of later date in spring (thru Jul 31) than indicated(*)								
	.10	.20	.30	.40	.50	.60	.70	.80	.90
36	7/07	7/02	6/28	6/25	6/22	6/19	6/16	6/12	6/07
32	6/23	6/18	6/15	6/12	6/09	6/07	6/04	6/01	5/27
28	6/17	6/10	6/06	6/02	5/29	5/25	5/22	5/17	5/11
24	5/31	5/23	5/18	5/13	5/09	5/05	4/30	4/25	4/17
20	5/12	5/04	4/29	4/24	4/20	4/15	4/10	4/05	3/28
16	4/24	4/17	4/12	4/08	4/04	3/31	3/27	3/22	3/15
Fall Freeze Dates (Month/Day)									
Temp (F)	Probability of earlier date in fall (beginning Aug 1) than indicated(*)								
	.10	.20	.30	.40	.50	.60	.70	.80	.90
36	8/24	8/30	9/03	9/07	9/11	9/14	9/18	9/23	9/29
32	9/11	9/15	9/18	9/20	9/22	9/25	9/27	9/30	10/04
28	9/24	9/29	10/02	10/05	10/08	10/11	10/14	10/17	10/22
24	10/02	10/08	10/12	10/15	10/18	10/21	10/25	10/29	11/03
20	10/14	10/19	10/22	10/25	10/28	10/31	11/03	11/07	11/12
16	10/22	10/28	11/01	11/05	11/08	11/11	11/15	11/19	11/25
Freeze Free Period									
Temp (F)	Probability of longer than indicated freeze free period (Days)								
	.10	.20	.30	.40	.50	.60	.70	.80	.90
36	106	97	91	85	80	75	70	63	54
32	120	114	111	107	104	101	98	94	89
28	155	147	141	136	131	126	121	115	107
24	189	180	173	167	161	156	150	143	133
20	220	210	203	197	191	185	179	172	162
16	247	237	229	223	217	211	205	197	187

* Probability of observing a temperature as cold, or colder, later in the spring or earlier in the fall than the indicated date.

0/00 Indicates that the probability of occurrence of threshold temperature is less than the indicated probability.

Derived from 1971-2000 serially complete daily data

Complete documentation available from: www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

035-D

Life365 v2.0 - Life-Cycle Costs

Project: SPR-673-Flagstaff

Description: Flagstaff area, (1 of 5)

Analyst: Tarif Jaber

Date: 04/15/2011

Life-Cycle Costs

Name	Construction Cost	Barrier Cost	Repair Cost	Life-Cycle Cost
Base case	$3.72 per sq. ft	$0.00 per sq. ft	$19.03 per sq. ft	$22.75 per sq. ft
Alt-1 FA	$3.85 per sq. ft	$0.00 per sq. ft	$18.37 per sq. ft	$22.21 per sq. ft
Alt-2 ES	$4.30 per sq. ft	$0.00 per sq. ft	$15.07 per sq. ft	$19.38 per sq. ft
Alt-3 FA+ES	$4.43 per sq. ft	$0.00 per sq. ft	$14.55 per sq. ft	$18.98 per sq. ft
Alt-4 FA+ES+SF	$4.80 per sq. ft	$0.00 per sq. ft	$7.82 per sq. ft	$12.62 per sq. ft
Alt-5 FA+SS+SF	$14.07 per sq. ft	$0.00 per sq. ft	$0.00 per sq. ft	$14.07 per sq. ft

Graphs

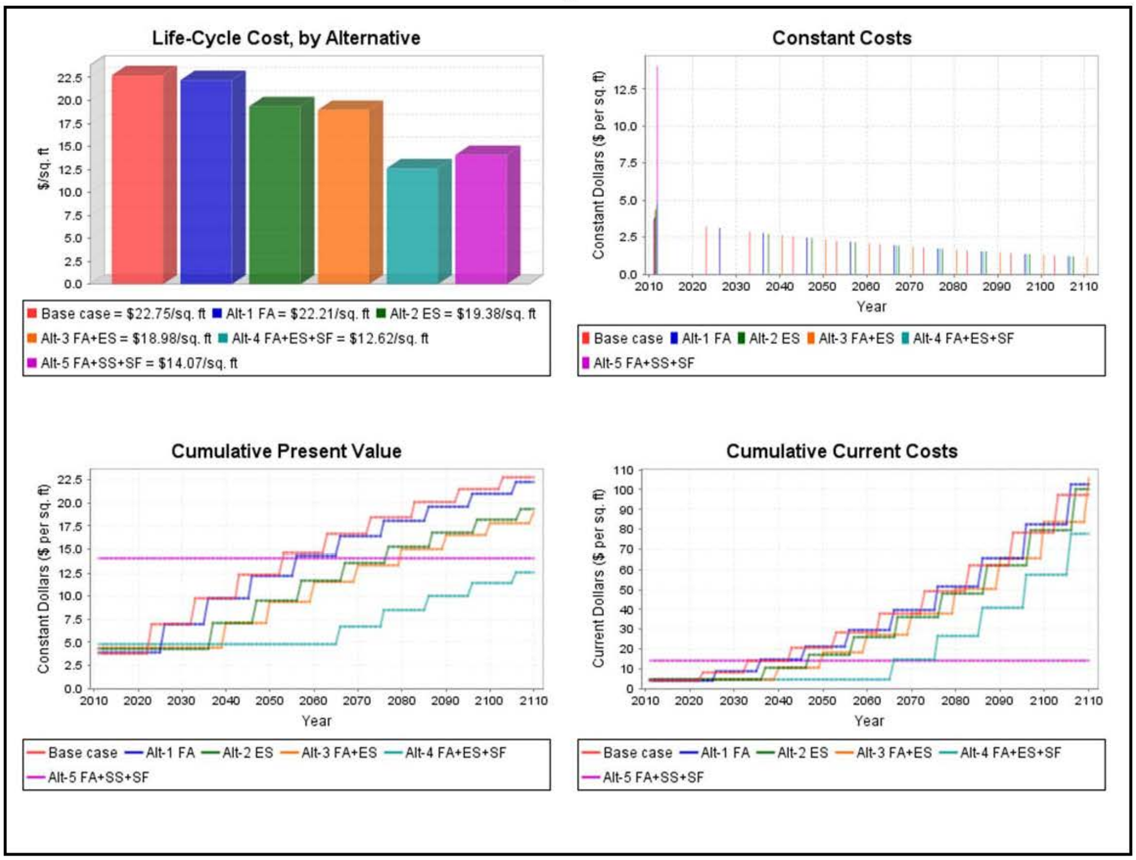


Figure A-1. Flagstaff, Life-Cycle Costs

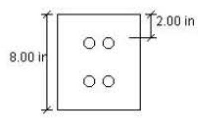
Life365 v2.0 - Concrete Mixes and Service Lives

Project: SPR-673-Flagstaff

Description: Flagstaff area, (1 of 5)

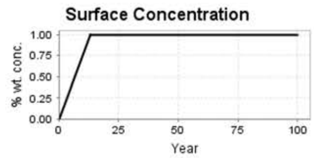
Analyst: Tarif Jaber

Date: 04/15/2011



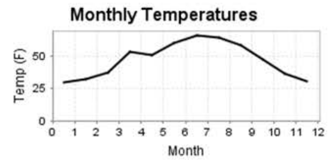
slabs and walls (1-D)

Outer dim: 8in; clear cover: 2in



Max surface: 1

Years to buildup: 13



Loc: user-defined

Type: user-defined

Concrete Mixes

Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
Base case		0.5				Black Steel
Alt-1 FA		0.5	Class F Fly Ash (20%);			Black Steel
Alt-2 ES		0.5				Epoxy Coated
Alt-3 FA+ES		0.5	Class F Fly Ash (20%);			Epoxy Coated
Alt-4 FA+ES+SF		0.4	Class F Fly Ash (20%); Silica Fume (6%);			Epoxy Coated
Alt-5 FA+SS+SF		0.4	Class F Fly Ash (20%); Silica Fume (6%);			316 Stainless

"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
Base case	2.14E-8 in*in/sec	0.2	0.05 % wt. conc.	6 yrs	6 yrs	**12 yrs**
Alt-1 FA	2.14E-8 in*in/sec	0.36	0.05 % wt. conc.	9.2 yrs	6 yrs	**15.2 yrs**
Alt-2 ES	2.14E-8 in*in/sec	0.2	0.05 % wt. conc.	6 yrs	20 yrs	**26 yrs**
Alt-3 FA+ES	2.14E-8 in*in/sec	0.36	0.05 % wt. conc.	9.2 yrs	20 yrs	**29.2 yrs**
Alt-4 FA+ES+SF	4.57E-9 in*in/sec	0.36	0.05 % wt. conc.	35.5 yrs	20 yrs	**55.5 yrs**
Alt-5 FA+SS+SF	4.57E-9 in*in/sec	0.36	0.5 % wt. conc.	100+ yrs	6 yrs	**106+ yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.

Figure A-2. Flagstaff, Concrete Mixes and Service Lives

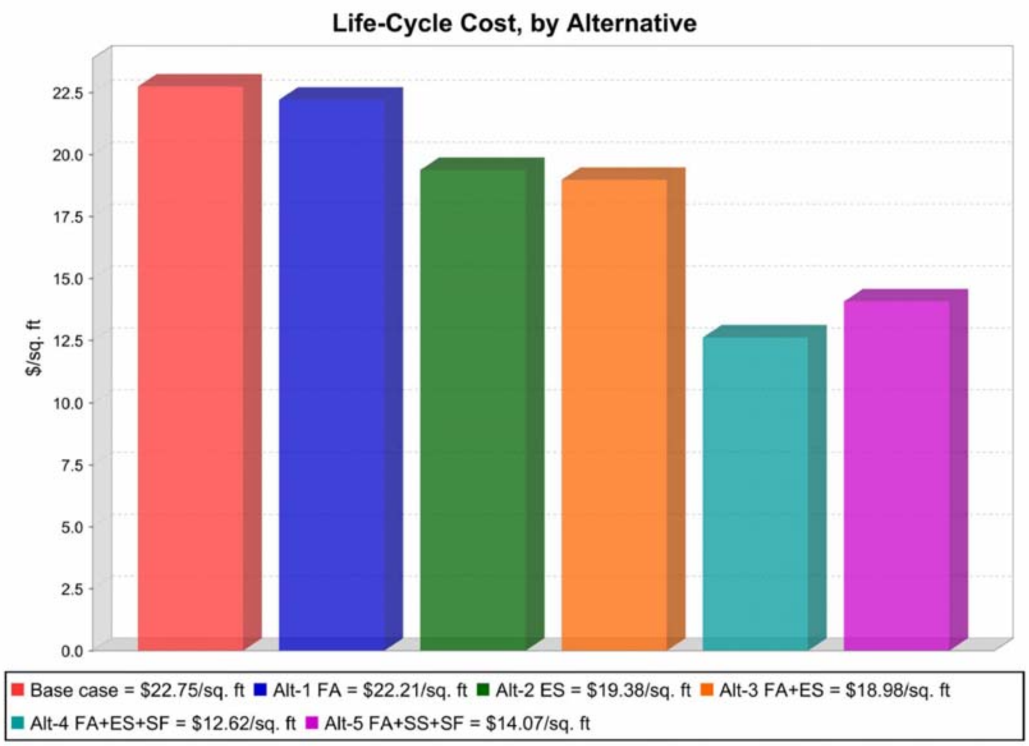


Figure A-3. Flagstaff, Life-Cycle Cost By Alternative

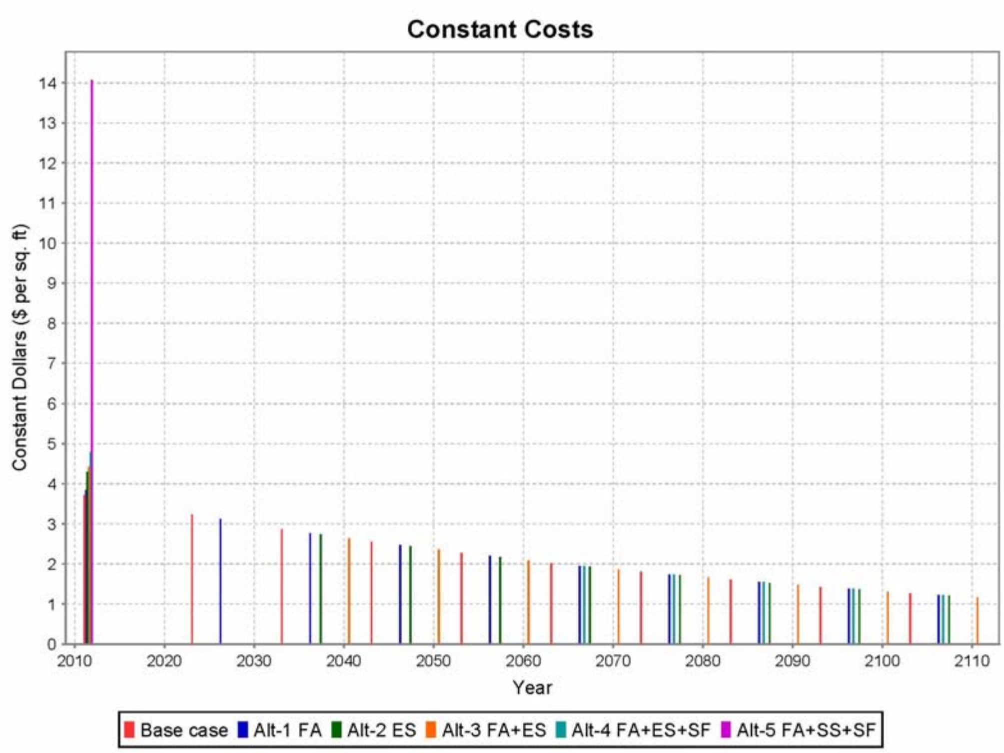


Figure A-4. Flagstaff, Constant Costs

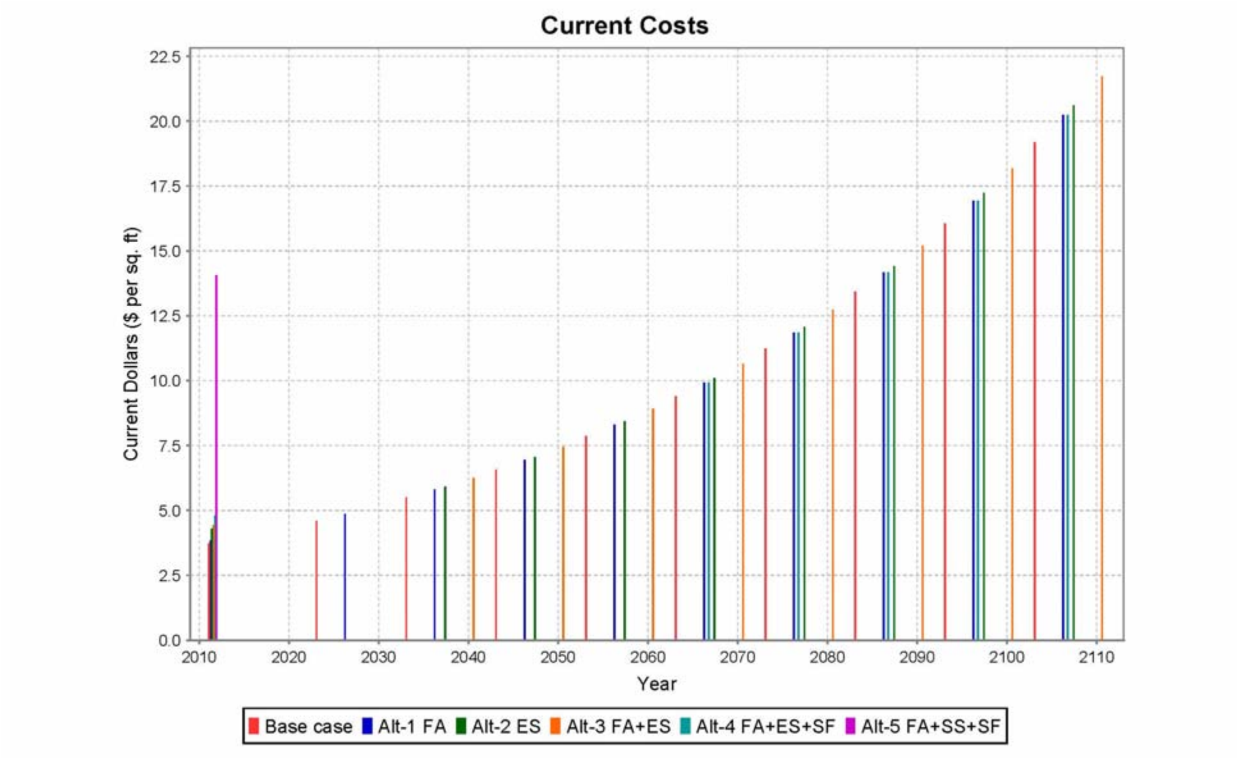


Figure A-5. Flagstaff, Current Costs

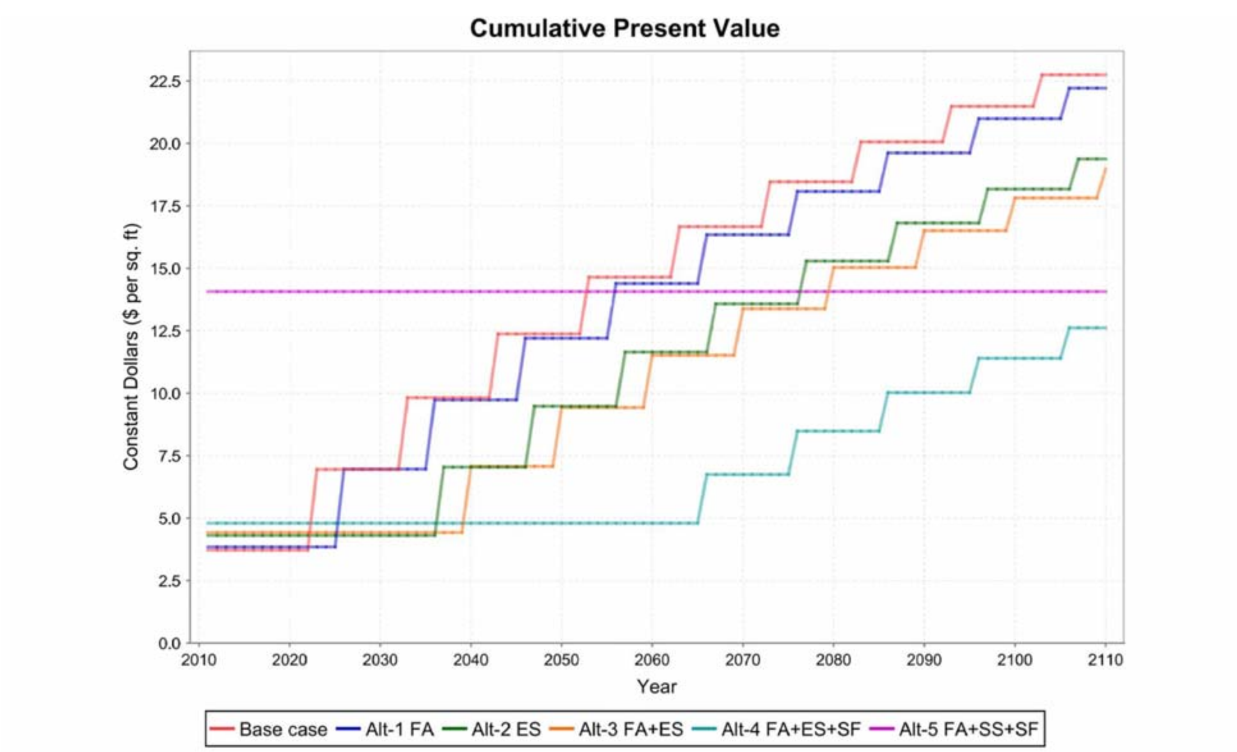


Figure A-6. Flagstaff, Cumulative Present Value

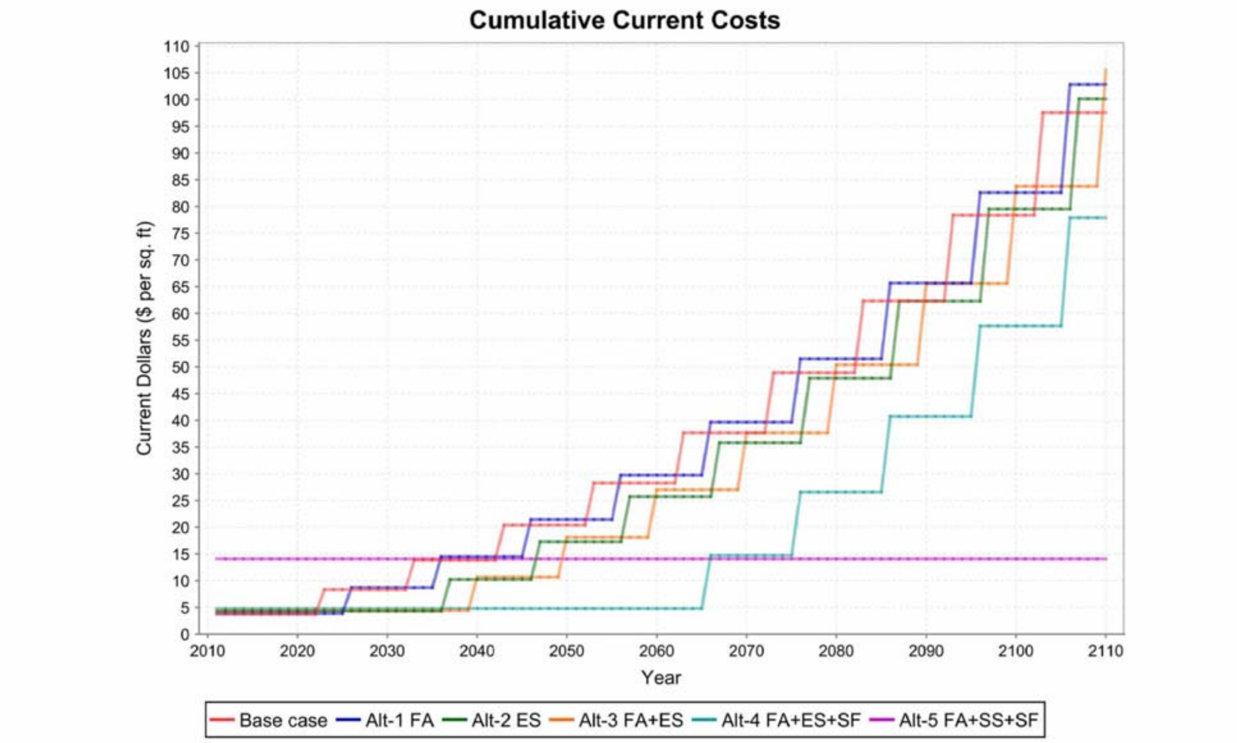


Figure A-7. Flagstaff, Cumulative Current Costs

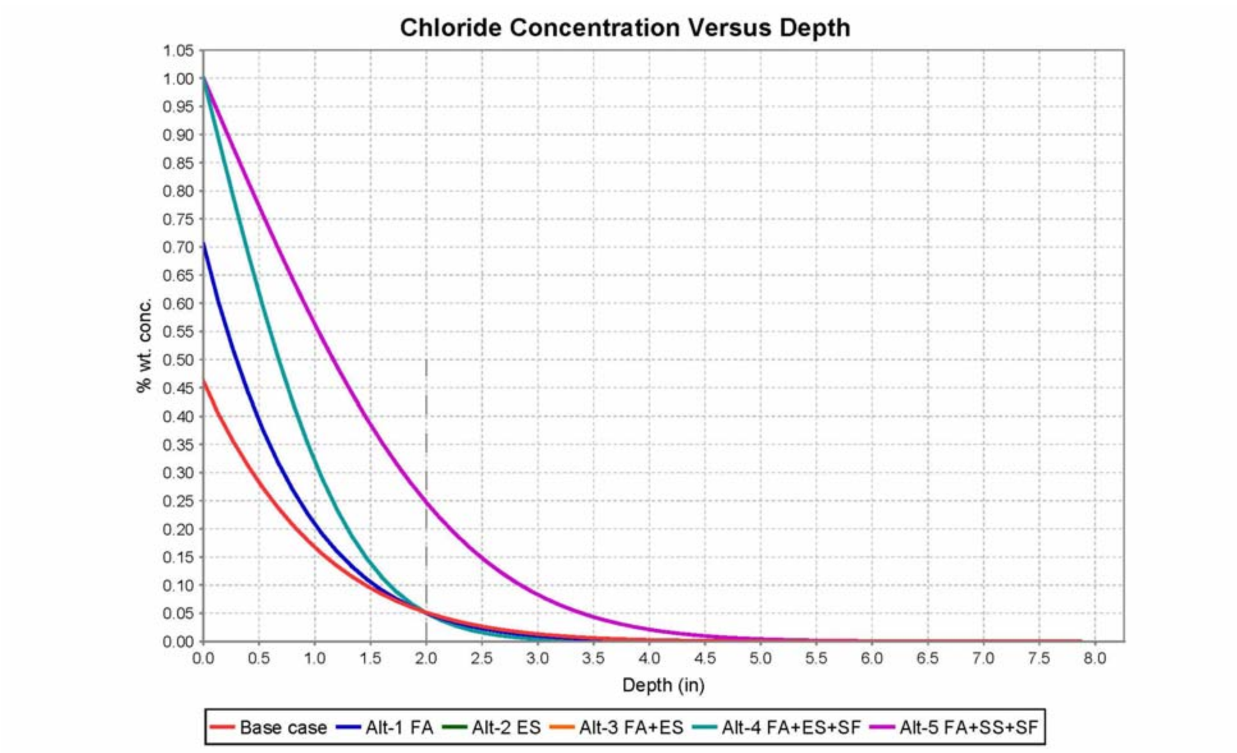


Figure A-8. Flagstaff, Chloride Concentration Versus Depth

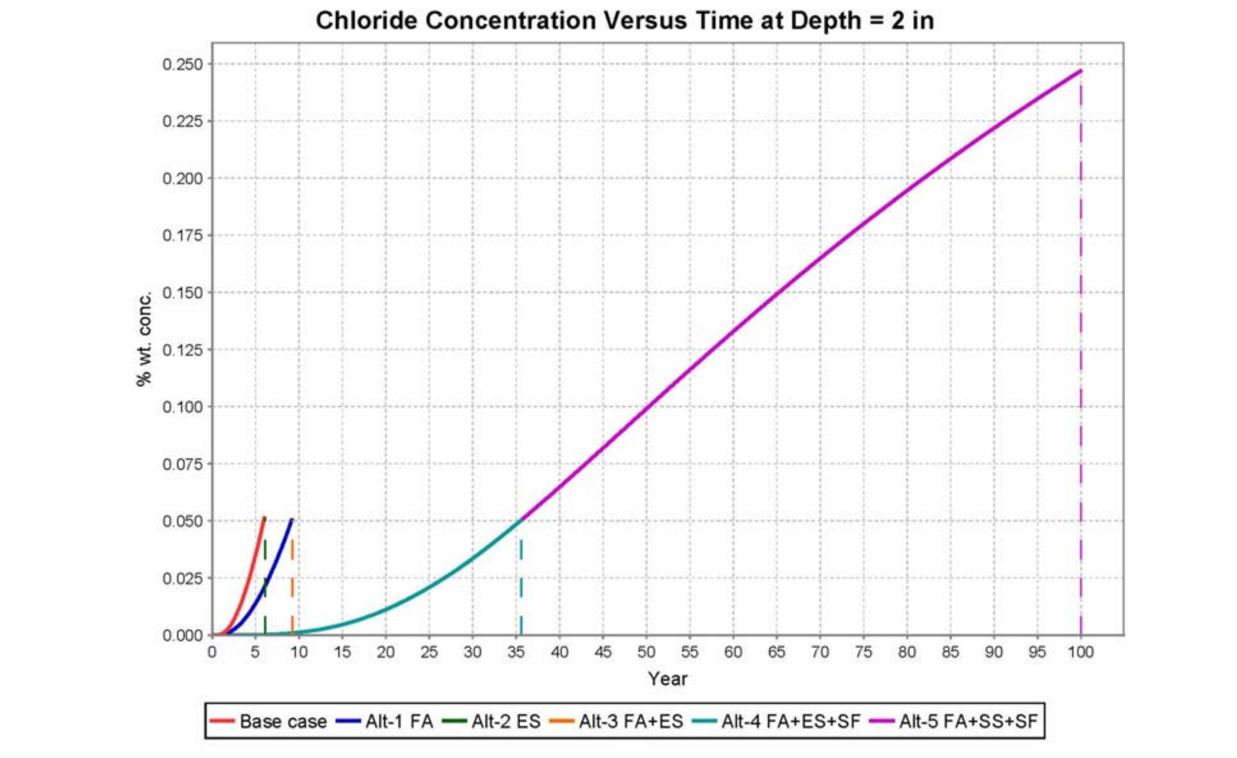


Figure A-9. Flagstaff, Chloride Concentration Versus Time at Depth = 2 in

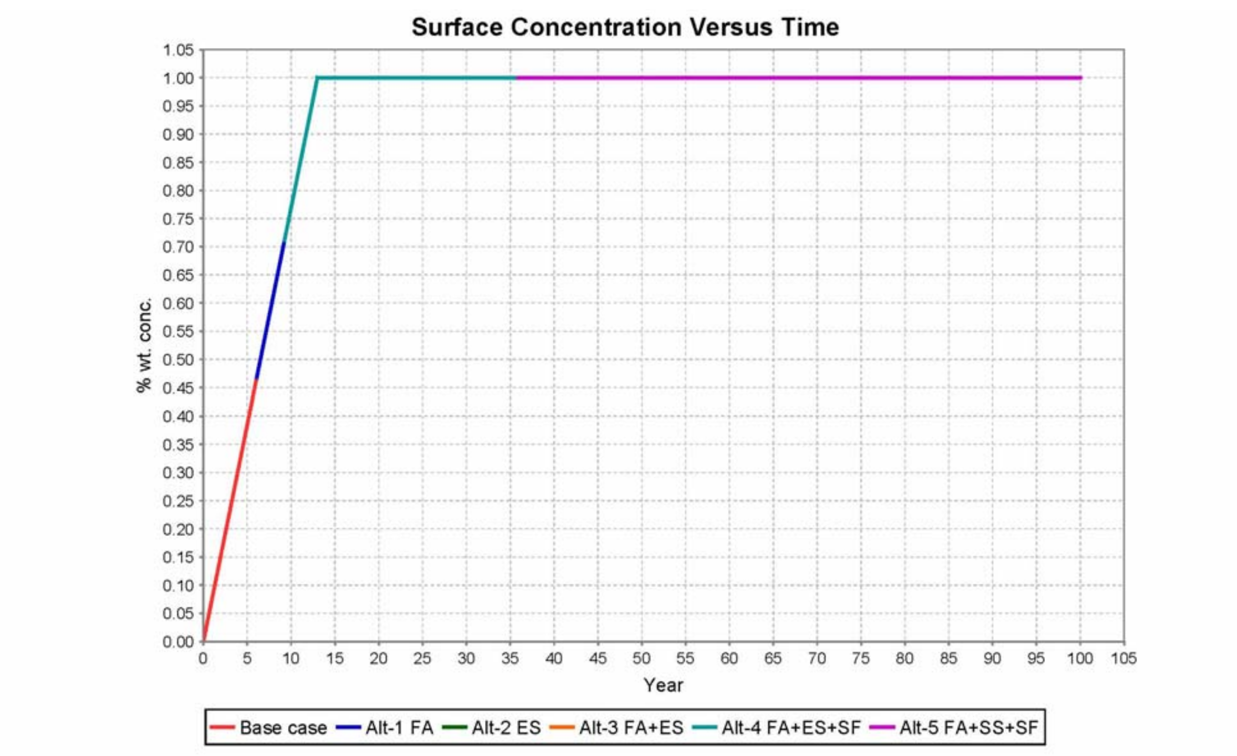


Figure A-10. Flagstaff, Surface Concentration Versus Time

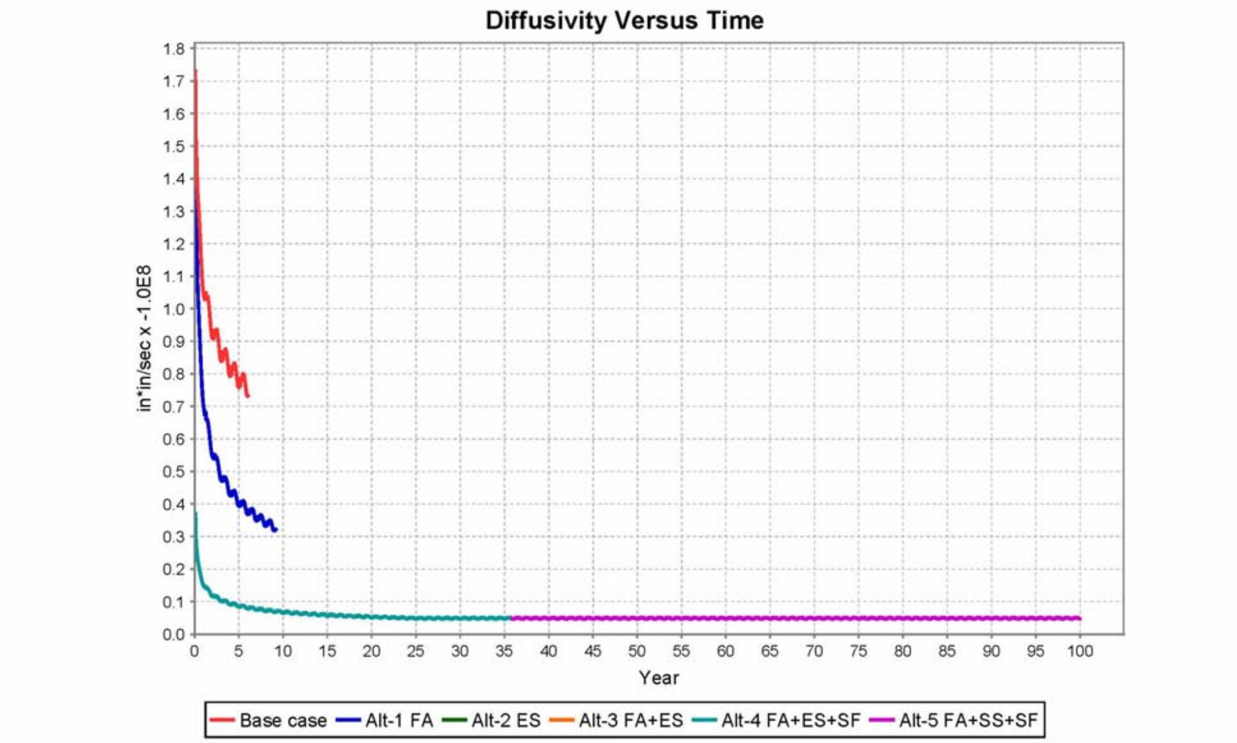


Figure A-11. Flagstaff, Diffusivity Versus Time

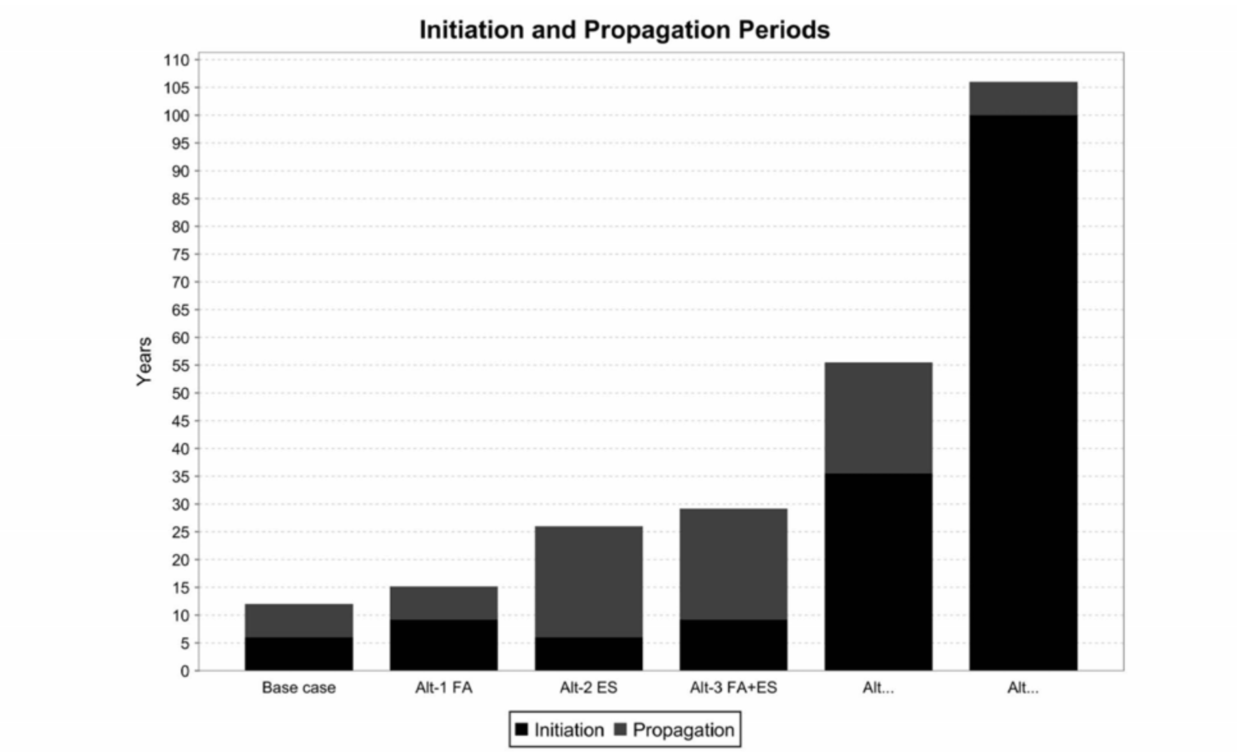


Figure A-12. Flagstaff, Initiation and Propagation Periods

SAFFORD AREA LIFE-CYCLE COST ANALYSIS

Table A-8. Life-Cycle Cost Analysis – Safford Area

ALTERNATIVE	BASE	Alternative-1 Base Plus Fly Ash Alt-1 (FA)	Alternative-2 Base Plus Epoxy Steel Alt-2 (ES)	Alternative-3 Base with Fly Ash and Epoxy Steel Alt-3 (FA+ES)	Alternative-4 HPC with Fly Ash, Epoxy Steel and Silica Fume Alt-4 (FA+ES+SF)	Alternative-5 HPC with Fly Ash, Stainless Steel and Silica Fume Alt-5 (FA+SS+SF)
Variable Data						
Concrete Mix and Materials						
Type	Class S ADOT	Class S ADOT	Class S ADOT	Class S ADOT	HPC	HPC
Water Cement Ratio (%)	0.50	0.50	0.50	0.50	0.40	0.40
Fly Ash (% of Cementitious)	-	20%	0%	20%	20%	20%
Silica Fume (% of Cement)	-	-	-	-	6%	6%
Concrete ($/cy)	$80.00	$85.00	$80.00	$85.00	$100.00	$100.00
Reinforcement						
Black Steel	YES	YES	-	-	-	-
Epoxy Steel	-	-	YES	YES	YES	-
Stainless Steel	-	-	-	-	-	YES

Fixed Data, All Alternatives	
Structural Data	
Bridge Element	Bridge Deck
Lane Width (ft)	50
Length (ft)	200
Analysis Area (sq. ft)	10,000
Slab Thickness (in)	8
Rein. Depth (in)	2
Rein. Percent of Concrete Volume (%)	1.20%
Repair	
Cost ($/sq. ft)	$37.16
Area to be repaired (%)	10%
Repair interval (yrs)	10
Material Cost	
Black Steel ($/lb)	$0.45
Epoxy-coated Steel ($/lb)	$0.60
Stainless Steel 316 ($/lb)	$3.00
Financial Parameters	
Base year	2011
Analysis Period (yrs)	100
Inflation Rate (%)	1.80%
Discount Rate (%)	3.00%

Table A-9. Environmental Data - Safford Area

Environmental Data	
Chloride Exposure	
Max. Surface Content. (% by wt. conc.)	1
Time to build to max (yrs)	40
Temperature History	
Month	**Mean Temperature (^{o}F)**
January	44.6
February	49.0
March	54.5
April	61.4
May	70.1
June	79.5
July	83.2
August	81.3
September	75.7
October	64.7
November	52.1
December	44.4

Table A-10. Salt Load Calculations - Safford Area

Salt Applications	**Area**
	2-Safford
Salt Data	
Rate of Application (tons per mile)	150
No of Applications per year	2
Annual Salt Application (tons per mile)	300
Annual Salt Application (pounds per feet)	125
Annual Salt Application (% of concrete weight)	3%
Years to reach threshold	40
Fixed Assumptions for all areas	
Bridge Element	Bridge Deck
Lane Width (ft)	50
Slab Thickness (in)	8
Salt Analysis Area (sq. ft)	1
Concrete Weight (pcf)	150
Analyzed area weight (psf)	100
Concrete Concentration (% of weight of concrete)	1

Table A-11. Weather Data for-Safford Area

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data,
and Information Service

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: SAFFORD AGRICULTRL CTR, AZ **COOP ID: 027390**

Climate Division: AZ 7 **NWS Call Sign: E74** **Elevation: 2,954 Feet** **Lat: 32°49N** **Lon: 109°41W**

Temperature (°F)																					
Mean (1)				Extremes										Degree Days (1) Base Temp 65		Mean Number of Days (3)					
Month	Daily Max	Daily Min	Mean	Highest Daily(2)	Year	Day	Highest Month(1) Mean	Year	Lowest Daily(2)	Year	Day	Lowest Month(1) Mean	Year	Heating	Cooling	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
Jan	60.2	29.0	44.6	79+	1999	26	48.5	1986	9+	1964	12	41.9	1973	633	0	.0	.0	28.3	.0	22.0	.0
Feb	65.3	32.7	49.0	87	1957	15	54.3	1996	9	1955	5	44.5	1974	449	0	.0	.0	27.1	.2	14.4	.0
Mar	71.2	37.7	54.5	92+	1989	12	60.8	1972	16	1965	4	49.6	1973	334	7	.0	.2	30.7	.0	6.1	.0
Apr	79.6	43.1	61.4	100	2000	28	67.7	1989	26+	1977	4	55.2	1975	159	48	@	2.9	29.9	.0	1.8	.0
May	88.7	51.5	70.1	108	2000	30	76.2	2000	28	1967	1	65.7	1975	29	188	1.5	15.0	31.0	.0	@	.0
Jun	98.3	60.7	79.5	114	1994	30	84.5	1994	39	1955	3	75.7	1991	0	435	13.4	27.8	30.0	.0	.0	.0
Jul	98.4	67.9	83.2	113	1995	29	86.6	1971	48+	1954	10	80.2	1986	0	562	14.4	29.0	31.0	.0	.0	.0
Aug	96.1	66.4	81.3	108+	1995	6	84.3	1995	47	1956	31	78.3	1990	0	504	7.2	28.0	31.0	.0	.0	.0
Sep	92.1	59.3	75.7	107+	1950	1	80.5	1997	37	1965	30	72.8	1985	1	322	2.3	21.6	30.0	.0	.0	.0
Oct	82.1	47.2	64.7	100+	2000	2	68.3	1988	23	1971	30	60.6	1976	85	75	.1	6.3	30.9	.0	.9	.0
Nov	69.2	34.9	52.1	89	2001	4	57.6	1999	15+	1992	26	47.4	2000	390	1	.0	.0	29.6	.0	9.9	.0
Dec	60.2	28.6	44.4	78+	1980	28	48.8	1980	7	1974	24	40.7	1974	638	0	.0	.0	27.9	.0	23.2	.0
Ann	80.1	46.6	63.4	114	Jun 1994	30	86.6	Jul 1971	7	Dec 1974	24	40.7	Dec 1974	2718	2142	38.9	130.8	357.4	.2	78.3	.0

+ Also occurred on an earlier date(s)

@ Denotes mean number of days greater than 0 but less than .05

Complete documentation available from: www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

Issue Date: February 2004 075-A

(1) From the 1971-2000 Monthly Normals

(2) Derived from station's available digital record: 1948-2001

(3) Derived from 1971-2000 serially complete daily data

Source: U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000

Table A–8. Weather Data for-Safford Area (Continued)

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data,
and Information Service

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: SAFFORD AGRICULTRL CTR, AZ **COOP ID: 027390**

Climate Division: AZ 7 **NWS Call Sign: E74** **Elevation: 2,954 Feet** **Lat: 32°49N** **Lon: 109°41W**

Precipitation (inches)

	Precipitation Totals									Mean Number of Days (3)				Precipitation Probabilities (1) Probability that the monthly/annual precipitation will be equal to or less than the indicated amount										
	Means/ Medians(1)		Extremes							Daily Precipitation				Monthly/Annual Precipitation vs Probability Levels These values were determined from the incomplete gamma distribution										
Month	Mean	Med-ian	Highest Daily(2)	Year	Day	Highest Monthly(1)	Year	Lowest Monthly(1)	Year	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.05	.10	.20	.30	.40	.50	.60	.70	.80	.90	.95
Jan	.74	.46	1.42	1979	18	3.10	1993	.00+	1999	5.0	2.3	.1	.1	.00	.03	.12	.23	.35	.50	.67	.90	1.22	1.77	2.33
Feb	.78	.69	1.23	1988	5	2.64	1980	.00+	1999	4.8	2.3	.4	.1	.00	.00	.08	.21	.35	.51	.71	.96	1.32	1.92	2.52
Mar	.61	.41	.97	1951	27	1.71	1991	.00+	1996	4.5	2.1	.2	.0	.00	.00	.08	.19	.30	.43	.57	.76	1.02	1.43	1.85
Apr	.22	.10	.91	2001	6	1.43	1988	.00+	2000	2.1	.6	.1	.0	.00	.00	.00	.03	.07	.12	.18	.27	.39	.60	.81
May	.27	.10	.77	1984	16	2.28	1992	.00+	2000	2.2	.8	.1	.0	.00	.00	.00	.00	.02	.10	.19	.32	.50	.80	1.10
Jun	.31	.21	1.12	1996	30	1.42	1996	.00+	1998	2.2	1.0	.1	@	.00	.00	.00	.02	.07	.13	.22	.35	.53	.86	1.20
Jul	1.45	1.40	1.76	1966	29	3.24+	1984	.25	1995	7.8	3.8	.8	.1	.33	.47	.68	.87	1.06	1.26	1.49	1.76	2.11	2.67	3.20
Aug	1.72	1.62	2.25	1963	31	4.34	1992	.06	1975	8.0	3.7	.9	.3	.26	.40	.65	.89	1.14	1.41	1.72	2.10	2.62	3.45	4.26
Sep	1.12	.80	2.13	1983	30	3.77	1983	.03	2000	5.3	2.5	.6	.2	.06	.13	.26	.41	.59	.79	1.04	1.35	1.80	2.56	3.32
Oct	1.10	.75	2.51	1983	2	4.39	2000	.00+	1995	4.4	2.5	.7	.2	.00	.00	.13	.29	.47	.70	.97	1.33	1.83	2.71	3.59
Nov	.56	.38	1.52	1994	12	2.39	1986	.00+	1999	3.5	1.5	.2	.1	.00	.04	.13	.21	.31	.41	.53	.69	.90	1.25	1.60
Dec	.91	.46	1.83	1991	21	4.14	1991	.00+	1999	5.1	2.4	.4	.1	.00	.00	.05	.15	.30	.49	.73	1.06	1.55	2.39	3.26
Ann	9.79	9.40	2.51	Oct 1983	2	4.39	Oct 2000	.00+	May 2000	54.9	25.5	4.6	1.2	5.49	6.24	7.25	8.05	8.77	9.49	10.24	11.09	12.14	13.71	15.09

+ Also occurred on an earlier date(s)
# Denotes amounts of a trace
@ Denotes mean number of days greater than 0 but less than .05
** Statistics not computed because less than six years out of thirty had measurable precipitation

(1) From the 1971-2000 Monthly Normals
(2) Derived from station's available digital record: 1948-2001
(3) Derived from 1971-2000 serially complete daily data
Complete documentation available from:
www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

075-B

Source: U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000

Table A–8. Weather Data for-Safford Area (Continued)

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data,
and Information Services

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: SAFFORD AGRICULTRL CTR, AZ **COOP ID: 027390**

Climate Division: AZ 7 **NWS Call Sign: E74** **Elevation: 2,954 Feet** **Lat: 32°49N** **Lon: 109°41W**

Snow (inches)																							
	Snow Totals														Mean Number of Days (1)								
	Means/Medians (1)				Extremes (2)										Snow Fall >= Thresholds					Snow Depth >= Thresholds			
Month	Snow Fall Mean	Snow Fall Median	Snow Depth Mean	Snow Depth Median	Highest Daily Snow Fall	Year	Day	Highest Monthly Snow Fall	Year	Highest Daily Snow Depth	Year	Day	Highest Monthly Mean Snow Depth	Year	0.1	1.0	3.0	5.0	10.0	1	3	5	10
Jan	.3	.0	#	0	3.0	1997	14	5.0	1997	1	1979	29	#	1979	.3	.2	@	.0	.0	@	.0	.0	.0
Feb	.2	.0	#	0	2.0	1971	21	2.5	1971	1	1971	20	#	1971	.2	.1	.0	.0	.0	@	.0	.0	.0
Mar	.0	.0	0	0	.5	1976	4	.5	1976	#	1976	4	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Apr	.1	.0	#	0	2.0	1976	16	2.5	1976	2	1976	16	#	1976	.1	.0	.0	.0	.0	@	.0	.0	.0
May	.0	.0	#	0	.0	0	0	.0	0	0	0	0	#	1997	.0	.0	.0	.0	.0	.0	.0	.0	.0
Jun	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Jul	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Aug	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Sep	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Oct	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Nov	#	.0	0	0	#	1976	13	#	1976	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Dec	.2	.0	0	0	1.5	1987	25	2.5	1990	#+	1985	12	0	0	.3	.1	.0	.0	.0	.0	.0	.0	.0
Ann	.8	.0	N/A	N/A	3.0	Jan 1997	14	5.0	Jan 1997	2	Apr 1976	16	#+	May 1997	.9	.4	@	.0	.0	.0	.0	.0	.0

+ Also occurred on an earlier date(s) #Denotes trace amounts

@ Denotes mean number of days greater than 0 but less than .05

-9/-9.9 represents missing values
Annual statistics for Mean/Median snow depths are not appropriate

(1) Derived from Snow Climatology and 1971-2000 daily data

(2) Derived from 1971-2000 daily data

Complete documentation available from:
www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

075-C

Source: U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000

Table A–8. Weather Data for-Safford Area (Continued)

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data,
and Information Service

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
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Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: SAFFORD AGRICULTRL CTR, AZ **COOP ID: 027390**

Climate Division: AZ 7 **NWS Call Sign: E74** **Elevation: 2,954 Feet** **Lat: 32°49N** **Lon: 109°41W**

Freeze Data

Spring Freeze Dates (Month/Day)

Temp (F)	Probability of later date in spring (thru Jul 31) than indicated(*)								
	.10	.20	.30	.40	.50	.60	.70	.80	.90
36	5/08	5/02	4/28	4/24	4/21	4/17	4/14	4/09	4/04
32	4/25	4/18	4/12	4/08	4/03	3/30	3/25	3/20	3/12
28	4/09	4/01	3/26	3/21	3/16	3/11	3/06	2/28	2/19
24	3/13	3/04	2/25	2/19	2/14	2/09	2/03	1/27	1/18
20	2/26	2/13	2/04	1/26	1/18	1/10	1/01	12/21	11/29
16	1/22	1/08	12/27	12/14	11/23	0/00	0/00	0/00	0/00

Fall Freeze Dates (Month/Day)

Temp (F)	Probability of earlier date in fall (beginning Aug 1) than indicated(*)								
	.10	.20	.30	.40	.50	.60	.70	.80	.90
36	10/12	10/17	10/20	10/23	10/25	10/28	10/31	11/03	11/08
32	10/24	10/28	10/31	11/02	11/05	11/07	11/10	11/13	11/17
28	11/02	11/06	11/09	11/12	11/15	11/17	11/20	11/23	11/28
24	11/12	11/18	11/21	11/25	11/28	12/01	12/04	12/08	12/14
20	11/22	12/01	12/07	12/13	12/19	12/24	12/30	1/07	1/22
16	12/07	12/18	12/29	1/09	0/00	0/00	0/00	0/00	0/00

Freeze Free Period

Temp (F)	Probability of longer than indicated freeze free period (Days)								
	.10	.20	.30	.40	.50	.60	.70	.80	.90
36	210	202	196	192	187	183	178	172	165
32	239	231	225	220	215	210	205	198	190
28	274	263	256	249	243	237	231	223	212
24	317	307	299	292	286	280	273	266	255
20	>365	>365	347	334	325	318	311	303	292
16	>365	>365	>365	>365	>365	>365	>365	>365	344

* Probability of observing a temperature as cold, or colder, later in the spring or earlier in the fall than the indicated date.

0/00 Indicates that the probability of occurrence of threshold temperature is less than the indicated probability.

Derived from 1971-2000 serially complete daily data

Complete documentation available from:
www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

075-D

Source: U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000

Life365 v2.0 - Life-Cycle Costs

Project: SPR-673-Safford

Description: Safford area, (2 of 5)

Analyst: Tarif Jaber

Date: 04/15/2011

Life-Cycle Costs

Name	Construction Cost	Barrier Cost	Repair Cost	Life-Cycle Cost
Base case	$3.72 per sq. ft	$0.00 per sq. ft	$18.16 per sq. ft	$21.88 per sq. ft
Alt-1 FA	$3.85 per sq. ft	$0.00 per sq. ft	$15.80 per sq. ft	$19.64 per sq. ft
Alt-2 ES	$4.30 per sq. ft	$0.00 per sq. ft	$13.23 per sq. ft	$17.54 per sq. ft
Alt-3 FA+ES	$4.43 per sq. ft	$0.00 per sq. ft	$12.33 per sq. ft	$16.76 per sq. ft
Alt-4 FA+ES+SF	$4.80 per sq. ft	$0.00 per sq. ft	$5.60 per sq. ft	$10.40 per sq. ft
Alt-5 FA+SS+SF	$14.11 per sq. ft	$0.00 per sq. ft	$0.00 per sq. ft	$14.11 per sq. ft

Graphs

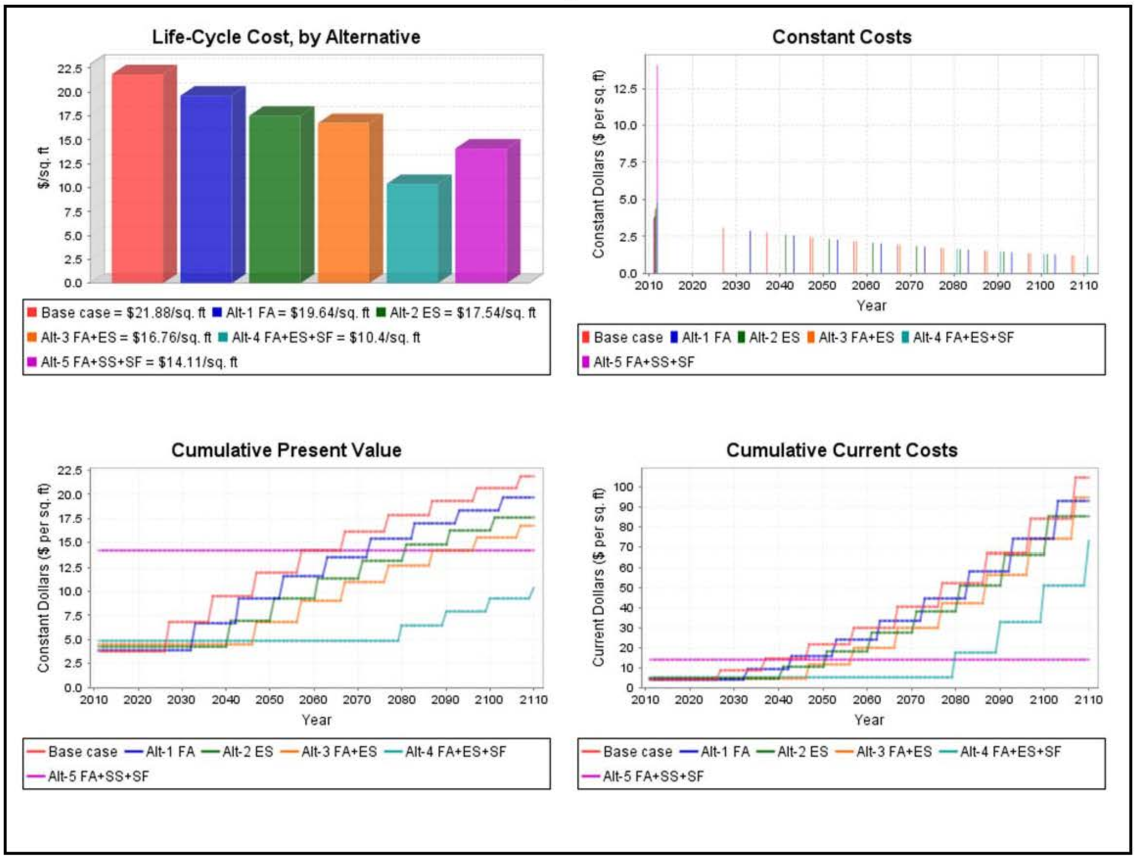


Figure A-13. Safford, Life-Cycle Costs

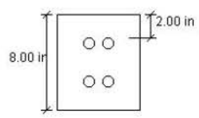
Life365 v2.0 - Concrete Mixes and Service Lives

Project: SPR-673-Safford

Description: Safford area, (2 of 5)

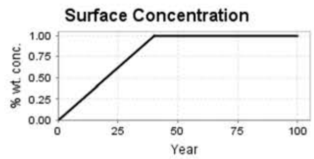
Analyst: Tarif Jaber

Date: 04/15/2011



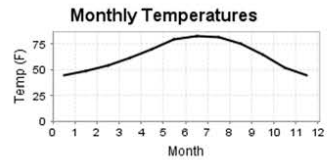
slabs and walls (1-D)

Outer dim: 8in; clear cover: 2in



Max surface: 1

Years to buildup: 40



Loc: user-defined

Type: user-defined

Concrete Mixes

Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
Base case		0.5				Black Steel
Alt-1 FA		0.5	Class F Fly Ash (20%);			Black Steel
Alt-2 ES		0.5				Epoxy Coated
Alt-3 FA+ES		0.5	Class F Fly Ash (20%);			Epoxy Coated
Alt-4 FA+ES+SF		0.4	Class F Fly Ash (20%); Silica Fume (6%);			Epoxy Coated
Alt-5 FA+SS+SF		0.4	Class F Fly Ash (20%); Silica Fume (6%);			316 Stainless

"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
Base case	2.14E-8 in*in/sec	0.2	0.05 % wt. conc.	10.6 yrs	6 yrs	**16.6 yrs**
Alt-1 FA	2.14E-8 in*in/sec	0.36	0.05 % wt. conc.	16.3 yrs	6 yrs	**22.3 yrs**
Alt-2 ES	2.14E-8 in*in/sec	0.2	0.05 % wt. conc.	10.6 yrs	20 yrs	**30.6 yrs**
Alt-3 FA+ES	2.14E-8 in*in/sec	0.36	0.05 % wt. conc.	16.3 yrs	20 yrs	**36.3 yrs**
Alt-4 FA+ES+SF	4.57E-9 in*in/sec	0.36	0.05 % wt. conc.	49.8 yrs	20 yrs	**69.8 yrs**
Alt-5 FA+SS+SF	4.57E-9 in*in/sec	0.36	0.5 % wt. conc.	100+ yrs	6 yrs	**106+ yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.

Figure A-14. Safford, Concrete Mixes and Service Lives

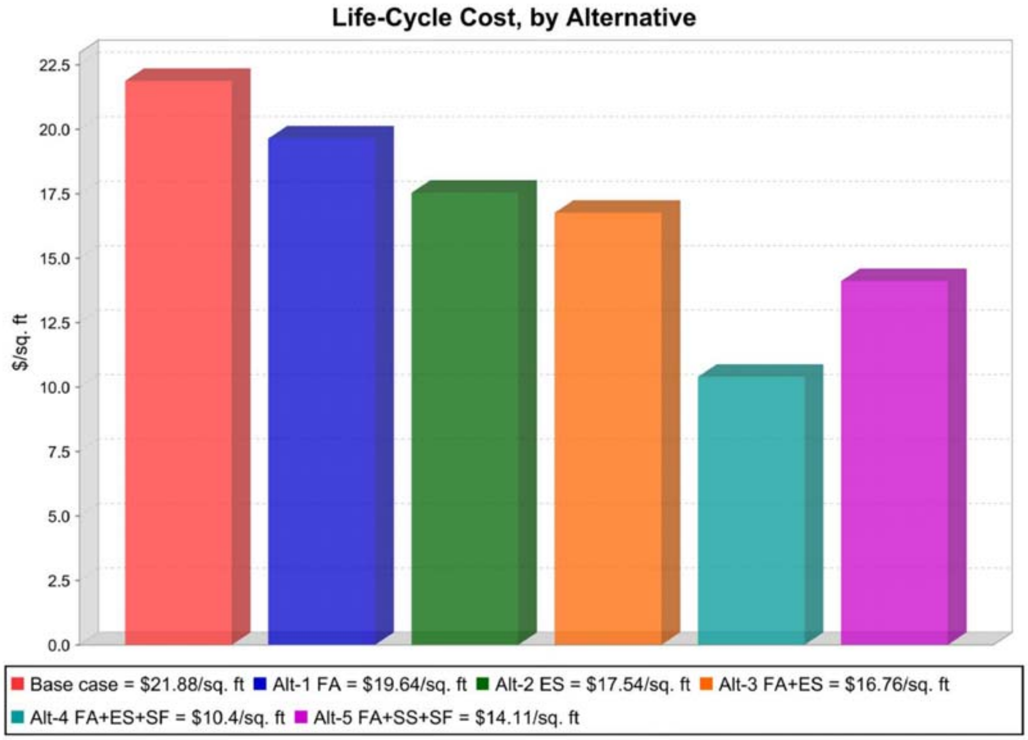


Figure A-15. Safford, Life-Cycle Cost by Alternative

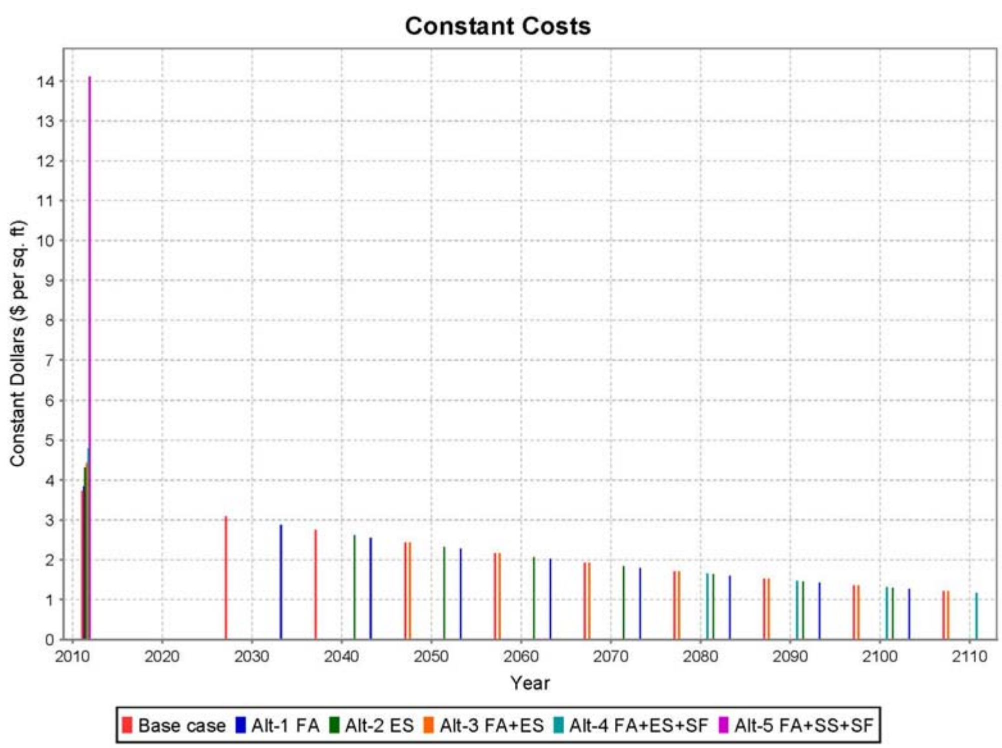


Figure A-16. Safford, Constant Costs

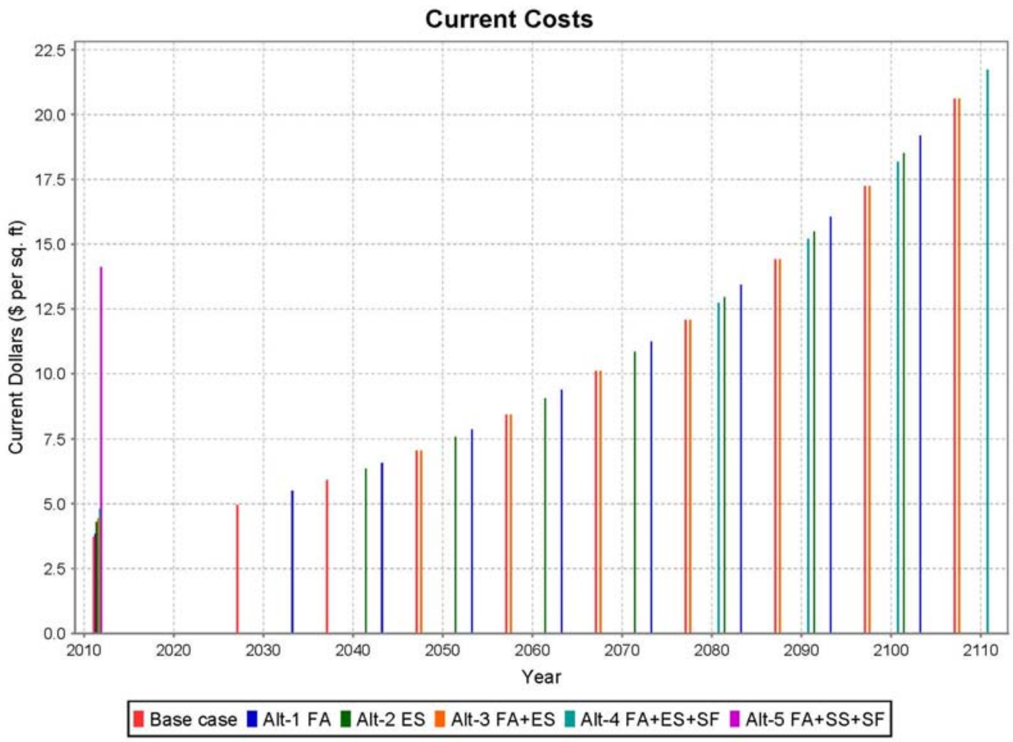


Figure A-17. Safford, Current Costs

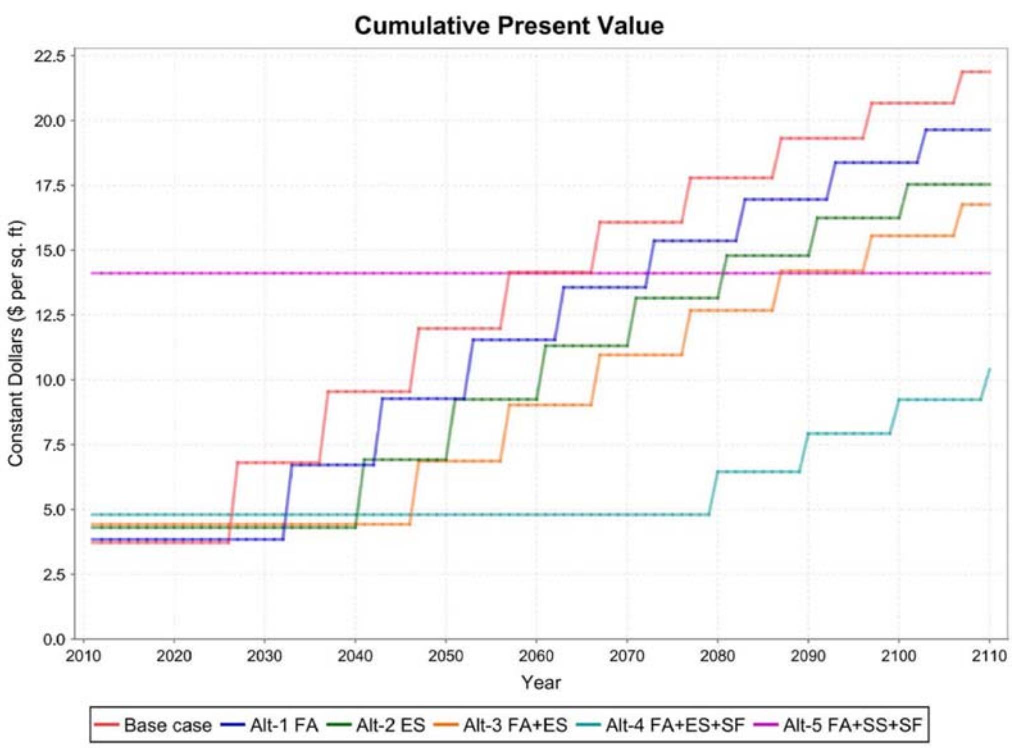


Figure A-18. Safford, Cumulative Present Value

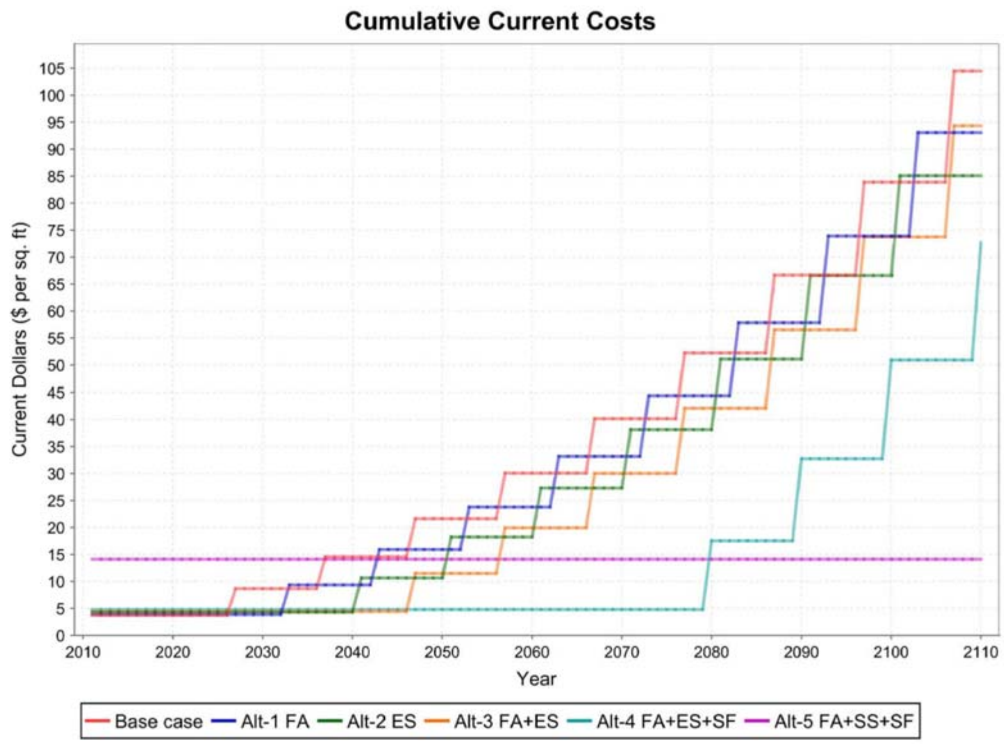


Figure A-19. Safford, Cumulative Current Costs

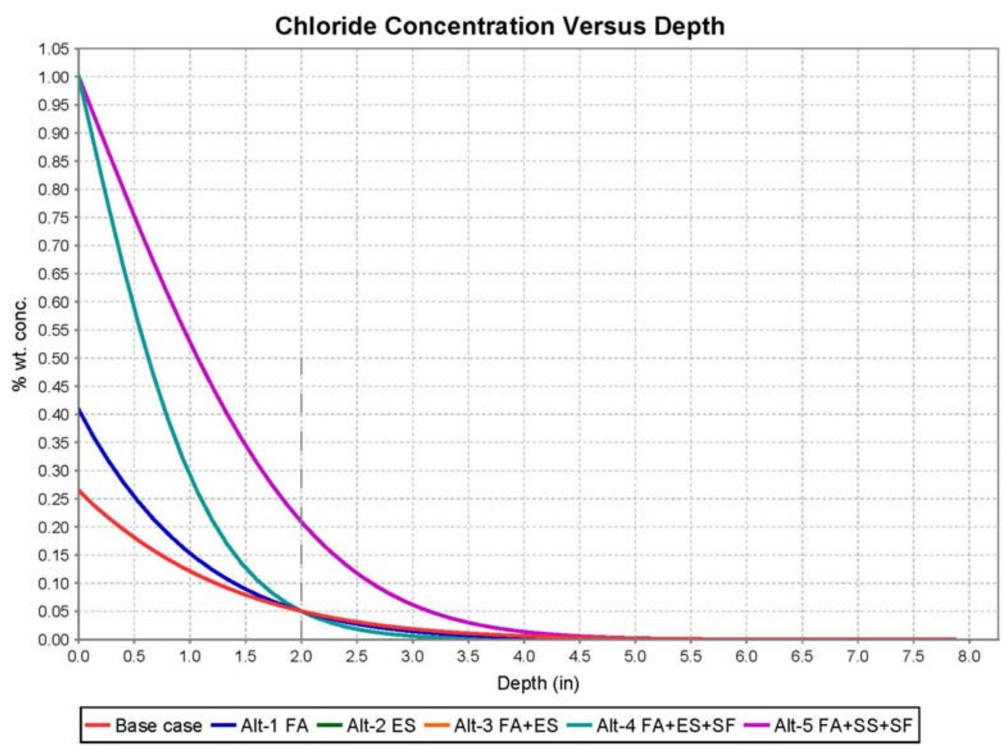


Figure A-20. Safford, Chloride Concentration Versus Depth

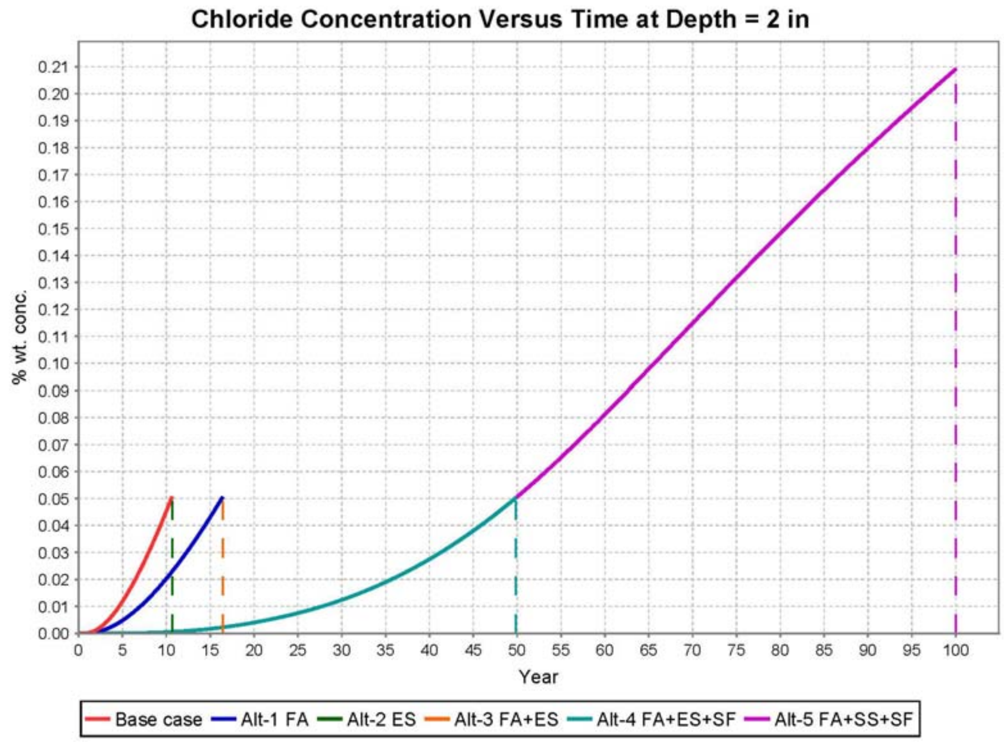


Figure A-21. Safford, Chloride Concentration Versus Time at Depth = 2 in

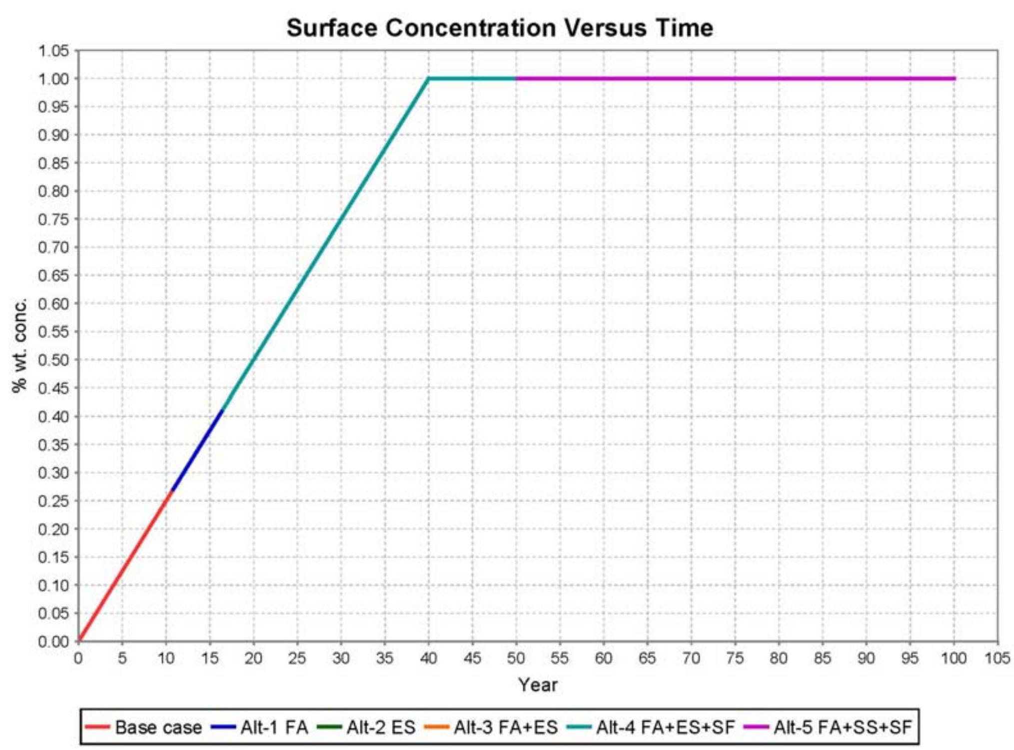


Figure A-22. Safford, Surface Concentration Versus Time

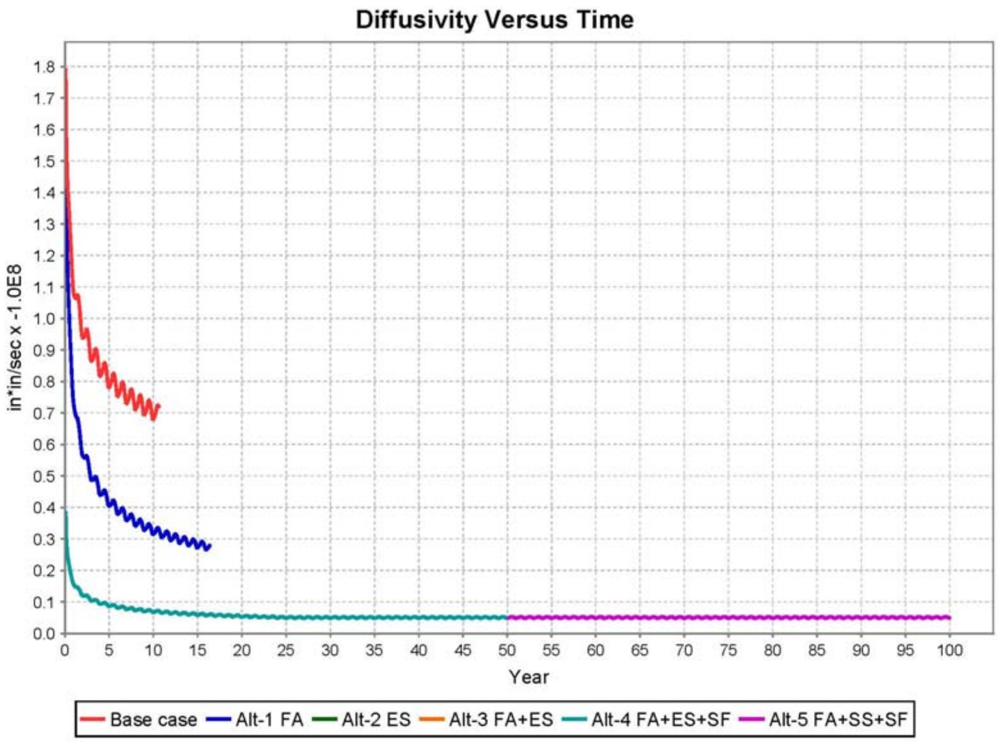


Figure A-23. Safford, Diffusivity Versus Time

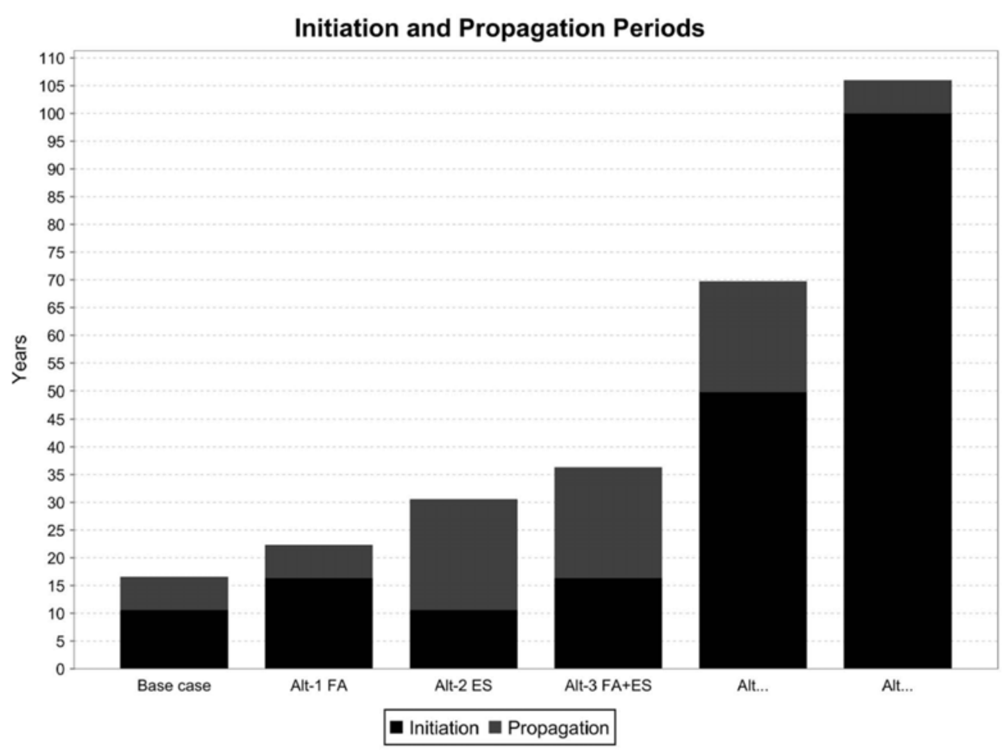


Figure A-24. Safford, Initiation and Propagation Periods

VIRGIN RIVER GORGE/INTERSTATE 15 AREA
LIFE-CYCLE COST ANALYSIS

Table A-12. Life-Cycle Cost Analysis - Virgin River Gorge I-15 Area

ALTERNATIVE	BASE	Alternative-1	Alternative-2	Alternative-3	Alternative-4	Alternative-5
		Base Case Plus Fly Ash	Base Plus Epoxy Steel	Base with Fly Ash and Epoxy Steel	HPC with Fly Ash, Epoxy Steel and Silica Fume	HPC with Fly Ash, Stainless Steel and Silica Fume
		Alt-1 (FA)	Alt-2 (ES)	Alt-3 (FA+ES)	Alt-4 (FA+ES+SF)	Alt-5 (FA+SS+SF)
Variable Data						
Concrete Mix and Materials						
Type	Class S ADOT	Class S ADOT	Class S ADOT	Class S ADOT	HPC	HPC
Water Cement Ratio (%)	0.50	0.50	0.50	0.50	0.40	0.40
Fly Ash (% of Cementitious)	-	20%	0%	20%	20%	20%
Silica Fume (% of Cement)	-	-	-	-	6%	6%
Concrete ($/cy)	$80.00	$85.00	$80.00	$85.00	$100.00	$100.00
Reinforcement						
Black Steel	YES	YES	-	-	-	-
Epoxy Steel	-	-	YES	YES	YES	-
Stainless Steel	-	-	-	-	-	YES

Fixed Data, All Alternatives	
Structural Data	
Bridge Element	Bridge Deck
Lane Width (ft)	50
Length (ft)	200
Analysis Area (sq. ft)	10,000
Slab Thickness (in)	8
Rein. Depth (in)	2
Rein. Percent of Concrete Volume (%)	1.20%
Repair	
Cost ($/sq. ft)	$37.16
Area to be repaired (%)	10%
Repair interval (yrs)	10
Material Cost	
Black Steel ($/lb)	$0.45
Epoxy-coated Steel ($/lb)	$0.60
Stainless Steel 316 ($/lb)	$3.00
Financial Parameters	
Base year	2011
Analysis Period (yrs)	100
Inflation Rate (%)	1.80%
Discount Rate (%)	3.00%

Table A-13. Environmental Data - Virgin River Gorge I-15 Area

Environmental Data	
Chloride Exposure	
Max. Surface Content. (% by wt. conc.)	1
Time to build to max (yrs)	24
Temperature History	
Month	**Mean Temperature (^{0}F)**
January	45.5
February	50.8
March	56.4
April	64.0
May	73.9
June	83.8
July	89.5
August	88.0
September	80.5
October	68.1
November	54.0
December	45.6

Table A-14. Salt Load Calculations - Virgin River Gorge I-15 Area

Salt Applications	Area 3-Virgin River Gorge I-15
Salt Data	
Rate of Application (tons per mile)	Trucks
No of Applications per year	Varies
Annual Salt Application (tons per mile)	490
Annual Salt Application (pounds per feet)	205
Annual Salt Application (% of concrete weight)	4%
Years to reach threshold	24
Fixed Assumptions for all areas	
Bridge Element	Bridge Deck
Lane Width (ft)	50
Slab Thickness (in)	8
Salt Analysis Area (sq. ft)	1
Concrete Weight (pcf)	150
Analyzed area weight (psf)	100
Concrete Concentration (% of weight of concrete)	1

Table A-15. Salt Source - Virgin River Gorge I-15 Area

Salt Source for Virgin River Gorge Area I-15	
Average Daily Traffic (truck)	9,000*
Assumed Average Salt Deposit (lbs/truck)	10
Total Daily Salt Deposits (lbs)	90,000
Average Salt Days per Season (day)	120
Total Annual Salt Deposits (lbs)	10,800,000
Distribution Distance (mile)	4898
Annual Salt Application (tons per mile)	490

*Data source: FHWA Corridors of the Future Fact Sheet 2007. Screenshot included below and also available at following link: http://www.fhwa.dot.gov/pressroom/fsi15.cfm

Corridors of the Future
- Interstate 5 (I-5)
- Interstate 10 (I-10)
- Interstate 15 (I-15)
- Interstate 69 (I-69)
- Interstate 70 (I-70)
- Interstate 95 (I-95)

CORRIDOR: Interstate 15 (I-15) - California to Utah

Submitted By
The Western States Coalition: Arizona, California, Nevada and Utah

Corridors of the Future Funding
$5 million under the Highways for Life program for the pavement rehabilitation project near the City of Ontario in Riverside County, California; $10 million under the Public Lands Highways discretionary program for the I-15/Interstate 215 North to Apex Interchange in Nevada.

Project Description
The application focuses on passenger and freight movement improvements to the I-15 corridor from San Diego, California at the junction of Interstate 5 through to Salt Lake City, Utah. In 2005, Union Pacific Railroad opened the country's third largest intermodal rail yard just outside Salt Lake City.

The proposed projects include capacity and operational improvements on both the highway and the rail portions of the corridor, including an ITS truck parking initiative; interchange reconstruction and modification; and road and bridge preservation. The overarching goal is a managed corridor for safe travel, sustained traffic flow, and reliable travel times. It includes two projects, the DesertXpress and the Commercial Corridor around Las Vegas, that have the potential to generate their own revenue streams as toll facilities and significantly limit the amount of public sector funds needed for these projects.

Status
Most of the projects needed along this corridor are in various stages of development that range from preliminary feasibility and project initiation studies to environmental studies and clearance phases. Further, a number of the innovative public private partnerships will require legislative changes in a number of the states that are part of this proposal.

Corridor Statistics
The I-15 corridor through the states of California, Arizona, Nevada, and Utah is over 840 miles with approximately 220 miles traversing through urban areas. Currently, the average daily traffic throughout the entire corridor is over 56,000 with a maximum over 250,000. Average daily truck traffic is over 9,000 with a maximum over 60,000. Among the 220 mile urban segments, over 60 percent is currently under heavy congestion.

Without any further improvement to the corridor, the projected 2035 average daily traffic will be over 150,000 which includes over 27,000 trucks. By 2035, 98 percent of urban segments will be under heavy congestion. Congestion for non-urban segments will increase from the current 21 percent to over 85 percent.

US DOT Home | FHWA Home | Corridors of the Future | Privacy Policy
For more information please e-mail: OperationsFeedback@dot.gov

Table A-16. Weather Data for Virgin River Gorge I-15 Area

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data,
and Information Service

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: BEAVER DAM, AZ **COOP ID: 020672**

Climate Division: AZ 1 **NWS Call Sign:** **Elevation: 1,875 Feet** **Lat: 36°54N** **Lon: 113°57W**

Temperature (°F)																					
Mean (1)				Extremes										Degree Days (1) Base Temp 65		Mean Number of Days (3)					
Month	Daily Max	Daily Min	Mean	Highest Daily(2)	Year	Day	Highest Month(1) Mean	Year	Lowest Daily(2)	Year	Day	Lowest Month(1) Mean	Year	Heating	Cooling	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
Jan	57.7	33.2	45.5	78	1971	21	52.7	1986	12+	1971	5	39.7	1979	606	0	.0	.0	26.7	.0	15.9	.0
Feb	64.1	37.4	50.8	87+	1986	26	56.1	1995	14	1985	1	46.4	1979	399	0	.0	.0	27.0	.1	7.9	.0
Mar	70.9	41.9	56.4	91+	1997	20	62.7	1972	19	1975	29	49.0	1991	293	26	.0	.2	30.8	.0	3.7	.0
Apr	79.9	48.1	64.0	101+	2000	26	71.0	2000	27	1999	1	57.2	1975	135	105	.1	4.7	30.0	.0	.7	.0
May	89.8	57.9	73.9	110	2000	23	81.1	1997	33	1975	7	67.0	1991	26	300	3.8	16.3	31.0	.0	.0	.0
Jun	100.6	66.9	83.8	117	1970	27	88.2	1974	42	1979	18	78.6	1991	0	561	16.7	27.4	30.0	.0	.0	.0
Jul	105.3	73.7	89.5	120	1998	16	93.1	1971	50	1958	5	86.5	1982	0	761	27.3	30.7	31.0	.0	.0	.0
Aug	103.2	72.8	88.0	115+	1980	11	91.6	1994	51+	1980	31	83.9	1979	0	713	22.8	30.3	31.0	.0	.0	.0
Sep	96.0	65.0	80.5	110+	1982	2	84.4	1974	37	1971	30	74.9	1986	1	466	9.3	24.6	30.0	.0	.0	.0
Oct	83.6	52.5	68.1	106	1980	1	74.7	1988	27+	1971	30	62.7	1984	70	164	.6	7.8	30.9	.0	.4	.0
Nov	68.0	40.0	54.0	89	1980	5	59.6	1995	15	1976	28	48.2	1994	338	8	.0	.0	29.3	.0	6.5	.0
Dec	58.5	32.7	45.6	85	1956	5	52.7	1980	4	1990	23	38.2	1990	602	0	.0	.0	27.4	.1	16.6	.0
Ann	81.5	51.8	66.7	120	Jul 1998	16	93.1	Jul 1971	4	Dec 1990	23	38.2	Dec 1990	2470	3104	80.6	142.0	355.1	.2	51.7	.0

+ Also occurred on an earlier date(s)

@ Denotes mean number of days greater than 0 but less than .05

Complete documentation available from: www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

Issue Date: February 2004 008-A

(1) From the 1971-2000 Monthly Normals

(2) Derived from station's available digital record: 1956-2001

(3) Derived from 1971-2000 serially complete daily data

Source: U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000

Table A–13. Weather Data for Virgin River Gorge I-15 Area (Continued)

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: BEAVER DAM, AZ **COOP ID: 020672**

Climate Division: AZ 1 **NWS Call Sign:** **Elevation: 1,875 Feet** **Lat: 36°54N** **Lon: 113°57W**

Precipitation (inches)

	Precipitation Totals									Mean Number of Days (3)			
	Means/ Medians(1)		Extremes							Daily Precipitation			
Month	Mean	Med-ian	Highest Daily(2)	Year	Day	Highest Monthly(1)	Year	Lowest Monthly(1)	Year	>= 0.01	>= 0.10	>= 0.50	>= 1.00
Jan	1.01	.76	1.11	1980	29	3.17	1993	.00+	1976	5.4	3.2	.4	.1
Feb	.95	.70	1.02	1969	26	4.19	1998	.00+	1977	5.3	2.9	.6	@
Mar	1.09	.69	.98	1979	28	3.23	1992	.00+	1999	6.3	3.5	.4	.0
Apr	.37	.23	.63	1967	12	1.50	1988	.00+	1992	3.4	1.2	@	.0
May	.34	.19	1.35	1958	11	1.96	1977	.00	1984	2.7	1.1	.1	.0
Jun	.18	.03	.67	2000	29	1.12	1987	.00+	1986	1.4	.5	.1	.0
Jul	.53	.34	1.25	1991	9	3.19	1984	.00+	2000	2.8	1.3	.3	.1
Aug	.67	.61	1.11	1998	24	2.24	1983	.00+	1985	3.9	1.8	.4	@
Sep	.48	.27	1.01	1972	19	1.78	1972	.00+	2000	2.8	1.3	.2	@
Oct	.76	.61	1.21	1983	1	2.15	1987	.00+	1999	4.0	2.1	.3	@
Nov	.69	.62	1.63	1967	29	2.06	1978	.00+	1999	3.7	1.9	.4	@
Dec	.52	.32	1.24	1971	25	2.22	1984	.00+	1999	3.5	1.7	.1	@
Ann	7.59	7.20	1.63	Nov 1967	29	4.19	Feb 1998	.00+	Sep 2000	45.2	22.5	3.3	.2

	Precipitation Probabilities (1) Probability that the monthly/annual precipitation will be equal to or less than the indicated amount										
	Monthly/Annual Precipitation vs Probability Levels These values were determined from the incomplete gamma distribution										
Month	.05	.10	.20	.30	.40	.50	.60	.70	.80	.90	.95
Jan	.00	.08	.24	.40	.56	.75	.98	1.25	1.62	2.25	2.87
Feb	.00	.00	.19	.35	.52	.70	.92	1.20	1.56	2.18	2.78
Mar	.00	.00	.17	.34	.53	.75	1.01	1.34	1.80	2.58	3.35
Apr	.00	.00	.05	.11	.17	.25	.34	.45	.62	.89	1.17
May	.00	.01	.04	.07	.13	.19	.28	.40	.57	.88	1.20
Jun	.00	.00	.00	.00	.01	.04	.09	.17	.30	.53	.79
Jul	.00	.01	.07	.14	.22	.33	.46	.63	.88	1.32	1.76
Aug	.00	.10	.24	.35	.45	.57	.69	.84	1.05	1.37	1.69
Sep	.00	.00	.03	.09	.17	.27	.40	.57	.81	1.23	1.66
Oct	.00	.05	.16	.27	.40	.54	.72	.93	1.23	1.73	2.23
Nov	.00	.00	.15	.27	.39	.52	.68	.87	1.12	1.54	1.96
Dec	.00	.00	.05	.11	.20	.31	.44	.62	.88	1.33	1.80
Ann	4.19	4.79	5.58	6.21	6.78	7.35	7.94	8.62	9.45	10.69	11.79

+ Also occurred on an earlier date(s)
# Denotes amounts of a trace
@ Denotes mean number of days greater than 0 but less than .05
** Statistics not computed because less than six years out of thirty had measurable precipitation

(1) From the 1971-2000 Monthly Normals
(2) Derived from station's available digital record: 1956-2001
(3) Derived from 1971-2000 serially complete daily data

Complete documentation available from:
www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

008-B

Source: U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000

Table A–13. Weather Data for Virgin River Gorge I-15 Area (Continued)

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National Environmental Satellite, Data, and Information Services

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: BEAVER DAM, AZ **COOP ID: 020672**

Climate Division: AZ 1 **NWS Call Sign:** **Elevation: 1,875 Feet** **Lat: 36°54N** **Lon: 113°57W**

Snow (inches)																							
Snow Totals															Mean Number of Days (1)								
Means/Medians (1)					Extremes (2)										Snow Fall >= Thresholds					Snow Depth >= Thresholds			
Month	Snow Fall Mean	Snow Fall Median	Snow Depth Mean	Snow Depth Median	Highest Daily Snow Fall	Year	Day	Highest Monthly Snow Fall	Year	Highest Daily Snow Depth	Year	Day	Highest Monthly Mean Snow Depth	Year	0.1	1.0	3.0	5.0	10.0	1	3	5	10
Jan	.2	.0	0	0	2.5	1975	28	2.5	1975	0	0	0	0	0	.1	.1	.0	.0	.0	.0	.0	.0	.0
Feb	.0	.0	0	0	1.0	1979	1	1.0	1979	0	0	0	0	0	@	@	.0	.0	.0	.0	.0	.0	.0
Mar	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Apr	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
May	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Jun	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Jul	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Aug	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Sep	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Oct	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Nov	.0	.0	#	0	1.0	1975	29	1.0	1975	#	1971	16	#	1971	@	@	.0	.0	.0	.0	.0	.0	.0
Dec	.0	.0	#	0	1.0	1990	20	1.0	1990	1	1990	31	#	1990	@	@	.0	.0	.0	@	.0	.0	.0
Ann	.2	.0	N/A	N/A	2.5	Jan 1975	28	2.5	Jan 1975	1	Dec 1990	31	#+	Dec 1990	.1	.1	.0	.0	.0	@	.0	.0	.0

+ Also occurred on an earlier date(s) #Denotes trace amounts

@ Denotes mean number of days greater than 0 but less than .05

-9/-9.9 represents missing values
Annual statistics for Mean/Median snow depths are not appropriate

(1) Derived from Snow Climatology and 1971-2000 daily data

(2) Derived from 1971-2000 daily data

Complete documentation available from:
www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

008-C

Source: U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000

Table A–13. Weather Data for Virgin River Gorge I-15 Area (Continued)

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data,
and Information Service

Climatography of the United States No. 20 1971-2000

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801
www.ncdc.noaa.gov

Station: BEAVER DAM, AZ **COOP ID: 020672**

Climate Division: AZ 1 **NWS Call Sign:** **Elevation: 1,875 Feet** **Lat: 36°54N** **Lon: 113°57W**

Freeze Data

Spring Freeze Dates (Month/Day)

Temp (F)	Probability of later date in spring (thru Jul 31) than indicated(*)								
	.10	.20	.30	.40	.50	.60	.70	.80	.90
36	5/03	4/25	4/19	4/13	4/08	4/03	3/29	3/23	3/14
32	4/21	4/12	4/05	3/30	3/25	3/19	3/14	3/07	2/26
28	3/29	3/19	3/12	3/07	3/01	2/24	2/18	2/11	2/02
24	3/03	2/20	2/12	2/05	1/29	1/23	1/16	1/07	12/27
20	2/15	2/03	1/25	1/16	1/07	12/27	12/08	0/00	0/00
16	1/09	12/20	11/24	0/00	0/00	0/00	0/00	0/00	0/00

Fall Freeze Dates (Month/Day)

Temp (F)	Probability of earlier date in fall (beginning Aug 1) than indicated(*)								
	.10	.20	.30	.40	.50	.60	.70	.80	.90
36	10/18	10/23	10/27	10/30	11/02	11/05	11/08	11/11	11/16
32	10/24	10/30	11/03	11/06	11/09	11/13	11/16	11/20	11/26
28	11/07	11/12	11/16	11/19	11/22	11/25	11/28	12/02	12/07
24	11/19	11/25	11/29	12/03	12/06	12/09	12/13	12/17	12/23
20	11/28	12/09	12/17	12/25	1/03	1/14	0/00	0/00	0/00
16	12/08	12/27	0/00	0/00	0/00	0/00	0/00	0/00	0/00

Freeze Free Period

Temp (F)	Probability of longer than indicated freeze free period (Days)								
	.10	.20	.30	.40	.50	.60	.70	.80	.90
36	236	226	219	213	207	201	195	188	178
32	260	249	241	235	229	223	216	209	198
28	294	284	277	271	265	259	253	246	236
24	354	334	323	315	308	300	293	284	271
20	>365	>365	>365	>365	>365	351	334	321	306
16	>365	>365	>365	>365	>365	>365	>365	>365	>365

* Probability of observing a temperature as cold, or colder, later in the spring or earlier in the fall than the indicated date.

0/00 Indicates that the probability of occurrence of threshold temperature is less than the indicated probability.

Derived from 1971-2000 serially complete daily data

Complete documentation available from:
www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

008-D

Source: U.S. Department of Commerce, February 2004, Climatography of the United States No. 20, Monthly Station Climate Summaries, 1971-2000

Life365 v2.0 - Life-Cycle Costs

Project: SPR-673-Virgin River Gorge, I-15

Description: Virgin River Gorge-Beaver Dam area, (3 of 5)

Analyst: Tarif Jaber

Date: 04/15/2011

Life-Cycle Costs

Name	Construction Cost	Barrier Cost	Repair Cost	Life-Cycle Cost
Base case	$3.72 per sq. ft	$0.00 per sq. ft	$18.59 per sq. ft	$22.31 per sq. ft
Alt-1 FA	$3.85 per sq. ft	$0.00 per sq. ft	$17.73 per sq. ft	$21.58 per sq. ft
Alt-2 ES	$4.30 per sq. ft	$0.00 per sq. ft	$14.73 per sq. ft	$19.03 per sq. ft
Alt-3 FA+ES	$4.43 per sq. ft	$0.00 per sq. ft	$12.93 per sq. ft	$17.35 per sq. ft
Alt-4 FA+ES+SF	$4.80 per sq. ft	$0.00 per sq. ft	$6.15 per sq. ft	$10.95 per sq. ft
Alt-5 FA+SS+SF	$14.11 per sq. ft	$0.00 per sq. ft	$0.00 per sq. ft	$14.11 per sq. ft

Graphs

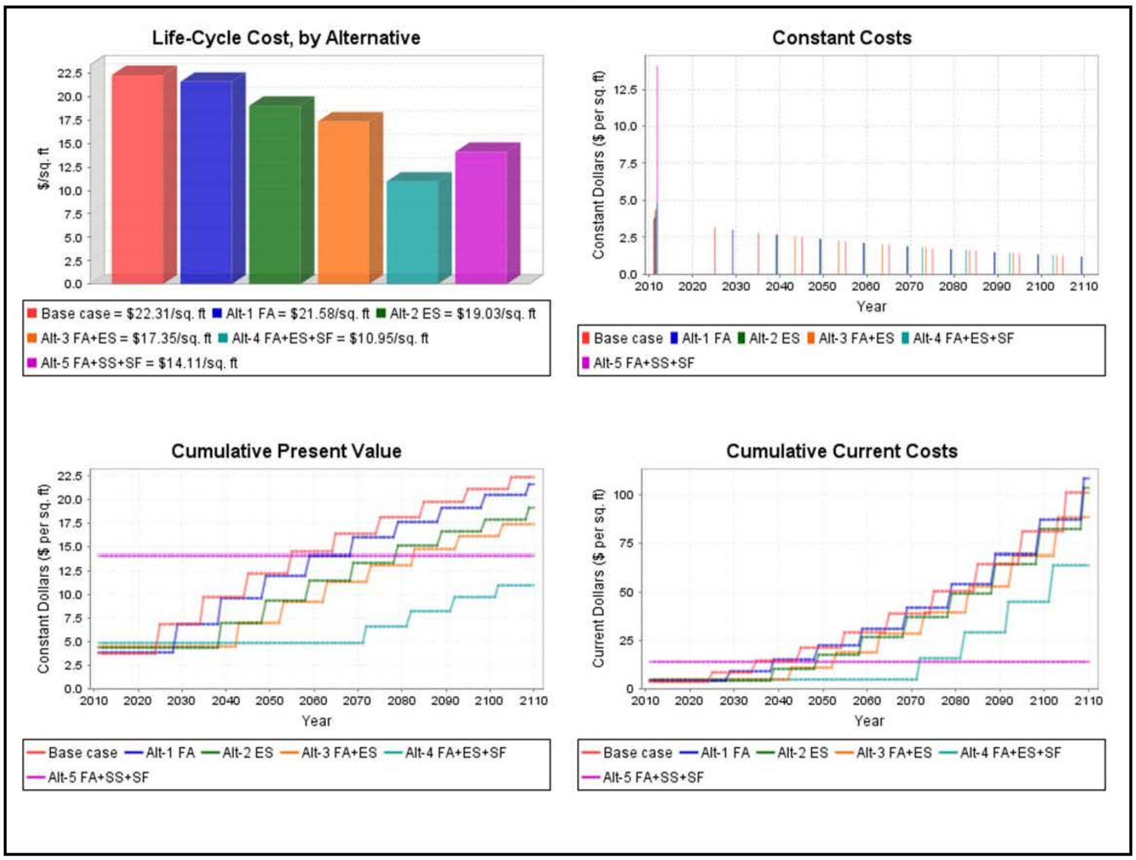


Figure A-25. Virgin River Gorge, Life-Cycle Costs

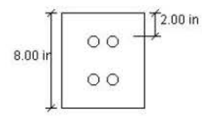
Life365 v2.0 - Concrete Mixes and Service Lives

Project: SPR-673-Virgin River Gorge, I-15

Description: Virgin River Gorge-Beaver Dam area, (3 of 5)

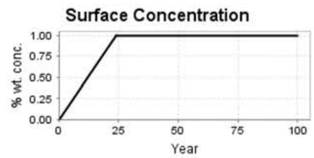
Analyst: Tarif Jaber

Date: 04/15/2011



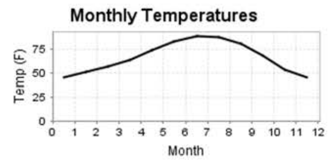
slabs and walls (1-D)

Outer dim: 8in; clear cover: 2in



Max surface: 1

Years to buildup: 24



Loc: user-defined

Type: user-defined

Concrete Mixes

Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
Base case		0.5				Black Steel
Alt-1 FA		0.5	Class F Fly Ash (20%);			Black Steel
Alt-2 ES		0.5				Epoxy Coated
Alt-3 FA+ES		0.5	Class F Fly Ash (20%);			Epoxy Coated
Alt-4 FA+ES+SF		0.4	Class F Fly Ash (20%); Silica Fume (6%);			Epoxy Coated
Alt-5 FA+SS+SF		0.4	Class F Fly Ash (20%); Silica Fume (6%);			316 Stainless

"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
Base case	2.14E-8 in*in/sec	0.2	0.05 % wt. conc.	8 yrs	6 yrs	**14 yrs**
Alt-1 FA	2.14E-8 in*in/sec	0.36	0.05 % wt. conc.	12.2 yrs	6 yrs	**18.2 yrs**
Alt-2 ES	2.14E-8 in*in/sec	0.2	0.05 % wt. conc.	8 yrs	20 yrs	**28 yrs**
Alt-3 FA+ES	2.14E-8 in*in/sec	0.36	0.05 % wt. conc.	12.2 yrs	20 yrs	**32.2 yrs**
Alt-4 FA+ES+SF	4.57E-9 in*in/sec	0.36	0.05 % wt. conc.	41.4 yrs	20 yrs	**61.4 yrs**
Alt-5 FA+SS+SF	4.57E-9 in*in/sec	0.36	0.5 % wt. conc.	100+ yrs	6 yrs	**106+ yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.

Figure A-26. Virgin River Gorge, Concrete Mixes and Service Lives

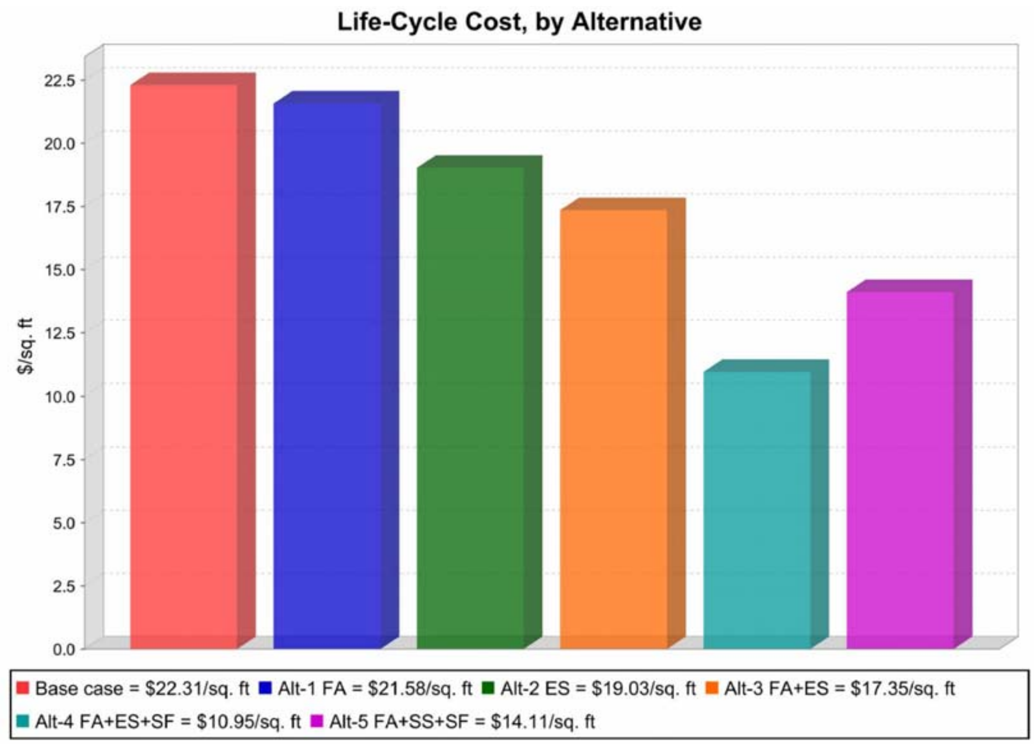


Figure A-27. Virgin River Gorge, Life-Cycle Cost by Alternative

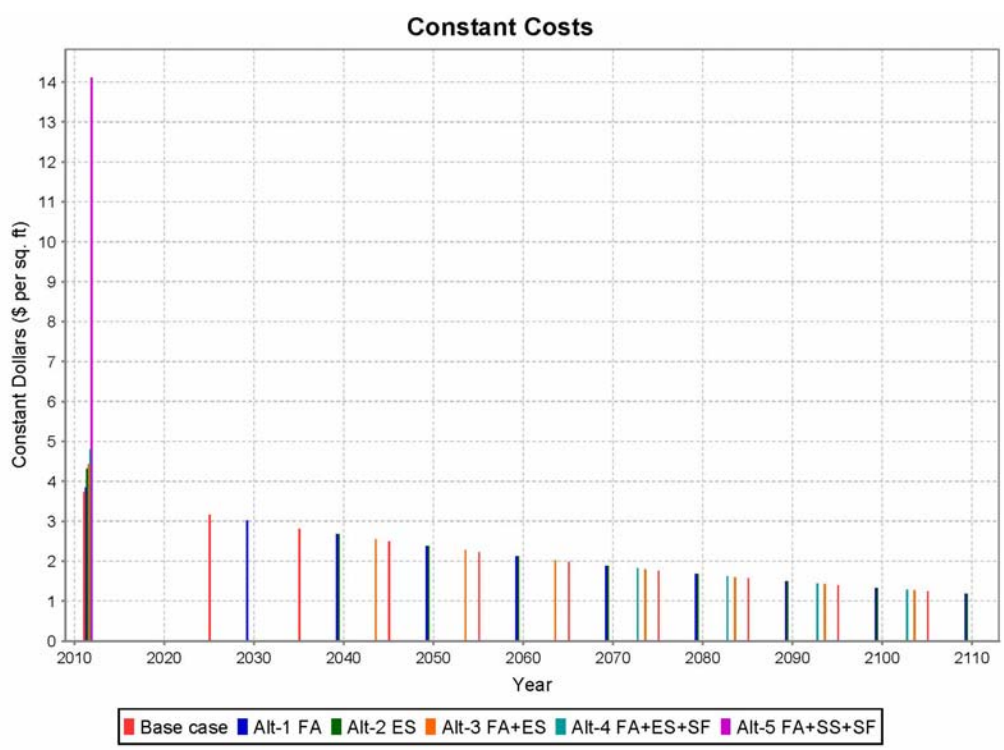


Figure A-28. Virgin River Gorge, Constant Costs

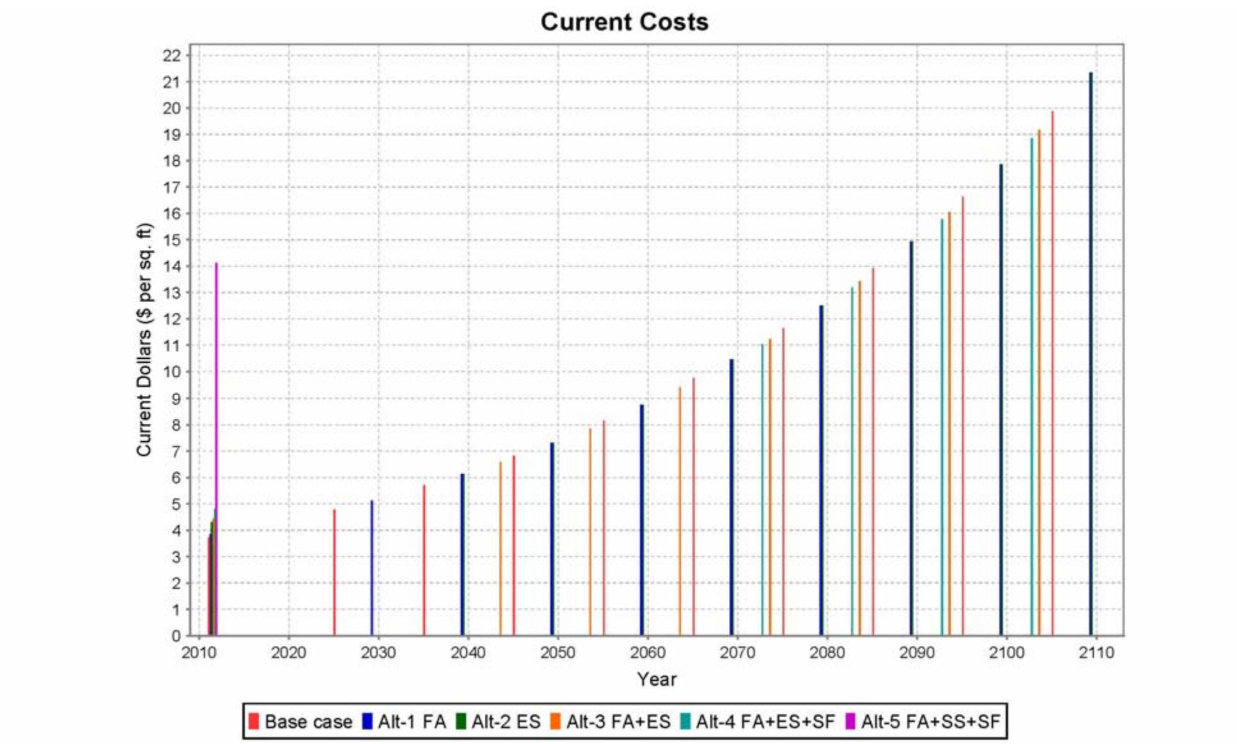


Figure A-29. Virgin River Gorge, Current Costs

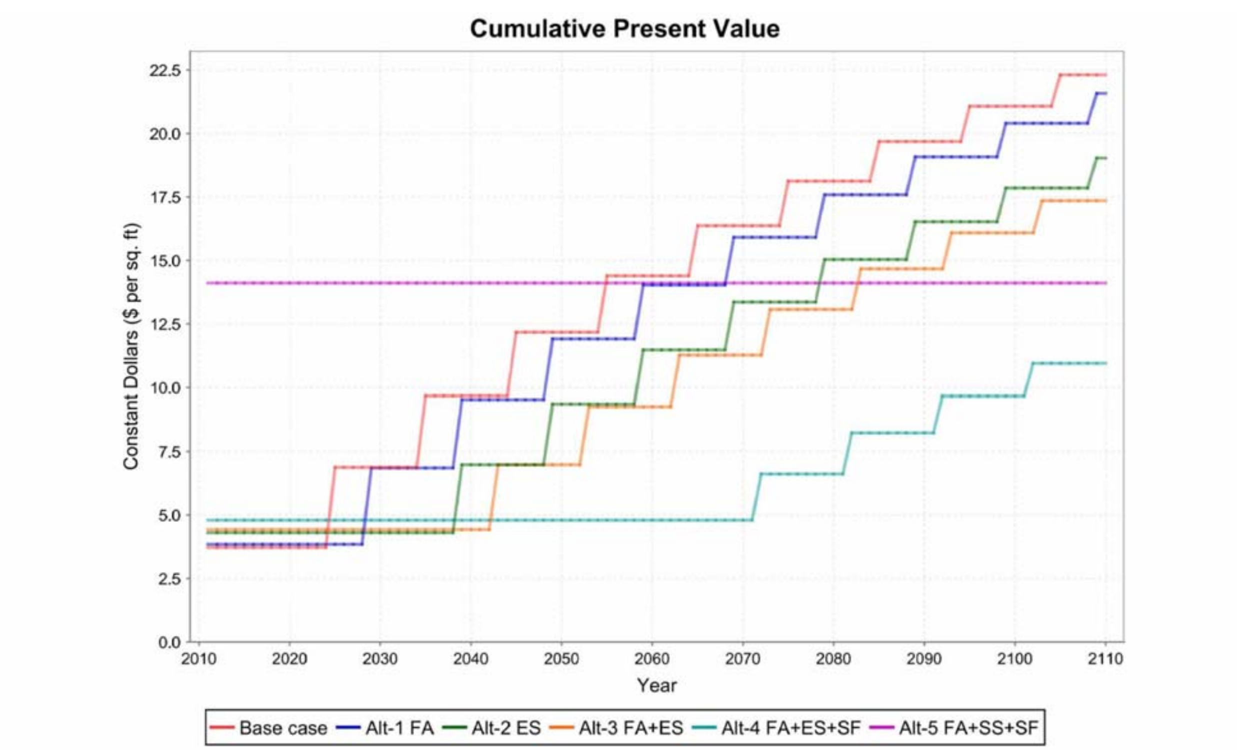


Figure A-30. Virgin River Gorge, Cumulative Present Value

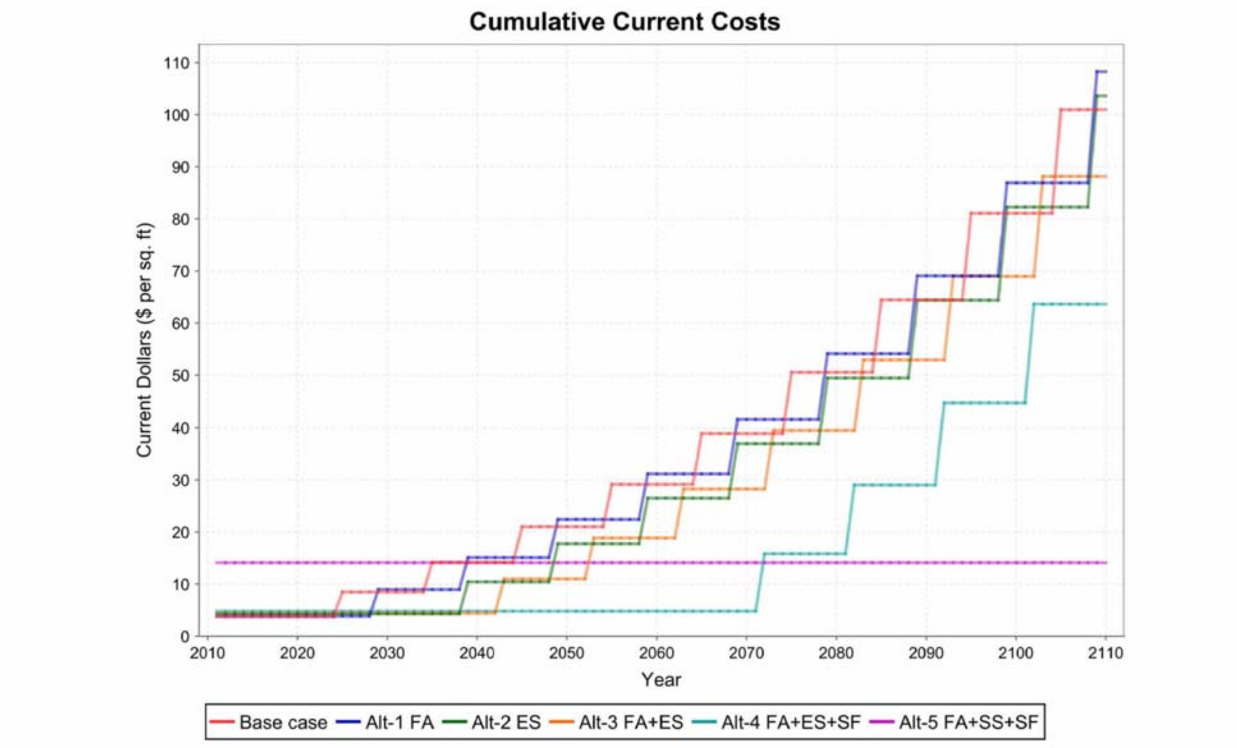


Figure A-31. Virgin River Gorge, Cumulative Current Costs

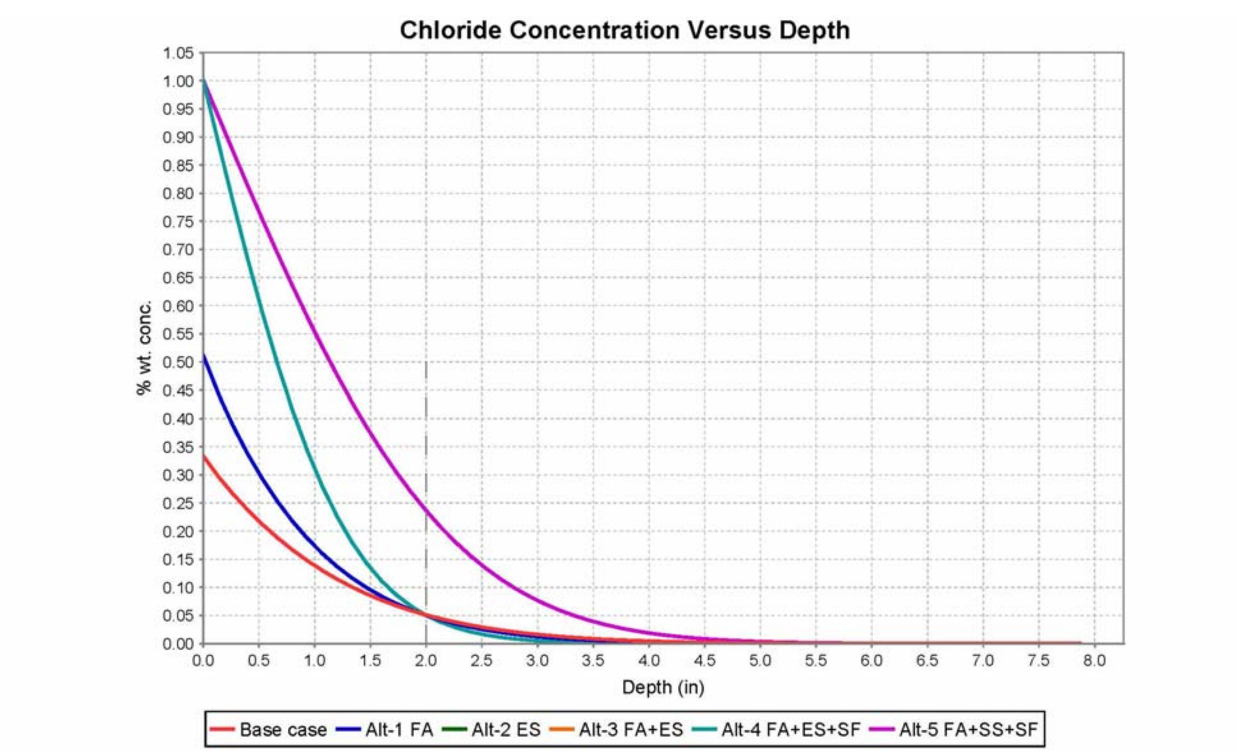


Figure A-32. Virgin River Gorge, Chloride Concentration Versus Depth

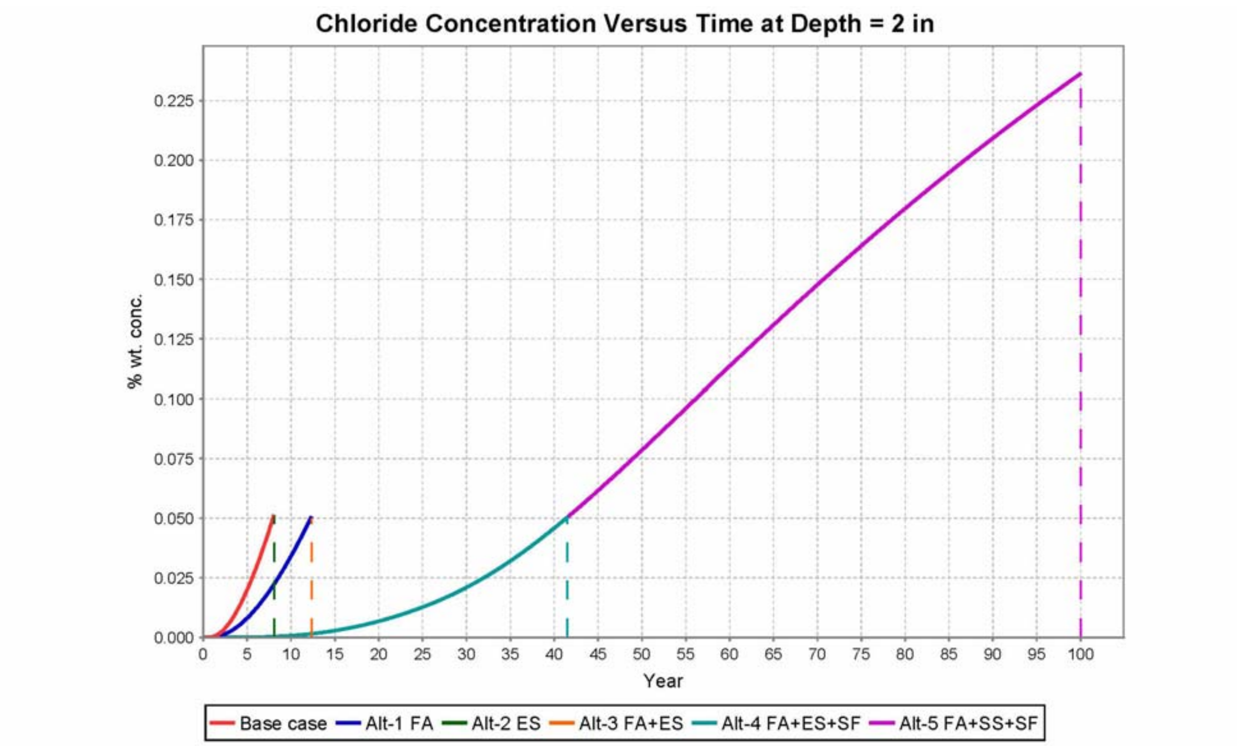


Figure A-33. Virgin River Gorge, Chloride Concentration Versus Time at Depth = 2 in

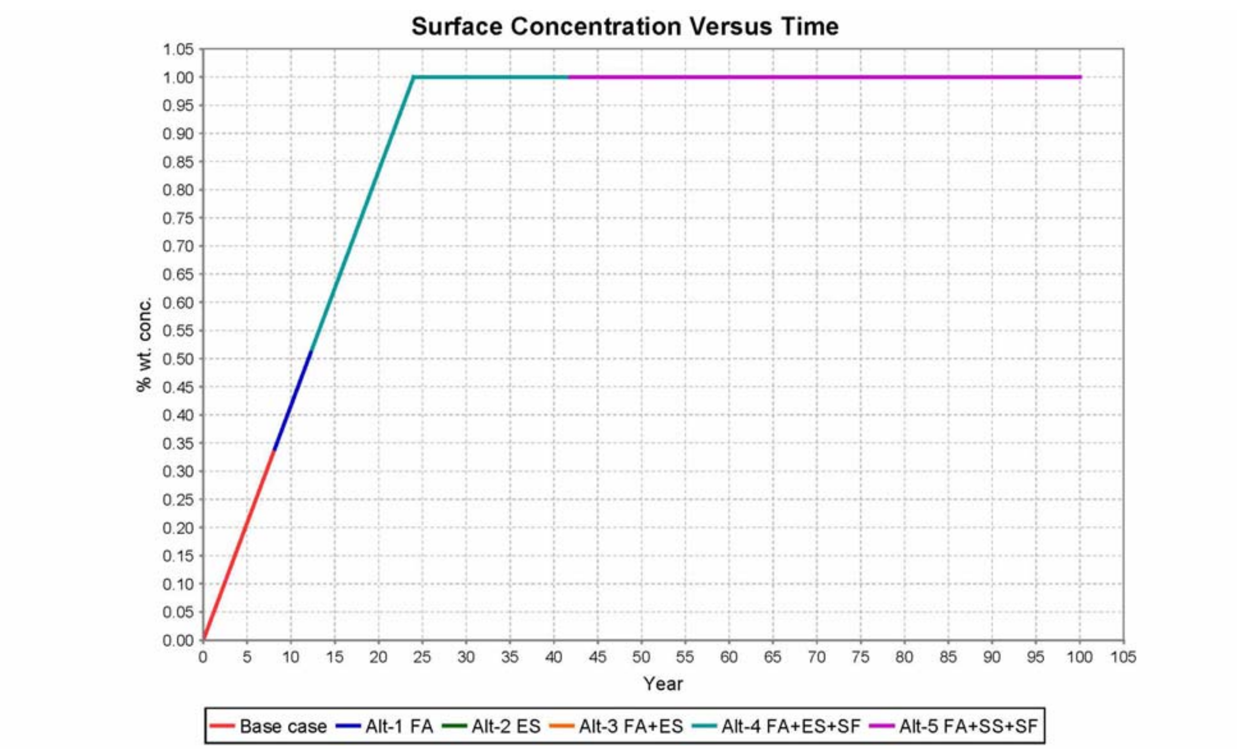


Figure A-34. Virgin River Gorge, Surface Concentration Versus Time

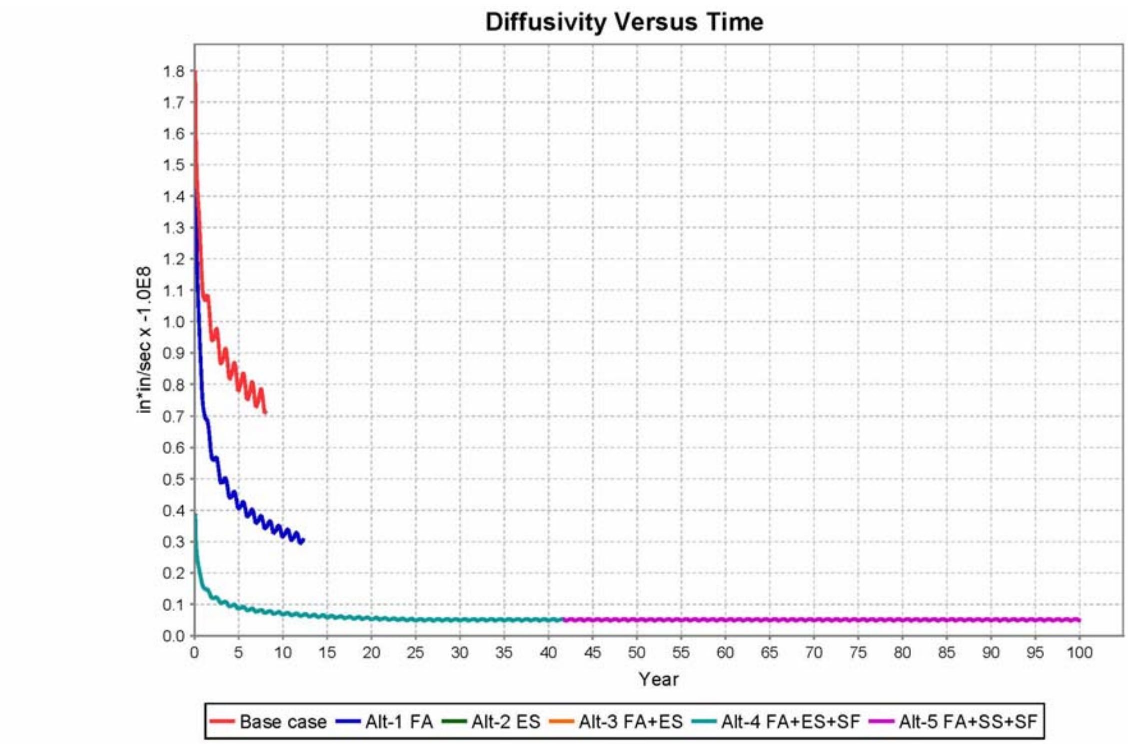


Figure A-35. Virgin River Gorge, Diffusivity Versus Time

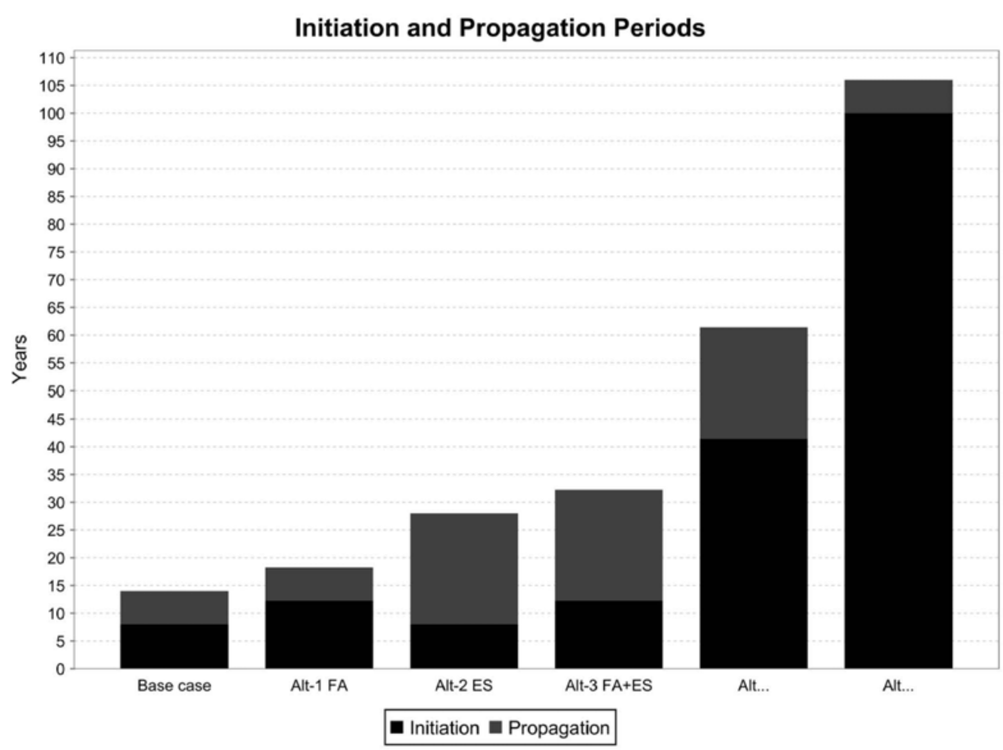


Figure A-36. Virgin River Gorge, Initiation and Propagation Periods

APPENDIX B: STATE SURVEY RESPONSES

Table B-1. Compilation of all DOT Survey Responses

NUMBER	QUESTION / STATE	1: Do you use HPC on your bridge decks	2: If not, what has been your state approach in improving the durability of your bridge decks	3: If yes, do you have a designated specification for the HPC	4: Is your HPC specification:	4-a: a). A stand alone	4-b: b). Incorporated in your DOT standard specification	4-c: A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are
1	Alabama	NO As part of a research project only.	Introduction of supplementary cementitious materials and enhance curing practices.	YES Please see attached word document for special provision used on the research project.			YES Both, conventional concrete and HPC were combined in a Special Provision. - See attached document in the email.	
2	Delaware	NO	All our PCC has either GGBFS or fly ash for ASR mitigation so we have low permeability concrete.			YES		
3	Florida	YES Class F fly ash or slag is required in our concrete, w/c is 0.44, minimum comp.strength at 28 days is 4500 psi. For concrete placed in aggressive environments we reduce w/c to 0.41, increase cementitious content to 658 #	Our decks do not deteriorate like most states, our issues are air born chlorides from sea water, where bridges are placed in these environments.	NO Recent specification changes will require all of our concrete to have fly ash or slag as a percentage of the cementitious material			NO	
4	Idaho	NO Not routinely	Silica Fume overlays	YES		YES		
5	Indiana	YES very limited basis for select structures only		YES		YES Unique Special Provision for select contracts		
6	Iowa	YES		YES		YES		
7	Louisiana	YES Some but not all bridges.		YES Its our main structural mix but with permeability requirements.		YES Currently but may soon be introduced into our std. specs.		
8	Massasussets	YES		YES			YES	
9	Maryland	YES		YES		YES		
10	Michigan	YES Only a few to date, project specific for demo purposes		YES		YES		

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION / STATE	1 Do you use HPC on your bridge decks	2 If not, what has been your state approach in improving the durability of your bridge decks	3 If yes, do you have a designated specification for the HPC	4 Is your HPC specification:	4-a a). A stand alone	4-b b). Incorporated in your DOT standard specification	4-c A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are
11	Minnesota	YES		YES			YES We only relace portions of our standard spec	
12	Missouri	NO	Seven-day wet cure, modified PCC mix w/ supplementary cementitious materials and Type A water reducer					
13	Nevada	YES		YES			YES	
14	New Hampshire	NO No HPC spec., but deck requirements considered to be HP	Control of w/c ratio and air content	NO			YES	
15	New Jersey	YES		YES			YES	
16	New Mexico	YES In NM, we use a 4000 psi mix, but require that it not exceed 0.05% shrinkager and it use a combined gradation approach in order to optimize the aggregate structure.	We require a minimum of 85% to 95% Durabilty Index after testing in accordane with ASTM C666, Method A, depending on what the freeze/thaw risk is.	NO			NO	
17	North Carolina	YES Add mineral admixture- flyash when salt exposure likely	Also, require 7 day wet cure (soaker hose - under cover)				YES	
18	North Dakota	NO	We are a participant in Kansas Crack Free Bridge Deck Research		We don't have a HPC specification			

Table B–1. Compilation of all DOT Survey Responses (Continued)

	QUESTION	1	2	3	4	4-a	4-b	4-c
NUMBER	STATE	Do you use HPC on your bridge decks	If not, what has been your state approach in improving the durability of your bridge decks	If yes, do you have a designated specification for the HPC	Is your HPC specification:	a). A stand alone	b). Incorporated in your DOT standard specification	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are
19	Ohio	YES You need to first specifically define what you mean by HPC. It has three meanings to FHWA and even more around the country. We try and achieve a low permeability.		BOTH We started with a designated mix design. We have now moved to a requirement for permeability but let the contractor develop the mix. My opinion the second is better.		Not all districts do it.	YES	
20	Ontario	YES		YES			YES	
21	Oregon	YES		YES			YES	
22	Puerto Rico	YES PRHTA has specify the used HPC since 1999		YES Special Provision 934		YES Special Provision 934		
23	Texas	YES Not on all of them though.	Use epoxy coated steel in about 1/3 of the State.	Use a special provision to the Standard Concrete Item			YES Attached.	
24	Washington	NO	Adjust the levels of pozzolans used in the bridge deck concrete and begin the process to develop a performance concrete					
25	West Virginia	YES		YES			YES It has been incorporated into the 2009 Supplemental Specs	
26	Wisconsin	YES Limited to major corridor projects		YES		YES		

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION / STATE	4-d: A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.	5: Based on the above, is your HPC specification:	5-a: a). Performance	5-b: b). Prescriptive	5-c: c). Combination	5-d: d). None of the above, please elaborate
1	Alabama					YES	
2	Delaware			YES			
3	Florida			Currently we have only one Performance based specification for structures that are constructed in non-aggressive enviroments. All other applications have prescriptive specifcations.	YES		
4	Idaho					YES	
5	Indiana					YES with QC/QA criteria added as well	
6	Iowa					YES	
7	Louisiana					YES	
8	Massasussets					YES	
9	Maryland					YES	
10	Michigan					YES	

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION / STATE	4-d: A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.	5: Based on the above, is your HPC specification:	5-a: a). Performance	5-b: b). Prescriptive	5-c: c). Combination	5-d: d). None of the above, please elaborate
11	Minnesota				We still use these in certain situations	YES	
12	Missouri						
13	Nevada				YES		
14	New Hampshire					YES Aggr gradation and admixtures are prescriptive	
15	New Jersey			YES			
16	New Mexico			YES			
17	North Carolina				YES		
18	North Dakota		Not Applicable				

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION	4-d	5	5-a	5-b	5-c	5-d
	STATE	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.	Based on the above, is your HPC specification:	a). Performance	b). Prescriptive	c). Combination	d). None of the above, please elaborate
19	Ohio					YES Mix is performance. Some of the placement mixing transporting etc are prescriptive	
20	Ontario					YES	
21	Oregon					YES	
22	Puerto Rico			YES			
23	Texas				YES Majority (90%) of contractors choose prescriptive option.	YES Allow performance option.	
24	Washington					YES	
25	West Virginia					YES We specify two options, both with specific cementitious material contents (cement+fly ash+silia fume or cement+GGBFS+silica fume) and maximum w/c, but other mix parameters are left up to	
26	Wisconsin					YES	

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION / STATE	6 Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	7 Do you specify any of the following as end results of the concrete.	7A If yes, please elaborate	7-a a). Strength	7-b b). Hardened air content
1	Alabama	NO No, only the percent substitution allowed for the supplementary cementitious materials were specified.			YES	YES
2	Delaware	NO			YES	
3	Florida	YES			YES Concrete must meet the minimum required strength in 28 days	NO
4	Idaho	YES Current Spec has a min and max cementious content requirement			YES	NO
5	Indiana	YES ternary mix with mins & max for each component, max on paste			YES 4400 psi min @ 28-day for sublot, Lot value > 4675 psi min	plastic air content at point of placement
6	Iowa	YES Cement, slag, and flyash			YES 4500-5000 psi depending on member	
7	Louisiana	NO Not really; just allowable ranges and liberal minimums.			YES	NO Air content isn't a factor here; just a 2-7% range.
8	Massasussets	NO Give the maximum cementitious amounts, contractor is responsible after that.			YES	YES
9	Maryland	YES minimum cementitious content			YES	
10	Michigan	YES			YES refer to standard deck 28 day compressive of 5000 psi	NO

Table B–1. Compilation of all DOT Survey Responses (Continued)

	QUESTION	6	7	7A	7-a	7-b
NUMBER	STATE	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	Do you specify any of the following as end results of the concrete.	If yes, please elaborate	a). Strength	b). Hardened air content
11	Minnesota	NO			YES May or maynot depending on Job	
12	Missouri					
13	Nevada	YES Allowable ranges are specified for cement and silica fume. Minimums are specified for flyash.			YES	NO
14	New Hampshire	YES Aggregate gradation is specified			YES	NO
15	New Jersey	NO			YES	NO
16	New Mexico	NO			YES	YES
17	North Carolina	YES 20% FA replacement 1.2 # per # cement			YES 4500 psi, which may increase shrinkage potential due to high cement factor	NO
18	North Dakota	NO	NO		NO	NO

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION	6	7	7A	7-a	7-b
	STATE	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	Do you specify any of the following as end results of the concrete.	If yes, please elaborate	a). Strength	b). Hardened air content
19	Ohio	YES ACI minimum and maximum limitations of cementatious and cement			YES Minimum for design purposes	NO
20	Ontario	NO			YES Compressive strength tested on cylinders.	YES Specified minimum air content of 3% and maximum spacing factor of 0.250mm.
21	Oregon	YES			YES	YES
22	Puerto Rico	NO We, however, specify maximum amounts (upper limit) of Supplementary Cementitious Materials (SCM's)			YES Acceptance based upon moving average and individual strength test (average of cylinders set)	
23	Texas	YES Maximum limit and % cement replacement with SCM.	YES		YES All concrete.	Measure fresh EA when EA required (1/3 of state)
24	Washington	YES Just minimum Cementitious			YES	NO
25	West Virginia	YES We specify cemeitious materials content, but not aggregates.			YES 4,000 psi minimum	NO
26	Wisconsin	YES specify a quantity range, contractor provides mix design			YES use PWL with lower spec limit of 4000 psi	NO

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION / STATE	7-c: c). Permeability	7-d: d). Other	8: Do you specify/impose penalties for not meeting the following requirements	8A: If yes, please elaborate	8-a: a). Strength
1	Alabama	NO Tested by research team as probable further specification consideration.	YES Temperature, slump, and unit weight.			YES
2	Delaware	YES				YES
3	Florida	YES We have a Surface Resitivity requirment when silica fume is required in the concrete due to the project enviroment.	YES Mass concrete temperature contols may be required for massive elements. In these cases high volumns of fly ash are normally required to control temerature differentials.			YES
4	Idaho	YES this is a design test for us and not used on production concrete				YES
5	Indiana	YES trial batch set target for permeability	YES Unit weight comparison to target, based on measured air %			YES Pay factors per Lot basis (150 cyd), lot & sublot min. value req.
6	Iowa	NO A target of 1500 coulombs but not required to meet - just rely on supplementary materials				NO
7	Louisiana	YES max 2000 coulombs in general with a max of 1000 for some jobs.		YES		YES Pay penalties ranging from 98% to 50% or remove and replace
8	Massasussets	YES				YES
9	Maryland	YES	YES corrosion inhibitor			YES
10	Michigan	NO				NO

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION	7-c	7-d	8	8A	8-a
	STATE	c). Permeability	d). Other	Do you specify/impose penalties for not meeting the following requirements	If yes, please elaborate	a). Strength
11	Minnesota	YES 1500 Coulombs at 56 days				YES We handle on case by case
12	Missouri					
13	Nevada	NO Permeability is specified as a mix design requirement. No production testing is completed.				YES
14	New Hampshire	YES 0 to 7,000 Coulombs	YES W/C ratio (tested by microwave oven) and concrete cover			YES Pay adjustment by formula, only penalties assessed
15	New Jersey	YES	YES			NO
16	New Mexico	YES	YES Durbility Index based on freeze/thaw risk, ASR mitigation and strength gain curve to assure early strength not too high, but strength gain continues at later ages.			YES
17	North Carolina	NO				YES % Price reduction = 1- (f'c achieved/ 4500)**2
18	North Dakota	NO	NO	NO		

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION	7-c	7-d	8	8A	8-a
	STATE	c). Permeability	d). Other	Do you specify/impose penalties for not meeting the following requirements	If yes, please elaborate	a). Strength
19	Ohio	YES 2000 @ maximum W/C - you could go lower but unless you figure how to control the high strengths you could get some additional cracking in the decks.	Maybe			YES
20	Ontario	YES Rapid chloride permeability test is specified to be 1000 Coulombs or less.	NO			YES Statistical approach used to evaluate performance (percent within limits). Penalty, full payment or bonus applied, referee process available.
21	Oregon	YES				YES
22	Puerto Rico	YES Permeability Test performed as per AASHTO T-277, cylinders are accelerated cured at 100 F for 21 days. We are also considering the use of the Surface Resistivity test to estimate permeability.				YES Acceptance based upon moving average and individual strength test (average of cylinders set)
23	Texas	YES Only as an option to the prescriptive specification.				YES
24	Washington	NO	NO			YES
25	West Virginia	YES 750 coulombs max at 90 days (or sooner) - AASHTO T277				YES Same penalty as our standard spec for low strength - very seldom seen with HPC unless a real problem occurs
26	Wisconsin	YES during mix design & every 3 months during production				YES

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION / STATE	8-b: b). Hardened air content	8-c: c). Permeability	8-d: d). Other	9: Have you been directly involved in HPC	10: If yes, what was your role	11: Were you satisfied with the outcome of the HPC project(s) in your state
1	Alabama	NO	NO	NO			YES
		Concrete not meeting specified requirements for total air was rejected upon testing in the field.	Not an accepting parameter	Temperature and slump were handled as "b" above			
2	Delaware				YES		YES
						wrote spec	
3	Florida		YES		YES		YES
			If the concrete does not meet the intended surface resistivity value the mix is not approved. The SR is not performed as a field acceptance method it is required for acceptance of the mix.			I've been involved with the specification writing of HPC for 15 or 20 years.	I'm satisfied because the projects have been very sucsessful when the specificaitons have been followed.
4	Idaho	NO	NO		YES		NO
						HQ Materials - specification review and mix design approval	
5	Indiana	NO	YES	YES	YES		YES
		plastic air content at point of placement	If density is low for measured air %, perm < (target + 200 C)	plastic air % has pay factor, Low density triggers permeability		Write specification, provide training & monitor construciton	varies, curing of deck is critial and not well enforced
6	Iowa	NO	NO		YES		YES
						Materials spec development	
7	Louisiana	NO	YES		YES		YES
			The max amount must be met. This is rarely a problem.			9 years as concrete research engineer at LTRC	See I-10 Twin Spans Bridge for example
8	Massasussets	YES	YES		YES		YES
			Will not approve mix design without a passing permeability test result			Review and approval of specification	
9	Maryland				YES		YES
						materials engineer on committee that put it together	
10	Michigan	NO	NO		YES		YES
						State Materials Engineer	To date, the demo projects have gone well

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION	8-b	8-c	8-d	9	10	11
	STATE	b). Hardened air content	c). Permeability	d). Other	Have you been directly involved in HPC	If yes, what was your role	Were you satisfied with the outcome of the HPC project(s) in your state
11	Minnesota		YES		YES		YES
			We handle on case by case			Help with writing spec.	We have had Both success and no Improvement over standard spec.
12	Missouri						
13	Nevada	NO	NO		YES		YES
						Maintain and modify specifications, perform field observations of HPC placement and perform forensic investigations.	
14	New Hampshire		YES	YES	NO		
			Assessed by formula when > 4k Coulombs, rejected over 7k	Concrete cover			
15	New Jersey	NO	NO	NO	YES		NO
						Materials Testing	We are seeing more cracking with HPC than we had in the past.
16	New Mexico	NO	NO		YES		
		Not tested in field	Not tested in field		Yes	Extensive over many years	Somewhat. Theres still plenty of room for improvement
17	North Carolina	NO	NO		YES		YES
						Policy development- from Bridge Design office	
18	North Dakota				YES		
						Represent NDDOT on KU research committee.	We haven't yet built a bridge deck with HPC

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION / STATE	8-b b). Hardened air content	8-c c). Permeability	8-d d). Other	9 Have you been directly involved in HPC	10 If yes, what was your role	11 Were you satisfied with the outcome of the HPC project(s) in your state
19	Ohio	NO	NO Amount of testing was a pain and since we set the min perm at max W/C and since we don't see much max w/c we dropped it.		Oh god yeah. Since 1994	Spec development - field issues - deck surveys - claims - court cases.	
20	Ontario	YES Evaluated on cores removed from structure. Penalty, full payment or bonus applied, referee process available.	YES Evaluated on cores removed from structure. Full payment/penalty applied as applicable. Referee process available.	NO	YES	Involved with specification development	YES
21	Oregon				YES Supervised developers.		YES
22	Puerto Rico		YES $0.10 per coulomb per cubic meters in excess of the permeability level indicated in the contract		YES		YES Altough the implementation has been a working progress, PRHTA feels that by specifying HPC we have considerably improve the quality of our Concrete structures.
23	Texas	NO Reject truck when fresh EA not obtained.	NO Mix design acceptance		YES	Specifier - specification writer.	YES This method works well for us.
24	Washington	NO	NO	NO	YES	Development of Specifications, construction of all Br. decks	Still Evaluating results.
25	West Virginia	NO	YES Penalty is imposed for high permeability, but no formula or price adjustment schedule is currently in our specs - Engineering judgment		YES	Spec development & implementation	YES
26	Wisconsin	NO	NO		YES	Quality Assurance Supervisor (Jim Parry)	YES

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION STATE	12 Please provide your comments regarding HPC and the method of specifying it on State DOT projects	13 Do you have a web site (or link) where we can download your HPC Specification, please provide	14 Please provide your contact information. Thank you for participating in this survey
1	Alabama	See page 3 of attached publication file.	The HPC specifications are not part of the public domain in ALDOT's web site -please see attached document in email.	Lyndi Blackburn, P.E.; Alabama Department of Transportation; Assistant Materials & Tests Engineer; blackburnl@dot.state.al.us; 334-206-2203
2	Delaware		NO	Jim Pappas
3	Florida		YES ftp://ftp.dot.state.fl.us/LTS/CO/Specifications/SpecBook/2010Book/346.pdf	Micahel Bergin, State Materials Office, Gainesville Fl. 32609, (352) 955-6666, michael.bergin@dot.state.fl.us
4	Idaho			
5	Indiana	hard to get construction to administer & enforce specification	NO	A. Zander, azander@indot.in.gov
6	Iowa	Some areas of state slag not available case by case basis	DS09012 http //www iowadot.gov/specifications/developmental_specs.aspx	wayne.Sunday@dot.iowa.gov todd hanson@dot.iowa.gov
7	Louisiana	I think LA DOTD approach to HPC has worked out fine for us.	NO Not at this time but we're rewriting our spec book now so hopefully soon.	See email.
8	Massasussets	The Bridge section issued a specification in August 2007 declaring all bridge decks be 4000 - 3/4" HP concrete	YES http //www.mhd state.ma.us/downloads/manuals/SSP022510MetEng.pdf	Bruce Noyes for John E. Grieco P.E. Director of Research and Materials, MassDOT - Highway Division
9	Maryland	use ot for bridge decks and we are looking for long term durability, not necessarily high strength	YES roads.maryland.gov then go to business standards and specifications	vicki stewart; vstewart@sha.state.md.us; 443-572-5134
10	Michigan		YES	Contact our Supervisor of Materials Investigation Group.

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION / STATE	12: Please provide your comments regarding HPC and the method of specifying it on State DOT projects	13: Do you have a web site (or link) where we can download your HPC Specification, please provide	14: Please provide your contact information. Thank you for participating in this survey
11	Minnesota	We have only used performance spec twice. We will be using it on three more projects in future.	NO	Ron Mulvaney-651-366-5575 Ronald.Mulvaney@state.mn.us
12	Missouri			
13	Nevada	HPC and wet curing methods have greatly improved the performance of our bridge decks. The concepts of densifying aggregate and cementitious systems to achieve better performance have proven to be sound in construction practice.	Our HPC specs are issued as special provisions and are not listed online. We are currently making modifications to the specification that will be available soon. Attached is our current HPC spec.	Mike Griswold, Principal Materials Engineer, 1263 S. stewart Steet, Carson City, NV 89712, ph: 775-888-7781, email:mgriswold@dot.state.nv.us
14	New Hampshire		http //www.nh.gov/dot/org/projectdevelopment/highway design/specifications/documents/Division500.pdf	Denis Boisvert, NHDOT Chief of Materials Technology Dboisvert@dot.state.nh.us (603) 271-3151
15	New Jersey		YES	Eileen Sheehy, Manager, Bureau of Materials, New Jersey DOT
16	New Mexico	Performance specs work best if they are properly prepared, reviewed, approved and ENFORCED		Bryce Simons, 505/827-5191 bryce.simons@state.nm.us
17	North Carolina	In theory, would be good to use a 56 day strength (thereby lowering cement factor) and test for permeability, but probably not practical (from contractor production perspective).		Greg Perfetti, State Bridge Design Engineer, NCDOT
18	North Dakota		NO You could contact Dr. JoAnn Browning, The University of Kansas, Learned Hall Lawrence, KS 785-864-3766 for information concerning the research project.	Larry Schwartz, Assistant Bridge Engineer, NDDOT 701-328-4446 lschwart@nd.gov

Table B–1. Compilation of all DOT Survey Responses (Continued)

NUMBER	QUESTION / STATE	12 Please provide your comments regarding HPC and the method of specifying it on State DOT projects	13 Do you have a web site (or link) where we can download your HPC Specification, please provide	14 Please provide your contact information. Thank you for participating in this survey
19	Ohio			Lloyd Welker lloyd.welker@dot.state.oh.us 614 275-1351
20	Ontario		YES Attached are: Ontario Provincial Standard Specification (OPSS) PROV 904-Construction Specification for Concrete Structures, OPSS PROV 1350-Material Specification for Concrete-Materials and Production and test methods.	jana.konecny@ontario.ca
21	Oregon	The Contractor has the option of using the prescriptive design or proposing one that meets the permeability requirement. Most use the prescriptive design.	YES http://www.oregon.gov/ODOT/HWY/SPECS/standard_specifications.shtml#2008_Standard_Specifications — Section 02001.30.	Keith Johnston, PE, Structure Services Engineer 503-986-3053 keith.r.johnston@odot.state.or.us
22	Puerto Rico		NO Attached please find our 2003 special provision and recent modifications included as instruction to bidders.	Andrés Alvarez-Ibáñez, Materials Testing Office, Puerto Rico Highway and Transportation Authority (PRHTA), Phone (787) 729-1592 - aalvarez@act.dtop.gov.pr
23	Texas		http://www.dot.state.tx.us/apps/specs/ShowSD.asp?year=3&type=SP&number=421	Kevin Pruski kpruski@dot.state.tx.us
24	Washington	Recommend performace specification to address cracking issues	NO	Kurt Williams, email: willikr@wsdot.wa.gov & Mohammad Sheikhizadeh Email: SheikhM@WSDOT.WA.GOV
25	West Virginia	It's now in our 2009 supplemental specs, but we started with it as a special provision. Mixing and curing immediatey with wet burlap are very important when silica fume is used.	YES See Section 601of the 2009 supplemental specs and refer to Class H. http://www.transportation.wv.gov/highways/engineering/Specifications/2009/2K09_SUP.pdf	Mike Mance. Telephone # (304) 558-9846. E-mail: mike.a.mance@wv.gov
26	Wisconsin		NO	Jim Parry, 608-246-7939, james.parry@dot.wi.gov

Table B-2. Alabama DOT Survey Response

Alabama DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	Answers		
		YES	NO	Alabama
1	Do you use HPC on your bridge decks	NO		As part of a research project only.
2	If not, what has been your state approach in improving the durability of your bridge decks			Introduction of supplementary cementitious materials and enhance curing practices.
3	If yes, do you have a designated specification for the HPC	YES		Please see attached word document for special provision used on the research project.
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	YES		Both, conventional concrete and HPC were combined in a Special Provision. - See attached document in the email.
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	NO		No, only the percent substitution allowed for the supplementary cementitious materials were specified.
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	YES		
	c). Permeability	NO		Tested by research team as probable further specification consideration.
	d). Other	YES		Temperature, slump, and unit weight.
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO		Concrete not meeting specified requirements for total air was rejected upon testing in the field.
	c). Permeability	NO		Not an accepting parameter
	d). Other	NO		Temperature and slump were handled as "b" above
9	Have you been directly involved in HPC			
10	If yes, what was your role			
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			See page 3 of attached publication file.
13	Do you have a web site (or link) where we can download your HPC Specification, please provide			The HPC specifications are not part of the public domain in ALDOT's web site -please see attached document in email.
14	Please provide your contact information. Thank you for participating in this survey			Lyndi Blackburn, P.E.; Alabama Department of Transportation; Assistant Materials & Tests Engineer; blackburnl@dot.state.al.us; 334-206-2203

Table B-3. Delaware DOT Survey Response

Delaware DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	Answers		
		YES	NO	Delaware
1	Do you use HPC on your bridge decks	NO	x	
2	If not, what has been your state approach in improving the durability of your bridge decks			All our PCC has either GGBFS or fly ash for ASR mitigation so we have low permeability concrete.
3	If yes, do you have a designated specification for the HPC			
4	Is your HPC specification:			
	a). A stand alone	YES		
	b). Incorporated in your DOT standard specification			
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance	YES		
	b). Prescriptive			
	c). Combination			
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	NO	x	
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content			
	c). Permeability	YES		
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content			
	c). Permeability			
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			wrote spec
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	NO	x	
14	Please provide your contact information. Thank you for participating in this survey			Jim Pappas

Table B-4. Florida DOT Survey Response

Florida DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS YES	NO	Florida
1	Do you use HPC on your bridge decks	YES		Class F fly ash or slag is required in our concrete, w/c is 0.44, minimum comp.strength at 28 days is 4500 psi. For concrete placed in aggressive environments we reduce w/c to 0.41, increase cementitious content to 658#
2	If not, what has been your state approach in improving the durability of your bridge decks			Our decks do not deteriorate like most states, our issues are air born chlorides from sea water, where bridges are placed in these environments.
3	If yes, do you have a designated specification for the HPC	NO	X	Recent specification changes will require all of our concrete to have fly ash or slag as a percentage of the cementitious material
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	NO	X	
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance		X	Currently we have only one Performance based specification for structures that are constructed in non- aggressive enviroments. All other applications have prescriptive specifcations
	b). Prescriptive	YES		
	c). Combination		X	
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		Concrete must meet the minimum required strength in 28 days
	b). Hardened air content	NO	X	
	c). Permeability	YES		We have a Surface Resitivity requirment when silica fume is required in the concrete due to the project enviroment.
	d). Other	YES		Mass concrete temperature contols may be required for massive elements. In these cases high volumns of fly ash are normally required to control temerature differentials.
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		If the strength is within 500 psi of the required minimum strength the contractor is assessed a penalty for all of the concrete that that particular sample represents. If the strength is greater than 500 psi less than the minimum then the contractor is required to hire a specialty engineer to evaluate the structure and provide an Engineering analysis to the project administrator.
	b). Hardened air content			
	c). Permeability	YES		If the concrete does not meet the intended surface resistivity value the mix is not approved. The SR is not performed as a field acceptance method it is required for acceptance of the mix.
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			I've been involved with the specification writing of HPC for 15 or 20 years.
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		I'm satisfied because the projects have been very sucsessful when the specificaitons have been followed.
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			We include the changes into the specifcation, the spec goes out to the industry for their review and comment, we respond to the comments then forward to FHWA. Normally we try to address any industry issues, but if there reson to not use the speificaiton si just becasue we've never done it that way before then thats typically not a good enough reason not to implement.
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	YES		ftp://ftp.dot.state.fl.us/LTS/CO/Specifications/SpecBook/2010Book/346.pdf
14	Please provide your contact information. Thank you for participating in this survey			Micehel Bergin, State Materials Office, Gainesville Fl. 32609, (352) 955-6666, michael.bergin@dot.state.fl.us

Table B-5. Idaho DOT Survey Response

Idaho DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	Idaho		
		YES	NO	Idaho
1	Do you use HPC on your bridge decks	NO	X	Not routinely
2	If not, what has been your state approach in improving the durability of your bridge decks			Silica Fume overlays
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone	YES		
	b). Incorporated in your DOT standard specification			
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		Current Spec has a min and max cementious content requirement
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO	X	
	c). Permeability	YES		this is a design test for us and not used on production concrete
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO	X	
	c). Permeability	NO	X	
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			HQ Materials - specification review and mix design approval
11	Were you satisfied with the outcome of the HPC project(s) in your state	NO	X	
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			
13	Do you have a web site (or link) where we can download your HPC Specification, please provide			
14	Please provide your contact information. Thank you for participating in this survey			

Table B-6. Indiana DOT Survey Response

Indiana DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS YES	ANSWERS NO	Indiana
1	Do you use HPC on your bridge decks	YES		very limited basis for select structures only
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone	YES		Unique Special Provision for select contracts
	b). Incorporated in your DOT standard specification			
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		with QC/QA criteria added as well
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		ternary mix with mins & max for each component, max on paste
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		4400 psi min @ 28-day for sublot, Lot value > 4675 psi min
	b). Hardened air content			plastic air content at point of placement
	c). Permeability	YES		trial batch set target for permeability
	d). Other	YES		Unit weight comparison to target, based on measured air %
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		Pay factors per Lot basis (150 cyd), lot & sublot min. value req.
	b). Hardened air content	NO		plastic air content at point of placement
	c). Permeability	YES		If density is low for measured air %, perm < (target + 200 C)
	d). Other	YES		plastic air % has pay factor, Low density triggers permeability
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Write specification, provide training & monitor construciton
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		varies, curing of deck is critial and not well enforced
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			hard to get construction to administer & enforce specification
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	NO	X	
14	Please provide your contact information. Thank you for participating in this survey			A. Zander, azander@indot.in.gov

Table B-7. Iowa DOT Survey Response

Iowa DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Iowa
1	Do you use HPC on your bridge decks	YES		
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone	YES		
	b). Incorporated in your DOT standard specification			
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		Cement, slag, and flyash
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		4500-5000 psi depending on member
	b). Hardened air content			
	c). Permeability	NO	x	A target of 1500 coulombs but not required to meet - just rely on supplementary materials
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	NO	x	
	b). Hardened air content	NO	x	
	c). Permeability	NO	x	
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Materials spec development
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			Some areas of state slag not available case by case basis
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	DS0901	DS0903	http://www.iowadot.gov/specifications/developmental_specs.aspx
14	Please provide your contact information. Thank you for participating in this survey			wayne.Sunday@dot.iowa.gov todd.hanson@dot.iowa.gov

Table B-8. Louisiana DOT Survey Response

Louisiana DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS YES	ANSWERS NO	Louisiana
1	Do you use HPC on your bridge decks	YES		Some but not all bridges.
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		Its our main structural mix but with permeability requirements.
4	Is your HPC specification:			
	a). A stand alone	YES		Currently but may soon be introduced into our std. specs.
	b). Incorporated in your DOT standard specification			
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	NO	X	Not really; just allowable ranges and liberal minimums.
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO	X	Air content isn't a factor here; just a 2-7% range.
	c). Permeability	YES		max 2000 coulombs in general with a max of 1000 for some jobs.
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements	YES		
	If yes, please elaborate			
	a). Strength	YES		Pay penalties ranging from 98% to 50% or remove and replace
	b). Hardened air content	NO	X	
	c). Permeability	YES		The max amount must be met. This is rarely a problem.
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			9 years as concrete research engineer at LTRC
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		See I-10 Twin Spans Bridge for example
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			I think LA DOTD approach to HPC has worked out fine for us.
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	NO	X	Not at this time but we're rewriting our spec book now so hopefully soon.
14	Please provide your contact information. Thank you for participating in this survey			See email.

Table B-9. Massachusetts DOT Survey Response

Massachusetts DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Massachusetts
1	Do you use HPC on your bridge decks	YES		
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	YES		
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	NO	X	Give the maximum cementitious amounts, contractor is responsible after that.
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	YES		
	c). Permeability	YES		
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	YES		
	c). Permeability	YES		Will not approve mix design without a passing permeability test result
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Review and approval of specification
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			The Bridge section issued a specification in August 2007 declaring all bridge decks be 4000 - 3/4" HP concrete
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	YES		http://www.mhd.state.ma.us/downloads/manuals/SSP022510MetEng.pdf
14	Please provide your contact information. Thank you for participating in this survey			Bruce Noyes for John E. Grieco P.E. Director of Research and Materials, MassDOT - Highway Division

Table B-10. Maryland DOT Survey Response

Maryland DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Maryland
1	Do you use HPC on your bridge decks	YES		
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone	YES		
	b). Incorporated in your DOT standard specification			
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		minimum cementitious content
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content			
	c). Permeability	YES		
	d). Other	YES		corrosion inhibitor
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content		NO	
	c). Permeability		NO	
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			materials engineer on committee that put it together
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			use ot for bridge decks and we are looking for long term durability, not necessarily high strength
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	YES		roads.maryland.gov then go to business standards and specifications
14	Please provide your contact information. Thank you for participating in this survey			vicki stewart; vstewart@sha.state.md.us; 443-572-5134

Table B-11. Michigan DOT Survey Response

Michigan DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Michigan
1	Do you use HPC on your bridge decks	YES		Only a few to date, project specific for demo purposes
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone	YES		
	b). Incorporated in your DOT standard specification		X	
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		refer to standard deck 28 day compressive of 5000 psi
	b). Hardened air content	NO	X	
	c). Permeability	NO	X	
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	NO	X	
	b). Hardened air content	NO	X	
	c). Permeability	NO	X	
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			State Materials Engineer
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		To date, the demo projects have gone well.
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			The standard test methods and specification thresholds for strength, permeability, and hardened air are not sufficient as a basis for accceptance for payment. In other words, they are not correlated to field performance using actual data. Further, some ofthese test methods are used primarily as investigatory tools and are not intended to be used for acceptance. Also, some of these tests are very labor intensive and not necessarily applicable for field use due to the labor and equipment intensity. Hence, HPC may be better achieved by citing the SCM's tat you desire along with aggregate optimization. Construction practices (curing, concrete temperature, evaporation rate, environmental considerations, etal) are also very important.
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	YES		
14	Please provide your contact information. Thank you for participating in this survey			Contact our Supervisor of Materials Investigation Group: Tim Stallard 517-322-6448; stallardt@michigan.gov

Table B-12. Minnesota DOT Survey Response

Minnesota DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Minnesota
1	Do you use HPC on your bridge decks	YES		
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	YES		We only relace portions of our standard spec
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			We still use these in certain situations
	c). Combination	YES		
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	NO	X	
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		May or maynot depending on Job
	b). Hardened air content			
	c). Permeability	YES		1500 Coulombs at 56 days
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		We handle on case by case
	b). Hardened air content			
	c). Permeability	YES		We handle on case by case
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Help with writing spec.
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		We have had Both success and no improvement over standard spec.
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			We have only used performance spec twice. We will be using it on three more projects in future.
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	NO	X	
14	Please provide your contact information. Thank you for participating in this survey			Ron Mulvaney-651-366-5575 Ronald.Mulvaney@state.mn.us

Table B-13. Missouri DOT Survey Response

Missouri DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Missouri
1	Do you use HPC on your bridge decks	NO	X	
2	If not, what has been your state approach in improving the durability of your bridge decks			Seven-day wet cure, modified PCC mix w/ supplementary cementitious materials and Type A water reducer
3	If yes, do you have a designated specification for the HPC			
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification			
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination			
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.			
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength			
	b). Hardened air content			
	c). Permeability			
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength			
	b). Hardened air content			
	c). Permeability			
	d). Other			
9	Have you been directly involved in HPC			
10	If yes, what was your role			
11	Were you satisfied with the outcome of the HPC project(s) in your state			
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			
13	Do you have a web site (or link) where we can download your HPC Specification, please provide			
14	Please provide your contact information. Thank you for participating in this survey			

Table B-14. Nevada DOT Survey Response

Nevada DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Nevada
1	Do you use HPC on your bridge decks	YES		
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	YES		
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance		x	
	b). Prescriptive	YES		
	c). Combination		x	
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		Allowable ranges are specified for cement and silica fume. Minimums are specified for flyash.
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO	x	
	c). Permeability	NO	x	Permeability is specified as a mix design requirement. No production testing is completed.
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO	x	
	c). Permeability	NO	x	
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Maintain and modify specifications, perform field observations of HPC placement and perform forensic investigations.
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			HPC and wet curing methods have greatly improved the performance of our bridge decks. The concepts of densifying aggregate and cementitious systems to achieve better performance have proven to be sound in construction practice.
13	Do you have a web site (or link) where we can download your HPC Specification, please provide			Our HPC specs are issued as special provisions and are not listed online. We are currently making modifications to the specification that will be available soon. Attached is our current HPC spec.
14	Please provide your contact information. Thank you for participating in this survey			Mike Griswold, Principal Materials Engineer, 1263 S. stewart Steet, Carson City, NV 89712, ph: 775-888-7781, email:mgriswold@dot.state.nv.us

Table B-15. New Hampshire DOT Survey Response

New Hampshire DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	New Hampshire
1	Do you use HPC on your bridge decks	NO	X	No HPC spec., but deck requirements considered to be HP.
2	If not, what has been your state approach in improving the durability of your bridge decks			Control of w/c ratio and air content
3	If yes, do you have a designated specification for the HPC	NO	X	
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	YES		
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		Aggr. gradation and admixtures are prescriptive
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		Aggregate gradation is specified
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO	X	
	c). Permeability	YES		0 to 7,000 Coulombs
	d). Other	YES		W/C ratio (tested by microwave oven) and concrete cover
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		Pay adjustment by formula; only penalties assessed
	b). Hardened air content			
	c). Permeability	YES		Assessed by formula when > 4k Coulombs; rejected over 7k
	d). Other	YES		Concrete cover
9	Have you been directly involved in HPC	NO	X	
10	If yes, what was your role			
11	Were you satisfied with the outcome of the HPC project(s) in your state			
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			
13	Do you have a web site (or link) where we can download your HPC Specification, please provide			http://www.nh.gov/dot/org/projectdevelopment/highwaydesigr /specifications/documents/Division500.pdf
14	Please provide your contact information. Thank you for participating in this survey			Denis Boisvert, NHDOT Chief of Materials Technology Dboisvert@dot.state.nh.us (603) 271-3151

Table B-16. New Jersey DOT Survey Response

New Jersey DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	New Jersey
1	Do you use HPC on your bridge decks	YES		
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	YES		
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance	YES		
	b). Prescriptive			
	c). Combination			
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	NO	X	
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO	X	
	c). Permeability	YES		
	d). Other	YES		
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	NO	X	
	b). Hardened air content	NO	X	
	c). Permeability	NO	X	
	d). Other	NO	X	
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Materials Testing
11	Were you satisfied with the outcome of the HPC project(s) in your state	NO	X	We are seeing more cracking with HPC than we had in the past.
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	YES		
14	Please provide your contact information. Thank you for participating in this survey			Eileen Sheehy, Manager, Bureau of Materials, New Jersey DOT

Table B-17. New Mexico DOT Survey Response

New Mexico DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	New Mexico
1	Do you use HPC on your bridge decks	YES		In NM, we use a 4000 psi mix, but require that it not exceed 0.05% shrinkager and it use a combined gradation approach in order to optimize the aggregate structure.
2	If not, what has been your state approach in improving the durability of your bridge decks			We require a minimum of 85% to 95% Durabilty Index after testing in accordane with ASTM C666, Method A, depending on what the freeze/thaw risk is.
3	If yes, do you have a designated specification for the HPC	NO	X	
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	NO	X	
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance	YES		Other than meeting basic ASTM C33 properties, we require documentation to confirm compressive strength, strength gain over time, durabilty ,impermebiity and freeze/thaw resistance. Once they have designated the w/c and wc+p and the aggregate structure required to chieve this, we hold them to reproducing this mix.
	b). Prescriptive			
	c). Combination			
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	NO	X	
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	YES		
	c). Permeability	YES		
	d). Other	YES		Durbility Index based on freeze/thaw risk, ASR mitigation and strength gain curve to assure early strength not too high, but strength gain continues at later ages.
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO		Not tested in field
	c). Permeability	NO		Not tested in field
	d). Other			
9	Have you been directly involved in HPC	YES		Yes
10	If yes, what was your role			Extensive over many years
11	Were you satisfied with the outcome of the HPC project(s) in your state			Somewhat. Theres still plenty of room for improvement
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			Performance specs work best if they are properly prepared, reviewed, approved and ENFORCED
13	Do you have a web site (or link) where we can download your HPC Specification, please provide			
14	Please provide your contact information. Thank you for participating in this survey			Bryce Simons, 505/827-5191 bryce.simons@state.nm.us

Table B-18. North Carolina DOT Survey Response

North Carolina DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	North Carolina
1	Do you use HPC on your bridge decks	YES		Add mineral admixture- flyash when salt exposure likely
2	If not, what has been your state approach in improving the durability of your bridge decks			Also, require 7 day wet cure (soaker hose - under cover)
3	If yes, do you have a designated specification for the HPC			
4	Is your HPC specification:			
	a). A stand alone		x	
	b). Incorporated in your DOT standard specification	YES		
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive	YES		
	c). Combination			
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		20% FA replacement 1.2 # per # cement
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		4500 psi, which may increase shrinkage potential due to high cement factor
	b). Hardened air content	NO	x	
	c). Permeability	NO	x	
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		% Price reduction = 1- (f'c achieved/ 4500)**2
	b). Hardened air content	NO	x	
	c). Permeability	NO	x	
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Policy development- from Bridge Design office
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			In theory, would be good to use a 56 day strength (thereby lowering cement factor) and test for permeability, but probably not practical (from contractor production perspective).
13	Do you have a web site (or link) where we can download your HPC Specification, please provide			
14	Please provide your contact information. Thank you for participating in this survey			Greg Perfetti, State Bridge Design Engineer, NCDOT

Table B-19. North Dakota DOT Survey Response

North Dakota DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	North Dakota
1	Do you use HPC on your bridge decks	NO	X	
2	If not, what has been your state approach in improving the durability of your bridge decks			We are a participant in Kansas Crack Free Bridge Deck Research
3	If yes, do you have a designated specification for the HPC			
4	Is your HPC specification:			We don't have a HPC specification
	a). A stand alone			
	b). Incorporated in your DOT standard specification			
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			Not Applicable
	a). Performance			
	b). Prescriptive			
	c). Combination			
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	NO	X	
7	Do you specify any of the following as end results of the concrete.	NO	X	
	If yes, please elaborate			
	a). Strength	NO		
	b). Hardened air content	NO		
	c). Permeability	NO		
	d). Other	NO		
8	Do you specify/impose penalties for not meeting the following requirements	NO	X	
	If yes, please elaborate			
	a). Strength			
	b). Hardened air content			
	c). Permeability			
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Represent NDDOT on KU research committee.
11	Were you satisfied with the outcome of the HPC project(s) in your state			We haven't yet built a bridge deck with HPC
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	NO	X	You could contact Dr. JoAnn Browning, The University of Kansas, Learned Hall Lawrence, KS 785-864-3766 for information concerning the research project.
14	Please provide your contact information. Thank you for participating in this survey			Larry Schwartz, Assistant Bridge Engineer, NDDOT 701-328-4446 lschwart@nd.gov

Table B-20. Ohio DOT Survey Response

Ohio DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS YES	NO	Ohio
1	Do you use HPC on your bridge decks	YES		You need to first specifically define what you mean by HPC. It has three meanings to FHWA and even more around the country. We try and achieve a low permeability.
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	BOTH		We started with a designated mix design. We have now moved to a requirement for permeability but let the contractor develop the mix. My opinion the second is better.
4	Is your HPC specification:			
	a). A stand alone			Not all districts do it.
	b). Incorporated in your DOT standard specification	YES		
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and impose penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		Mix is performance. Some of the placement mixing transporting etc are prescriptive
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		ACI minimum and maximum limitations of cementatious and cement
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		Minimum for design purposes
	b). Hardened air content	NO		Too many arguments and truthfully has little to do (performance wise) with HPC (I know that sounds like a stupid statement but do you check hardened air for your current concrete? Do you have freeze thaw failures. Actually HPC shows laboratory data that lower airs or more poorly spaced airs can be handled betterr by HPC-not suggesting changing your air spec just suggesting that if you don't do hardened now why do it with HPC)
	c). Permeability	YES		2000 @ maximum W/C - you could go lower but unless you figure how to control the high strengths you could get some additional cracking in the decks.
	d). Other	Maybe		We are moving to require well graded aggregate. We found that all our concretes perform better with a well graded versus a 57 and sand. Did a deck survey of 500 bridge decks and found that mixes using a 3 stone blend #57 #8 and sand had better constraint cracking performance than #57 and sand (no matter what type of mix)
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO		
	c). Permeability	NO		Amount of testing was a pain and since we set the min perm at max W/C and since we don't see much max w/c we dropped it.
	d). Other			
9	Have you been directly involved in HPC			Oh god yeah. Since 1994
10	If yes, what was your role			Spec development - field issues - deck surveys - claims - court cases.
11	Were you satisfied with the outcome of the HPC project(s) in your state			
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			
13	Do you have a web site (or link) where we can download your HPC Specification, please provide			
14	Please provide your contact information. Thank you for participating in this survey			Lloyd Welker lloyd.welker@dot.state.oh.us 614 275-1351

Table B-21. Ontario, Canada Survey Response

Ontario, Canada

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Ontario
1	Do you use HPC on your bridge decks	YES		
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	YES		
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		Minimum compressive strength of 50MPa, low permeability to chlorides and moisture, air void system providing good resistance to freeze/thaw action. Contractors have flexibility with respect to material selection, cement content, supplementary cementing materials, and slump and air content of plastic concrete. No flexibility with respect to curing requirements--moist curing for 7days, fog misting, prompt application of burlap (within 2-4m of finishing machine), use of soaker hoses and moist curing regardless of ambient air temperature.
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	NO	NO	
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		Compressive strength tested on cylinders.
	b). Hardened air content	YES		Specified minimum air content of 3% and maximum spacing factor of 0.250mm.
	c). Permeability	YES		Rapid chloride permeability test is specified to be 1000 Coulombs or less.
	d). Other	NO	NO	
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		Statistical approach used to evaluate performance (percent within limits). Penalty, full payment or bonus applied; referee process available.
	b). Hardened air content	YES		Evaluated on cores removed from structure. Penalty, full payment or bonus applied; referee process available.
	c). Permeability	YES		Evaluated on cores removed from structure. Full payment/penalty applied as applicable. Referee process available.
	d). Other	NO	NO	
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Involved with specification development.
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	YES		Attached are: Ontario Provincial Standard Specification (OPSS) PROV 904-Construction Specification for Concrete Structures, OPSS.PROV 1350-Material Specification for Concrete-Materials and Production and test methods.
14	Please provide your contact information. Thank you for participating in this survey			jana.konecny@ontario.ca

Table B-22. Oregon DOT Survey Response

Oregon DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Oregon
1	Do you use HPC on your bridge decks	YES		
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	YES		
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	YES		
	c). Permeability	YES		
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content		X	
	c). Permeability		X	
	d). Other		X	
9	Have you been directly involved in HPC	YES		Supervised developers.
10	If yes, what was your role			
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			The Contractor has the option of using the prescriptive design or proposing one that meets the permeability requirement. Most use the prescriptive design.
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	YES		http://www.oregon.gov/ODOT/HWY/SPECS/standard_specifications.shtml#2008_Standard_Specifications --- Section 02001.30.
14	Please provide your contact information. Thank you for participating in this survey			Keith Johnston, PE, Structure Services Engineer 503-986-3053 keith.r.johnston@odot.state.or.us

Table B-23. Puerto Rico DOT Survey Response

Puerto Rico DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Puerto Rico
1	Do you use HPC on your bridge decks	YES		PRHTA has specify the used HPC since 1999
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		Special Provision 934
4	Is your HPC specification:			
	a). A stand alone	YES		Special Provision 934
	b). Incorporated in your DOT standard specification			
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance	YES		
	b). Prescriptive			
	c). Combination			
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	NO	X	We, however, specify maximum amounts (upper limit) of Supplementary Cementitious Materials (SCM's)
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		Acceptance based upon moving average and individual strength test (average of cylinders set)
	b). Hardened air content			
	c). Permeability	YES		Permeability Test performed as per AASHTO T-277, cylinders are accelerated cured at 100 F for 21 days. We are also considering the use of the Surface Resistivity test to estimate permeability.
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		Acceptance based upon moving average and individual strength test (average of cylinders set)
	b). Hardened air content			
	c). Permeability	YES		$0.10 per coulomb per cubic meters in excess of the permeability level indicated in the contract
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Participated in the development of the special provison in 1999 and all subsequent revisions. Our laboratories, part of my office, have perform all testing. To date I'm part of the PRHTA's Concrete Committee that is revising this specification as well as others.
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		Altough the implementation has been a working progress, PRHTA feels that by specifying HPC we have considerably improve the quality of our Concrete structures.
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			As indicated above we have used an end result specification, with some limited prescriptive requirements. We feel that this type of specification (performance/end result) provides flexibility to our Local Industry in achiving HPC while directly measuring/testing performace.
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	NO	X	Attached please find our 2003 special provision and recent modifications included as instruction to bidders.
14	Please provide your contact information. Thank you for participating in this survey			Andrés Alvarez-Ibáñez, Materials Testing Office, Puerto Rico Highway and Transportation Authority (PRHTA), Phone (787) 729-1592 - aalvarez@act.dtop.gov.pr

Table B-24. Texas DOT Survey Response

Texas DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS YES	NO	Texas
1	Do you use HPC on your bridge decks	YES		Not on all of them though.
2	If not, what has been your state approach in improving the durability of your bridge decks			Use epoxy coated steel in about 1/3 of the State.
3	If yes, do you have a designated specification for the HPC			Use a special provision to the Standard Concrete Item
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	YES		Attached.
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive	YES		Majority (90%) of contractors choose prescriptive option.
	c). Combination	YES		Allow performance option.
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		Maximum limit and % cement replacement with SCM.
7	Do you specify any of the following as end results of the concrete.	YES		
	If yes, please elaborate			
	a). Strength	YES		All concrete.
	b). Hardened air content			Measure fresh EA when EA required (1/3 of state)
	c). Permeability	YES		Only as an option to the prescriptive specification.
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO		Reject truck when fresh EA not obtained.
	c). Permeability	NO	X	Mix design acceptance
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Specifier - specification writer.
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		This method works well for us.
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			
13	Do you have a web site (or link) where we can download your HPC Specification, please provide			http://www.dot.state.tx.us/apps/specs/ShowSD.asp?year=3&type=SP&number=421
14	Please provide your contact information. Thank you for participating in this survey			Kevin Pruski kpruski@dot.state.tx.us

Table B-25. Washington DOT Survey Response

Washington DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Washington
1	Do you use HPC on your bridge decks	NO	NO	
2	If not, what has been your state approach in improving the durability of your bridge decks			Adjust the levels of pozzolans used in the bridge deck concrete and begin the process to develop a performance concrete specification
3	If yes, do you have a designated specification for the HPC			
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification			
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		Just minimum Cementitious
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO	NO	
	c). Permeability	NO	NO	
	d). Other	NO	No	
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO		
	c). Permeability	NO		
	d). Other	NO		
9	Have you been directly involved in HPC	YES	Yes	
10	If yes, what was your role			Development of Specifications, construction of all Br. decks
11	Were you satisfied with the outcome of the HPC project(s) in your state			Still Evaluating results.
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			Recommend performace specification to address cracking issues
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	NO	No	
14	Please provide your contact information. Thank you for participating in this survey			Kurt Williams, email: willikr@wsdot.wa.gov & Mohammad Sheikhizadeh Email: SheikhM@WSDOT.WA.GOV

Table B-26. West Virginia DOT Survey Response

West Virginia DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	West Virginia
1	Do you use HPC on your bridge decks	YES		
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone			
	b). Incorporated in your DOT standard specification	YES		It has been incorporated into the 2009 Supplemental Specs
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		We specify two options, both with specific cementitious material contents (cement+fly ash+silia fume or cement+GGBFS+silica fume) and maximum w/c, but other mix parameters are left up to the Contractor
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		We specify cemeitious materials content, but not aggregates.
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		4,000 psi minimum
	b). Hardened air content	NO	x	
	c). Permeability	YES		750 coulombs max at 90 days (or sooner) - AASHTO T277
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		Same penalty as our standard spec for low strength - very seldom seen with HPC unless a real problem occurs
	b). Hardened air content	NO	x	
	c). Permeability	YES		Penalty is imposed for high permeability, but no formula or price adjustment schedule is currently in our specs - Engineering judgment
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Spec development & implementation
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			it's now in our 2009 supplemental specs, but we started with it as a special provision. Mixing and curing immediatey with wet burlap are very important when silica fume is used.
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	YES		See Section 601of the 2009 supplemental specs and refer to Class H. http://www.transportation.wv.gov/highways/engineering/Specifications/2009/2K09_SUP.pdf
14	Please provide your contact information. Thank you for participating in this survey			Mike Mance. Telephone # (304) 558-9846. E-mail: mike.a.mance@wv.gov

Table B-27. Wisconsin DOT Survey Response

Wisconsin DOT

ARIZONA Department of Transportation (ADOT) is in the process of developing a High Performance Concrete (HPC) Specification for concrete bridge decks in Arizona. ADOT is considering two types of specifications, a prescriptive and a performance specification for HPC, and would like to benefit from other State DOT experience with HPC. The purpose of this survey is to collect information about the use, specification and construction of HPC by State DOT. This information will help ADOT develop a better specification by relying on other State DOT experience in HPC.

#	QUESTIONS	ANSWERS		
		YES	NO	Wisconsin
1	Do you use HPC on your bridge decks	YES		Limited to major corridor projects
2	If not, what has been your state approach in improving the durability of your bridge decks			
3	If yes, do you have a designated specification for the HPC	YES		
4	Is your HPC specification:			
	a). A stand alone	YES		
	b). Incorporated in your DOT standard specification			
5	A performance specification requires the contractor to achieve the end results with little focus on the materials or the methods he uses to achieve those end results, and imposes penalty when end results are not achieved			
	A prescriptive specification requires the contractor to follow specific guidelines and methods to achieve the end results with little focus on penalty if the end results are not met.			
	Based on the above, is your HPC specification:			
	a). Performance			
	b). Prescriptive			
	c). Combination	YES		
	d). None of the above, please elaborate			
6	Do you specify the concrete mix quantities: Cement, fly ash, silica fume, aggregates, etc.	YES		specify a quantity range, contractor provides mix design
7	Do you specify any of the following as end results of the concrete.			
	If yes, please elaborate			
	a). Strength	YES		use PWL with lower spec limit of 4000 psi
	b). Hardened air content	NO		
	c). Permeability	YES		during mix design & every 3 months during production
	d). Other			
8	Do you specify/impose penalties for not meeting the following requirements			
	If yes, please elaborate			
	a). Strength	YES		
	b). Hardened air content	NO		
	c). Permeability	NO		
	d). Other			
9	Have you been directly involved in HPC	YES		
10	If yes, what was your role			Quality Assurance Supervisor (Jim Parry)
11	Were you satisfied with the outcome of the HPC project(s) in your state	YES		
12	Please provide your comments regarding HPC and the method of specifying it on State DOT projects			
13	Do you have a web site (or link) where we can download your HPC Specification, please provide	NO		
14	Please provide your contact information. Thank you for participating in this survey			Jim Parry, 608-246-7939, james.parry@dot.wi.gov

APPENDIX C:
DRAFT PRESCRIPTIVE SPECIFICATION FOR HPC USED ON ARIZONA BRIDGE DECK PROJECTS

Prescriptive Specification for
HIGH PERFORMANCE PORTLAND CEMENT CONCRETE
Used on Bridge Deck Projects for the State of Arizona
Section 10HPC

1 - General Requirements:

Portland cement concrete shall consist of a mixture of hydraulic cement, fine aggregate, coarse aggregate, and water. It may also contain air-entraining admixtures, chemical admixtures, and supplementary cementitious materials.

The contractor shall determine the mix proportions and shall furnish concrete which conforms to the requirements of this specification. All concrete shall be sufficiently workable, at the slump proposed by the contractor within the specified range, to allow proper placement of the concrete without harmful segregation, bleeding, or incomplete consolidation. It shall be the responsibility of the contractor to proportion, mix, place, finish, and cure the concrete properly in accordance with the requirements of this specification.

1.01 Definitions:

High Performance Concrete (HPC) in this specification means concrete with a minimum specified 28-day compressive strength of 4,500 psi or design strength, includes fly ash, silica fume, and may include other supplementary cementitious materials, and have a maximum rapid chloride permeability of 1200 coulombs at 56 days.

2 - Materials:

2.01 Cementitious Material:

2.01-A Hydraulic Cement:

Hydraulic cement shall consist of either Portland cement or Portland-pozzolan cement.

Portland cement shall conform to the requirements of ASTM C 150 for Type II, III, or V, and shall be low alkali cement containing not more than 0.60 percent total alkali (Na_2O equivalent).

Portland-pozzolan cement shall conform to the requirements of ASTM C 595 for blended hydraulic cement with moderate sulfate resistance, Type IP (MS).

Cementitious material is defined as an inorganic material or a mixture of inorganic materials that sets and develops strength by chemical reaction with water by formation of hydrates and is capable of doing so under water. In this specification, cementitious materials are defined as: hydraulic cement (Portland cement or Portland-pozzolan cement) and supplementary cementitious material (Fly Ash, Natural Pozzolan, or Silica Fume).

Hydraulic cement shall be approved prior to its use in accordance with Materials Policy and Procedure Directive No. 13, "Certification and Acceptance of Hydraulic Cement, Fly Ash, Natural Pozzolan, Silica Fume, and Lime".

Cement of different types or brands shall not be intermingled or used in the same batch. The contractor shall provide suitable means for storing and protecting the cement against dampness. Cement which for any reason has become partially set or which contains caked lumps shall not be used.

The use of either sacked cement or bulk cement is permissible. The use of fractional bags of sacked cement will not be permitted unless the contractor elects to weigh the cement into each batch.

2.01-B Supplementary Cementitious Material (Fly Ash, Silica Fume and Natural Pozzolan):

Supplementary cementitious materials shall be approved prior to their use in accordance with Materials Policy and Procedure Directive No. 13, "Certification and Acceptance of Hydraulic Cement, Fly Ash, Natural Pozzolan, and Silica Fume".

Fly ash and natural pozzolan shall conform to the requirements of ASTM C 618 for Class C, F, or N mineral admixture, except that the loss on ignition shall not exceed 3.0 percent.

Silica fume shall conform to the requirements of ASTM C 1240. Only densified silica fume shall be permitted. Dissolved bagged silica fume or interground silica fume with cement will not be acceptable.

When a supplementary cementitious material with a calcium oxide content greater than 15 percent is proposed, the hydraulic cement/supplementary cementitious material blend shall be tested for sulfate expansion in accordance with ASTM C 1012. The maximum expansion shall be 0.10 percent at six months.

When either moderate or high sulfate resistant concrete is specified in the Special Provisions, the proposed hydraulic cement/supplementary cementitious material blend shall be tested for sulfate expansion in accordance with ASTM C 1012. When moderate sulfate resistance is specified, the maximum expansion shall be 0.10 percent at six months. When high sulfate resistance is specified, the maximum expansion shall be 0.05 percent at six months or 0.10 percent at one year.

When Class C fly ash is used, the cement intended to be used shall be tested for sulfate expansion in accordance with ASTM C 1157 and ASTM C 1012 and shall have a maximum expansion of 0.05 percent at six months and 0.10 percent at one year.

2.02 Water:

The water used shall be free from injurious amounts of oil, acid, alkali, clay, vegetable matter, silt or other harmful matter. Water shall contain no more than 1,000 parts per million of chlorides as CL and not more than 1,000 parts per million of sulfates as SO_4.

Water shall be sampled and tested in accordance with the requirements of AASHTO T 26. Potable water obtained from public utility distribution lines will be acceptable.

2.03 Aggregates:

2.03-A General Requirements:

The fine and coarse aggregate used in HPC shall be subject to five cycles of the sodium sulfate soundness test in accordance with the requirements of AASHTO T 104. The total loss shall not exceed 10 percent by weight of the aggregate as a result of the test. Tests for soundness may be waived when aggregates from the same source have been approved and the approved test results apply to the current production from that source.

Mill tailings or material from mine dumps shall not be used in the production of fine or coarse aggregate.

The handling and storage of concrete aggregate shall be such as to minimize segregation or the intermixing and contamination with foreign materials. The Engineer may require that aggregates be stored separately. Different sizes of aggregate shall be separated by bulkheads or stored in separate stockpiles sufficiently removed from each other to prevent the material from becoming intermixed.

When aggregates are stored on the ground, the sites for the stockpiles shall be level and clear of all vegetation. The bottom one-foot layer of aggregate shall not be disturbed or used.

The handling and storage of concrete aggregate for HPC at the job site shall be such as to minimize segregation. Stockpiles shall be neat and regular in form and shall occupy as small an area as possible. Stockpiles shall be constructed by first distributing the aggregate over the entire base and then building upward in successive layers not more than five feet in depth. Aggregate shall not be dumped or spilled over the side of the pile. When a conveyor is used to stockpile aggregate, it shall be equipped with an adequate rock tremie or rock ladder to reduce segregation and it shall be moved continuously across the stockpile. The distance the material drops from the tremie shall not exceed 10 feet. Aggregate shall be distributed over the stockpile so that the formation of conical piles higher than 10 feet is prevented.

Contamination of concrete aggregate by contact with the ground at the job site shall be positively prevented. The contractor shall take the necessary measures to prevent such contamination. Such preventive measures shall include, but not necessarily be limited to, placing aggregate on hardened surfaces consisting of Portland cement concrete, asphaltic concrete, or cement treated material.

TABLE 10HPC-2.03-A.1 Standards and test methods used for the evaluation of the quality of aggregates for concrete	
Arizona 105	Sampling
ASTM C 33	Standard Specifications for concrete aggregates.
ASTM C 29	Bulk density and voids in aggregates.
AASHTO T 21	Organic impurities of fine aggregates for concrete.
AASHTO T 104	Soundness of aggregates by use of sodium sulfate or magnesium sulfate.
AASHTO T 113	Lightweight particles in aggregates.(see note)
AASHTO T 85	Specific gravity and absorption of coarse aggregates.
AASHTO T 84	Specific gravity and absorption of fine aggregates.
AASHTO T 96	Resistance to degradation of small-size coarse aggregates by abrasion and impact in the Los Angeles machine.
AASHTO T 112	Clay lumps and friable particles in aggregates.
ASTM C 1260	Potential alkali reactivity of aggregate (Mortar bar method).
ASTM C 1567	Determining the potential Alkali-Silica Reactivity of Combination of Cementitious Materials and aggregate.(Accelerated Mortar-Bar Method)
Arizona 212	Fractured coarse aggregates particles.
Arizona 201	Sieving of coarse and fine graded soils and aggregates.
AASHTO T 248	Reducing field samples to testing size
AASHTO T 176	Sand equivalent
AASHTO T 71	Mortar Strength (see note)
Note: AASHTO T 113 and T 71 are modified as specified in Subsections 10HPC-2.03-B and 10HPC-2.03-C.	

Coarse and fine aggregate to be used in HPC shall be at a moisture content greater than or equal to saturated surface dry for the 24-hour period before it is used in HPC.

The contractor shall submit test results to the Engineer showing the compliance of the fine and coarse aggregate sources with the above standards. The aggregates testing shall be performed within one year prior to the date that the aggregates testing results are submitted to the Engineer.
The fine and coarse aggregates shall be in compliance with this specification and shall be approved by the Engineer.

2.03-B Fine Aggregate:

Fine aggregate shall be natural sand, or other approved inert material with similar characteristics, composed of clean, hard, strong, durable, uncoated particles. The aggregate shall be washed and shall conform to the requirements of AASHTO M 6, with the following exceptions:

The amount of deleterious substances in the washed fine aggregate shall not exceed the limits, by dry weight, given in Table 10HPC-2.03-B.1.

TABLE 10HPC-2.03-B.1 Limits of deleterious substances in washed fine aggregate (see note 1)		
Clay lumps and friable particles	AASHTO T 112	0.5%
Lightweight particles (Specific gravity less than 2.0)	AASHTO T 113 (Except that the percent of lightweight particles shall be reported to the nearest 0.01 %.)	1.25% (0.25% Max. Coal and Lignite) (see note 2)
Note 1: The total amount of all deleterious substances shall not exceed 1.25 percent by dry weight. Note 2: Only material that is brownish-black, or black, shall be considered coal or lignite.		

Fine aggregate shall meet the following gradation requirements given in Table 10HPC-2.03-B.2 when tested in accordance with Arizona Test Method 201.

TABLE 10HPC-2.03-B.2 Fine aggregates gradation requirements	
Sieve Size	**Percent Passing**
3/8 in.	100
No. 4	95 – 100
No. 16	45 – 80
No. 50	0 – 30
No. 100	0 – 10
No. 200	0 - 4.0

Fine aggregate shall have a sand equivalent value of not less than 75.

Fine aggregates shall be subjected to AASHTO T 21 testing for organic impurities. Aggregates producing a color darker than the standard color shall be rejected unless the material passes the mortar strength specified in the following paragraph.
Fine aggregate shall be made into mortar and subjected to testing under AASHTO T 71, except that the mortar shall develop a compressive strength at seven and 28 days of not less than 90 percent of that developed by a mortar prepared in the same manner with the same Type II cement and graded sand conforming to the requirements of ASTM C 778.

2.03-C Coarse Aggregate:

Coarse aggregate shall consist of crushed stone, gravel, crushed gravel, or other approved inert material of similar characteristics, including cinders when specified, having hard, strong and durable pieces free of clay and other deleterious substances. The aggregate shall be washed. The aggregate gradation, when tested in accordance with Arizona Test Method 201, shall conform to the appropriate size designation of AASHTO M 43, except as shown below.

The amount of deleterious substances in the washed coarse aggregate shall not exceed the limits, by dry weight, given in Table 10HPC-2.03-C.1.

TABLE 10HPC-2.03-C.1
Limits of deleterious substances in washed coarse aggregate
(see note 1)

Clay lumps and friable particles	AASHTO T 112	0.3%
Lightweight particles (Specific gravity less than 2.0)	AASHTO T 113 (Except that the percent of lightweight particles shall be reported to the nearest 0.01 %)	1.25% (0.25% Max. Coal and Lignite) (see note 2)
Material passing No. 200 sieve	Arizona Test Method 201	1.0%

Note 1: The total amount of all deleterious substances shall not exceed 1.25 percent by dry weight.

Note 2: Only material that is brownish-black, or black, shall be considered coal or lignite.

The percent of wear of coarse aggregate at 500 revolutions, when tested in accordance with the requirements of AASHTO T 96, shall not exceed 40.

2.04 Admixtures:

2.04-A General Requirements:

All concrete admixtures shall be stored in suitable containers in accordance with the manufacturer's recommendations. All liquid admixtures shall be protected from freezing. Liquid admixtures that have frozen shall not be used.
Admixtures shall be uniform in properties throughout their use in the work.

Use of calcium chloride is not permitted.

If more than one admixture is used, the admixtures shall be compatible with each other so that the desired effects of all admixtures used will be realized.

2.04-B Air-Entraining Admixtures:

Air-entraining admixtures shall conform to the requirements of ASTM C 260.

Air-entraining admixtures shall be approved prior to their use in accordance with Materials Policy and Procedure Directive No. 2, "Certification and Acceptance of Chemical and Air-Entraining Admixtures for Portland Cement Concrete".

Only those air-entraining admixtures shown on the Department's Approved Products List (APL) shall be used.

Air-entraining admixtures having a chloride concentration of 10,000 parts per million (one percent by mass of the admixture) or less, as determined in accordance with Arizona Test Method 738, are acceptable unless otherwise specified.

2.04-C Chemical Admixtures:

Chemical admixtures shall conform to the requirements of ASTM C 494.

Chemical admixtures shall be approved prior to their use in accordance with Materials Policy and Procedure Directive No. 2, "Certification and Acceptance of Chemical and Air-Entraining Admixtures for Portland Cement Concrete".

Only those chemical admixtures shown on the Department's Approved Products List (APL) shall be used.

Chemical admixtures having a chloride concentration of 10,000 parts per million (one percent by mass of the admixture) or less, as determined in accordance with Arizona Test Method 738, are acceptable unless otherwise specified.

3 - HPC Concrete Mixtures:

3.01 Design Criteria:

HPC shall be proportioned according to ACI 318-5.3 procedure, and shall be consistent with the mix design guidelines listed in Table 10HPC-3.01-A.

TABLE 10HPC-3.01-A **HPC Mix Design Guidelines**			
28-Day Compressive Strength = 4,500 psi			
Material	Min.	Max.	Unit
Hydraulic Cement	450	475	Lbs/CY
Fly Ash	110	150	Lbs/CY
Silica Fume (by weight of Hydraulic Cement)	5%	6%	Percent
Water	230	260	Lbs/CY
Coarse and Fine Aggregates (see note 1)			
Water Reducers (mid and high range) (see note 2)			
Air-Entraining Admixture (see note 2)			
Air Content, percent	4.5	7.5	Percent
Water/Cementitious Materials Ratio	0.40	0.42	
Note 1: The amount of coarse and fine aggregates, maximum size aggregates, and combined gradation shall be provided by the contractor, subject to approval by the Engineer. Note 2: The type and amount of air-entraining and chemical admixtures shall be provided by the contractor, subject to approval by the Engineer.			

HPC mix shall include hydraulic cement, fly ash, silica fume, fine and coarse aggregate, chemical admixtures, and air-entraining admixtures as approved by the Engineer.

The contractor is responsible for the submittal of HPC mix design(s) to the Engineer for review and approval in sufficient time so that a delay of work shall not occur. The mix design shall be submitted at least 60 days prior to any HPC placement and in sufficient detail to be reproducible in the laboratory and the field. Both the proportion and source of the materials shall be provided. No proprietary mixes will be accepted.

The mix design shall be submitted with the following test data (at a minimum) demonstrating the properties of the HPC mix:

a) Compressive strength @ 28-day.
b) Water/cementitious material ratio.
c) Paste content percent calculation.
d) Slump before and after pumping.
e) Air content before and after pumping.
f) Concrete temperature before and after pumping.
g) Air voids analysis of hardened concrete according to ASTM C 457.
h) Rapid Chloride Permeability (RCP) test result according to ASTM C 1202.
i) Shrinkage potential test results according to ASTM C 157.

HPC shall meet the following properties and performance criteria for trial batches made in the field/batch plant prior to placement:

The contractor shall perform a full scale trial batch of the proposed HPC at the batch plant before submitting the HPC mix design for review. The HPC shall meet the following properties and performance criteria and shall be documented in the mix design submittal.

TABLE 10HPC-3.01-B
HPC Properties and Performance Criteria

Concrete Properties	Minimum	Maximum
28-Day Compressive Strength	4,500 psi	-
Ratio of 28-day/7-day compressive strength	1.65	-
Water/Cementitious materials ratio	0.40	0.42
Slump, at point of placement	4 in.	6 in.
Air Content, at point of placement	4.5%	7.5%
Concrete Temperature, at point of placement	50ºF	90ºF
Paste content percent (cementitious materials + water)	22%	28%
Air void parameters in hardened concrete shall be in compliance with ACI 212, Chapter 2, “Air-Entraining Admixtures”. When tested according to ASTM C 457, the air void parameters shall have the following properties: • Spacing factor of 0.008 inches or less. • Specific surface of 600 in^2/in^3 or greater.		
Rapid Chloride Permeability (RCP) according to ASTM C 1202 shall be: • Maximum of 1,200 coulombs at 56 days.		
Shrinkage Potential according to ASTM C 157, standard curing shall be: • Maximum of 0.04 percent at 28 days.		

The Engineer is the sole authority to determine compliance of HPC mix design with the requirements of this specification. Review and approval by the Engineer will not relieve the contractor of the responsibility to provide HPC conforming to this specification.

The coarse aggregate size designation for HPC shall be chosen by the contractor and approved by the Engineer and shall conform to the size designation and grading requirements of AASHTO M 43. In choosing the size designation, the maximum size of coarse aggregate shall not be larger than one fifth of the narrowest dimension between sides of adjacent forms, or two thirds of the minimum clear spacing between reinforcing bars, or one third the depth of the slab, whichever is least. If two or more stockpiles are utilized to manufacture an AASHTO M 43 size designation, at the time of proportioning for mixing, the aggregate from each stockpile shall be measured by weight and proportioned so that the resulting mixture of coarse aggregate meets the requirements for the chosen size designation. The percent of fractured coarse aggregate particles shall be at least 30 when tested in accordance with the requirements of Arizona Test Method 212.

3.02 Design Procedures:

At least 60 days prior to any HPC placement, the contractor shall furnish the HPC mix design for review and approval. More than one mix design may be submitted for approval provided specific items and locations of intended uses accompany the mix design. The contractor shall substantiate each mix design by furnishing test data and providing all details of the mixtures proposed for use. The mix design shall be prepared by or under the direction of, and signed by, a registered professional engineer, a NICET Level III or higher certified technician in the concrete subfield, a NRMCA Level 3 Certified Concrete Technologist, or an ACI certified Concrete Laboratory Testing Technician Level 2 or Grade II. Individuals preparing and submitting HPC mix designs shall have experience in HPC technology and the development of HPC mix designs and testing.

The complete solid volume mix designs submitted for approval shall include all weights and volumes of all ingredients. The brand, type, and source of hydraulic cement and admixtures, the coarse aggregate size number designation, source of aggregates, the specific gravities of all ingredients, the proposed slump, the water/cementitious material ratio, a product code to identify the mix design, and the intended use of each mix design shall be an integral part of each mix design.

The use of new and previously used mix designs, and the requirements for trial batches, will be as required by Materials Policy and Procedure Directive No. 15, “Submittal and Approval of Portland Cement Concrete Mix Designs”.

Changes in approved mix designs may be made by the contractor with the approval of the Engineer as listed in section 601HPC-3.01-B.

In no case shall the approval of a mix design relieve the contractor of the responsibility for the results obtained by the use of such approved mix design.

A new or revised mix design shall be submitted for approval any time the test results of an approved mix design indicate that the concrete does not meet the required performance criteria.

When approved by the Engineer, concrete from trial batches may be used in the work at locations where concrete of a lower strength is required and such concrete will meet the requirements of the class of concrete at that location. The basis of payment for such concrete shall be that which applies to the concrete required at that location.

4 - Concrete Production:

4.01 General Requirements:

The contractor shall furnish a delivery ticket for every load of concrete. The minimum information to be shown on each delivery ticket shall be according to Subsection 10HPC-4.02-E.

4.02 Batching:

4.02-A Cementitious Material:

When the quantity of hydraulic cement exceeds 30 percent of the full capacity of the scale, the batching accuracy of mixtures containing supplementary cementitious material shall be such that the quantity of the hydraulic cement, and the cumulative quantity of the hydraulic cement plus the supplementary cementitious material, is within ± 1.0 percent of the sum of their designated batch weights.

4.02-A.1 Hydraulic Cement:

A separate scale shall be used to weigh the hydraulic cement. A load indicating device, positioned so as to be easily visible to the Engineer and accurate to ± 0.2 percent of scale capacity, shall be provided to weigh hydraulic cement. The batching accuracy shall be within ± 1.0 percent of the required weight. Load-indicating devices for the scale or a load cell providing a digital printed readout will be required when weighing all cementitious material.

Hydraulic cement shall be conveyed by means of an enclosed conveying system and the weighing hopper shall be equipped with one or more vibrators as required to ensure the complete discharge of all cement from the hopper after each batch is weighed.

4.02-A.2 Supplementary Cementitious Material:

When a supplementary cementitious material (such as fly ash, natural pozzolan, or silica fume) is specified in the mix design, it may be weighed cumulatively with the hydraulic cement on the same scale. If the same scale is used, the hydraulic cement shall be weighed first, then the supplementary cementitious material. If the same scale is not used, a separate scale with a load-indicating device, positioned so as to be easily visible to the Engineer and accurate to ± 0.2 percent of scale capacity, shall be provided to weigh the supplementary cementitious material.

Supplementary cementitious material shall be conveyed by means of an enclosed conveying system, and the weighing hopper shall be equipped with one or more vibrators as required to ensure the complete discharge of the supplementary cementitious material from the hopper after each batch is weighed.

4.02-B Water:

Water shall be measured by volume or by weight. Measurement by volume will be by metering.

Scales shall be accurate within ± 0.2 percent of scale capacity. Volumetric measuring devices shall have an accuracy of ± 1.5 percent. The batching devices shall be capable of routinely batching water within ± 1.5 percent.

4.02-C Aggregates:

All aggregates shall be proportioned by weight.

Suitable scales shall be provided by the contractor to weigh each size of aggregate. Load indicating devices for the scales shall be positioned so as to be easily visible to the Engineer and accurate to ± 0.2 percent of scale capacity. The batching accuracy shall be within ± two percent of the target weight. The weighing equipment shall be arranged so as to permit the convenient removal of excess material from the weighing hopper and the equipment shall be arranged to enable the operator to have convenient access to all controls. The scales and load indicating devices shall be so graduated and equipped that the weights of materials can be accurately determined. Necessary efforts shall be made to obtain and preserve uniform moisture content in the coarse and fine aggregates. The moisture content shall not vary more than three percent during any day's concrete production. The estimated percent of free moisture in each of the coarse and fine aggregates shall be determined by the contractor using acceptable test methods.

The moisture content of the aggregate shall be such that no free drainage of water from the aggregate will be visible during transportation from the stockpile to the point of mixing. Aggregate containing excess moisture shall be stockpiled prior to use until it is sufficiently dry to meet the above requirement.

In the event that either the coarse or fine aggregate has a moisture absorption rate of more than 1.5 percent, the materials shall be thoroughly prewetted and allowed to drain in advance of use until the moisture content is stable.

4.02-D Admixtures:

The equipment and the procedures used to measure admixtures and dispense them into the concrete batch shall be approved by the Engineer prior to use.

Dry admixtures shall be measured by weight with a separate scale. A load indicating device for the scale shall be positioned so as to be easily visible to the Engineer and accurate to within ± 1.0 percent of the amount being weighed. Paste or liquid admixtures shall be measured either by weight or by volume. Only mechanical dispensing equipment shall be used for adding admixtures. Dosage rates shall conform to the manufacturer's recommendations or approved rates, or as determined from field trial batches.

Dispensers for admixtures shall have sufficient capacity to measure at one time the full quantity required for each batch. Admixtures shall be added in accordance with the manufacturer's recommendations and in a manner such that the admixture is incorporated uniformly in the concrete mixture. The amount of liquid admixtures shall not vary from the required amount by more than ± 3.0 percent.

Equipment for measurement shall be designed for convenient confirmation of measurement accuracy. If more than one liquid admixture is used, each admixture shall be dispensed by separate equipment unless otherwise permitted in writing by the Engineer.

4.02-E Delivery Ticket:

Each concrete load shall be accompanied by a delivery ticket. Each delivery ticket shall contain the following information at a minimum and the information shall be printed on each ticket at the plant using an automated printing device:

a) Name, location, and identification of batch plant.
b) Name of contractor.
c) Name of the project and its location.
d) Date of concrete batch, including year, month, and day.
e) Truck identification number.
f) Batch unique control number.
g) Load size and cumulative quantity of concrete delivered.
h) Time of concrete batching which indicates when the mix water was in contact with the cement.
i) Mix design number assigned by the contractor or the supplier’s unique mix design number (product code) verified to correspond to the mix design number submitted by the contractor.
j) Concrete mix materials weights including cement, fly ash, silica fume, other cementitious materials, chemical admixtures, air-entraining admixtures, and trim water.
k) Number of revolutions that the concrete has been mixed at mixing speed in a truck mixer.
l) Specified minimum 28-day compressive strength of concrete.

When an electronic ticketing system is not used, concrete batching time shall be stamped by a time clock, within 5 minutes of batching.

In addition, the contractor shall record in writing on the delivery ticket the following:

a) The amount of any material added after batching including any water, chemical admixtures, or air-entraining admixtures, or other materials added during transit or at the jobsite.
b) Truck arrival time at the job site.
c) Time truck started discharging.
d) Time truck finished discharging.
e) Rejection of a load or part thereof.

An authorized representative of the contractor shall be responsible for each delivery ticket and shall sign each delivery ticket accepting the contractor's responsibility for the concrete. The representative shall immediately furnish the delivery ticket to the Engineer.

4.03 Mixing:

4.03-A General Requirements:

Mixing of the HPC shall be according to the material supplier's recommendations and shall be approved by the Engineer. Water reducers shall be added during batching, and if necessary, on-site. When air-entraining admixtures are used, they shall be added during batching and may be added on-site to restore any air loss in concrete.

The contractor shall demonstrate to the Engineer, on-site, the procedure for adding admixtures on-site. The process involves backing the load of concrete up to the chute and stopping short of discharge. The admixture is spread over the surface of the concrete and then mixed for an additional 30 revolutions at mixing speed. The contractor shall have a representative of the chemical admixtures supplier available on an as-needed basis during batching and placement of the HPC.

Testing for slump and air content shall commence before HPC is placed into any concrete structure and shall be performed as frequently as necessary to maintain required concrete properties and field control. The minimum and maximum allowable slump at point of placement shall be as defined in Table 10HPC-3.01-B. All loads shall be consistent to within ± one (1) inch slump. When slump maintenance or adjustment are needed, it should accomplished only by the proper addition of ASTM C494 Type F or G chemical admixture, high-range water reducer.

Water shall not be added to the HPC after it is batched and placed on the truck for delivery to the project site. Water to rinse the chute and fins, after the addition of admixtures, may be allowed provided such water is accounted for on the approved HPC mix design and shall not exceed the maximum water/cementitious material ratio stated in Table 10HPC-3.01-A.

The concrete may be mixed in a stationary mixer, either at a central mixing plant or at the site, or it may be mixed in a truck mixer, either at a central mixing plant or at the site.

Each mixer shall meet the specified requirements for type and size and shall have attached in a prominent place a manufacturer's plate showing the gross volume of the mixer and the recommended speeds of the mixer for mixing and for agitating.

Each batch plant shall be equipped to control the time when the water enters the mixer during the mixing cycle. Batch and mixing time shall be from the time hydraulic cement is combined with water.

Mixers shall be cleaned at suitable intervals. Water used for cleaning the mixer shall be discharged prior to further batching.

Equipment having components made of aluminum or magnesium alloys, which would have contact with plastic concrete during mixing and transporting, shall not be used.

All concrete shall be homogeneous and thoroughly mixed, and there shall be no lumps or evidence of un-dispersed cement.

4.03-B Mixing in a Stationary Mixer:

The volume of concrete mixed per batch shall not exceed the capacity of the mixer as shown on the manufacturer's plate. No spillage of concrete will be allowed during the process of mixing.

While mixing, the mixer shall be operated at the speed shown on the manufacturer's plate as the mixing speed.

The mixing time for HPC shall be not less than 60 seconds for one cubic yard and shall be increased 15 seconds for each additional cubic yard or fraction thereof.

The mixers shall have an automatic timing device which locks the discharge equipment until the required mixing time has been completed. The mixer shall be operating at mixing speed at the time that all ingredients enter the mixer to ensure the immediate beginning of the mixing cycle. Mixing time shall end when the discharge chute opens. The contents of the mixer shall be completely discharged before the succeeding batch is placed in the mixer.

Any concrete discharged before the mixing time is completed shall be disposed of by the contractor at no additional cost to the Department.

Mixed concrete shall be transported in truck mixers, truck agitators or in non-agitating trucks having special bodies.
When truck mixers or truck agitators are used, the concrete shall be continuously agitated from the time of loading until the time of discharge. Agitation shall be by rotation of the drum at the speed shown on the manufacturer's plate as agitating speed.

The truck mixer or truck agitator shall be loaded and operated within a capacity not to exceed 80 percent of the gross volume of the drum. The rate of discharge shall be controlled by the speed of rotation of the drum in the discharge direction with the discharge gate fully opened.

Discharge from the truck mixer or truck agitator shall be completed within 90 minutes from the time batched, unless otherwise noted in the mix design and approved by the Engineer.

Bodies of non-agitating trucks shall be smooth, mortar-tight, metal containers and shall be capable of discharging the concrete at a satisfactory controlled rate without segregation. If discharge of concrete is accomplished by tilting the body, the surface of the load shall be retarded by a suitable baffle. Covers shall be provided when needed for protection.

Discharge from non-agitating trucks shall be completed within 45 minutes from the time concrete is batched.

Concrete hauled in open-top vehicles shall be protected against rain and moisture loss. When the ambient temperature exceeds 85 degrees F, the concrete shall be covered if it will be exposed for more than 10 minutes.

4.03-C Mixing in Truck Mixers:

Truck-mixed concrete shall be mixed entirely in the truck mixer and shall be mixed at the batch plant or at the site.

Truck mixers shall be operated within a capacity not to exceed 63 percent of the gross volume of the drum and at speeds shown on the manufacturer's plate as mixing and agitating speeds.

Each batch of concrete shall be mixed for not less than 70 nor more than 100 revolutions of the drum at mixing speed and after all materials have been loaded into the drum, except that when approved by the Engineer, the maximum of 100 revolutions may be increased. Any revolving of the drum beyond the maximum number of revolutions shall be at the agitating speed. Mixing shall begin within 10 minutes after the cement has been combined with either the aggregate or water.

The truck mixer shall be equipped with an electrically or mechanically activated revolution counter by which the number of drum revolutions may be verified. The counter shall accurately register the number of revolutions. It shall be mounted on the truck mixer or just inside the truck cab, so that it may be safely and conveniently read from beside the truck. The revolution counter shall be reset to zero after all materials have been loaded into the drum.

Discharge from the truck mixer shall be completed within 90 minutes from the time batched, unless otherwise noted in the mix design and approved by the Engineer.

If additional mixing water is required to maintain the mix design water/cementitious material ratio, the concrete shall be mixed by a minimum of 30 revolutions of the drum at mixing speed after the water has been added, prior to discharge of any concrete for placement. Any additional mixing water and required mixing revolutions shall be recorded on the delivery ticket specified in Subsection 10HPC-4.02-E. This additional mixing may be in excess of the maximum revolutions previously specified.

4.04 Consistency:

The contractor shall furnish HPC having a slump within the range specified in Table 10HPC-3.01-B. Concrete that fails to conform to the consistency requirements will be rejected.

When HPC is pumped, samples for consistency will be taken both as the concrete leaves the mixer and at the pump hose discharge. If the Engineer determines that there is a good correlation between the results of consistency tests on samples obtained from the mixer and from the pump hose, the Engineer may discontinue sampling from one of the sources; however, the Engineer may take periodic samples from both sources to verify the correlation of test results.

5 - Concrete Temperature and Weather Limitations:

5.01 General Requirements:

Under rainy conditions, placing of HPC shall be stopped before the quantity of surface water is sufficient to cause a flow or wash of the concrete surface or have a detrimental effect on the finished concrete and acceptance parameters.

Placing of concrete shall immediately cease if the hauling vehicles or any equipment or pedestrian traffic tracks mud on the prepared base or changes the allowable subgrade dimensional tolerances for HPC and slabs placed on subgrade for HPC.

5.02 Hot Weather Concreting:

The temperature of the concrete mixture immediately before placement shall not exceed that listed in Table 10HPC-3.01-B.

Forms, subgrade and reinforcing steel, shall be sprinkled with cool water just prior to placement of concrete.

Mix water may be cooled by refrigeration, liquid nitrogen, or well-crushed ice of a size that will melt completely during the mixing operation. If crushed ice is used, the weight of the ice shall substitute part of the mix water on a pound for pound basis.

5.03 Cold Weather Concreting:

The temperature of the mixed concrete immediately before placing shall not be less than that listed in Table 10HPC-3.01-B.

Concrete shall not be placed on or against ice-coated forms, reinforcing steel, structural steel, conduits or construction joints, nor on or against snow, ice, or frozen earth materials.

Concrete operations shall be discontinued immediately when a descending ambient temperature in the shade, and away from artificial heat, falls below 40 degrees F. No concrete operation can be resumed until an ascending ambient temperature in the shade, and away from artificial heat, exceeds 35 degrees F unless otherwise approved by the Engineer.

Mixing, batching, and placing of HPC shall be discontinued immediately to allow sufficient time for placement, finishing, and protection of concrete already placed in the forms or on grade before the ambient temperature drops to 35 degrees F.

Concrete shall be protected in a manner to maintain all concrete surface temperatures at not less than 50 degrees F for a period of 72 hours after placement and at not less than 40 degrees F for an additional 96 hours.

The contractor may use equipment to heat the aggregates or water, or both, prior to mixing. If aggregates are heated, the minimum temperature of the heated aggregate shall be 60 degrees F and the aggregates shall have no chunks of ice or frozen aggregate present. Equipment used to heat the aggregates shall be such that consistent temperatures are obtained throughout the aggregate within each batch and from one batch to another. Water shall not be heated in excess of 150 degrees F unless the water is mixed with the aggregate prior to the addition of cement to the batch. During the heating or mixing process, cement shall not be added to water and aggregate combinations which exceed 100 degrees F.

When weather forecasts indicate a probability that ambient temperatures will fall below 35 degrees F during the placement or curing periods, the contractor shall submit a cold weather concreting plan to the Engineer for approval prior to concrete placement. The cold weather concreting plan shall detail methods and equipment which will be used to ensure that the required concrete temperatures are maintained. The contractor shall provide adequate cold weather protection in the form of insulation and/or heated enclosures to protect the concrete after placement. For bridge decks and suspended structures, the cold weather concreting plan shall include protection measures for both the top and bottom surfaces of the concrete. This protection shall maintain concrete surface temperatures as specified above at all locations in the structure. When artificial heating is required, the heating units shall not locally heat or dry the surface of the concrete.

When a cold weather concreting plan is required, the Engineer may require concrete temperatures to be measured and continuously recorded by the use of temperature sensing devices during the entire curing period. The contractor shall provide the temperature sensing devices and recording instruments. The contractor shall install temperature sensing devices near the surface of the concrete at locations and depths designated by the Engineer. When concrete is placed on a bridge deck or suspended structure, both the bottom surface and the top surface shall be monitored with temperature sensing devices. Temperature sensing devices and recording instruments shall be approved by the Engineer. The contractor shall continuously monitor the concrete temperature and provide the recorded data to the Engineer at any time upon request.

If the surface concrete temperature at any location in the structure falls below 35 degrees F during the curing period, the Engineer may direct the contractor to core the areas in question at the locations indicated by the Engineer. The contractor shall submit the cores for petrographic examination according to ASTM C 856. Concrete damaged by frost, as determined by the petrographic examination shall be removed and replaced at no additional cost to the Department. All costs associated with coring, transmittal of cores, and petrographic examination shall be borne by the contractor regardless of the outcome of the petrographic examination.

The placing of concrete will not be permitted until the Engineer is satisfied that all the necessary protection equipment and materials are on hand at the site and in satisfactory working condition.

Concrete requiring cold weather protection shall have such protection removed at the end of the required curing period in such a manner that will permit a gradual drop in the concrete temperatures.

6 - Curing HPC Concrete:

6.01 General Requirements:

All HPC surfaces shall be cured by the water curing method described in Subsection 10HPC- 6.01-B unless approved otherwise by the engineer.

The top surface of bridge decks, approach slabs, and anchor slabs shall be cured by the water curing method only. Water curing shall be applied progressively and immediately following the surface finishing operation as specified herein.

The contractor shall submit a proposed curing plan to the Engineer for approval. The contractor’s curing plan shall include proper equipment and material in adequate amounts and shall have the proposed methods, equipment and material, and shall be approved by the Engineer prior to placing HPC.

No traffic, hauling, storing of material or other work shall be allowed on any HPC surface during the required curing periods.

HPC shall be cured by one or a combination of more than one of the methods specified herein.

Immediately prior to placing HPC, the contractor shall demonstrate to the Engineer and on site the initial curing procedure, described in Subsection 10HPC-6.01-B for the Engineer’s approval. Inadequate curing and/or facilities shall be cause for the Engineer to delay or stop all HPC placements on the job until remedial action is taken.

All HPC shall be wet cured for a minimum period of 14 curing days. A curing day is defined as a calendar day when the temperature, taken in the shade away from artificial heat, is above 50^{o}F for at least 19 hours or on colder days if satisfactory provisions are made to maintain the temperature of all HPC surfaces above the minimum curing temperature of 40^{o}F for the entire 24 hours. The required curing period shall begin when HPC has attained its initial set.

All exposed surfaces of the HPC shall be kept wet continuously for the required curing time. The water used for curing shall meet the requirements for concrete mixing water as specified in Subsection 10HPC-2.02. Water used for curing that stains or leaves an unsightly residue shall not be used.

6.01-A Curing Equipment and Material:

6.01-A.1 Fogging Equipment:

Fogging equipment shall consist of a mechanically operated pressurized system using triple headed nozzles or equivalents. Each fogging nozzle shall be capable of producing a fine fog mist that atomizes water flow so that a mist and not a spray is formed. The fog mist must increase the relative humidity of the air 2 to 3 feet above the plastic or fresh HPC surfaces without accumulating any water on the HPC.

The nozzles shall be pointing horizontally and away from the HPC surfaces and moisture from the nozzles shall not be applied under pressure directly upon the HPC and shall not be allowed to accumulate on the HPC surface in a quantity sufficient to cause an accumulation, a flow or wash the surface.

The fogging equipment shall be mounted on the finishing equipment. Controls shall be designed to vary the volume of water flow, shall be easily accessible, and shall immediately shut off the water when in the off position. Hand-held fogging equipment will not be allowed.

6.01-A.2 Windscreens:

Windscreens shall be used to reduce the evaporation rate when the fogging equipment alone is not sufficient to maintain the evaporation rate within acceptable limits. Windscreens shall project at least six feet, or as deemed appropriate, depending upon weather conditions, above the prepared bridge deck surface. Windscreens may be made of any construction material that would provide sufficient strength to resist the force of the wind.

6.01-A.3 Wet Curing Medium:

Curing medium shall be capable of temporarily accepting and holding moisture, then gradually releasing that moisture to the concrete surface in contact. Acceptable curing medium include: burlap, burlap/plastic combination, or equal material.

6.01-A.4 Curing Compound:

Liquid membrane forming compound shall conform to the requirements of AASHTO M 148. A type-2 compound may be used only when water curing method cannot be reasonably used on HPC surface.

Acceptance of concrete curing materials shall be as specified in Materials Policy and Procedure Directive No. 3, "Curing Compounds".

6.01-B Water Curing Method:

HPC surfaces not covered by reasonably waterproof forms shall be wet cured according to the wet curing method specified herein. Curing shall begin immediately after completion of machine or hand finishing of the fresh concrete.

A curing medium as specified in Subsection 10HPC-6.01-A.3 shall be used to maintain continuously-moist concrete surfaces for the entire curing period. Application of the curing medium shall take place immediately at the end of the initial surface protection period Subsection 10HPC-6.01-B.1 and as soon as placement of the curing medium can be made without marring the surfaces of the concrete.

If a curing medium as specified in Subsection 10HPC-6.01-A.3 is not used, the entire surfaces of HPC shall be continuously sprinkled with water for the entire curing period.

6.01-B.1 Surface Protection:

Surface protection is required for protecting all bridge elements placed with HPC.

Immediately after the HPC is placed and brought to grade, the entire area of 2 to 3 feet above the HPC surfaces shall be kept continuously moist by applying a fog mist as described in Subsection 10HPC-6.01-A.1 This initial surface protection shall be continued until HPC concrete surfaces are covered with the curing medium as specified in Subsection 10HPC-6.01-A.3 and water curing starts according to Subsection 10HPC-6.01-B.2.

6.01-B.2 Wet Curing:

Wet curing shall begin immediately after the initial surface protection described in Subsection 10HPC-6.01-B.1. Wet curing shall begin no later than 10 minutes after HPC surface has been screed or when the finished surface of HPC is not more than ten feet behind the finishing machine whichever comes first.

Wet curing shall consist of keeping the HPC surfaces continuously wet by maintaining layer(s) of curing medium specified in Subsection 10HPC-6.01-A.3 continuously wet and in direct contact with the fresh concrete surfaces for the required curing period. The curing medium shall be wetted down (without dripping) prior to being placed over the HPC surfaces. The curing medium shall be kept wet during the entire curing period. Continuous wetting shall be accomplished by supplying water (directly on a porous type curing medium such as burlap) or through holes made in the burlap/plastic combination sheets and distributed throughout to saturate HPC surfaces. The curing medium shall be weighted down adequately to provide continuous contact with all HPC where possible.

Regardless of the type of medium used, wet curing shall not be interrupted anytime during the entire curing period.

6.01-C Liquid-Membrane Curing Compound Method:

All surfaces not covered by reasonably waterproof forms shall be cured by the liquid-membrane forming compound method. The curing compound shall be applied to the concrete immediately following the surface finishing operation in one or more applications totaling a rate of not less than one gallon per 100 square feet.

The curing compound shall form a continuous unbroken surface. If the membrane film is broken during the curing period, the broken area shall be given a new application of compound at a rate sufficient to assure uniform coverage the rate of one gallon per 200 square feet.

The use of liquid-membrane curing compound method for HPC curing must be approved by the engineer.

In no case shall curing be interrupted by more than one hour during the curing period.

6.01-D Forms in Place Method:

Formed surfaces of concrete may be cured by retaining the forms in place. The forms shall remain in place for the entire curing period. When forms are left in contact with the concrete, other curing methods will not be required except for exposed surfaces and for cold weather protection. If forms are removed and HPC surfaces are exposed before the end of the 14 day specified curing period, water curing method according to Subsection 10HPC-6.01-B, or Subsection 10HPC-6.01C shall start immediately on the exposed surfaces.

All joints in the forms and the joints between the end of forms and concrete shall be kept moisture tight during the curing period.

Cracks in the forms and cracks between the forms and the concrete shall be resealed by methods approved by the Engineer.

7 - Acceptance Sampling and Testing:

7.01 General:

Rejection of HPC will occur due to improper temperature, slump, and/or air content for the concrete mixture delivered to the site. The Engineer may allow failed concrete mixture already placed to remain in place subject to acceptance by compressive strength or may require its removal.

Rejection of concrete will also occur due to insufficient compressive strength. Concrete compressive strength requirements consist of the specified strength which the concrete shall attain before various loads or stresses are applied and a minimum strength at 28 days.

Acceptance and penalties for placed concrete which meets the above mixture requirements or is allowed to remain in place shall be determined by the results of the 28-day compressive strength. Sampling and testing for compressive strength will be performed on HPC concrete furnished, including each strength specified on the project plans for HPC.

7.02 Sampling and Testing of Concrete:

Samples of HPC for measuring temperature, slump, and air content and testing compressive strength will be taken at random at the specified sampling frequency.

HPC samples shall be of sufficient size to perform all the required tests and fabricate the necessary test cylinders. HPC samples shall be taken in accordance with the requirements of AASHTO T 141, and the concrete shall be sampled during discharge in the middle portion of the batch. At the discretion of the Engineer, a concrete sample may be obtained at the beginning of the discharge if, in the Engineer's opinion, the properties of the concrete do not appear to be within the specification limits for slump or temperature.

If concrete is pumped, at the discretion of the Engineer, samples may be taken from the truck and pump hose discharge to determine that the compressive strength specifications are met in the structure, and to correlate temperature, slump and air content results. If the correlation is satisfactory and meets with the approval of the Engineer, sampling may continue from the most convenient location with occasional re-testing for correlation. Rejection of concrete due to improper temperature or slump may occur at either the truck or pump hose discharge; however, rejection of concrete due to improper air content will only occur due to a failing test for a sample obtained at the final point of discharge.

Temperature of the concrete mixture will be determined in accordance with ASTM C 1064. Slump of the concrete mixture will be determined in accordance with AASHTO T 119. Air content of the concrete mixture will be determined in accordance with AASHTO T 152. All compressive strength test cylinders will be made, cured, handled, protected, and transported in accordance with the requirements of AASHTO T 23. Testing for compressive strength of cylinders shall be in accordance with the requirements of Arizona Test Method 314.

Compressive strength for HPC at any specified age shall be determined by the average of the results of three test cylinders fabricated as specified in Subsection 10HPC-7.03. However, if the compressive strength of any one of the test cylinders differs by more than 10 percent from the average of the three, its result shall be discarded and the compressive strength shall be the average of the remaining two cylinders. Should the individual compressive strength of any two of the three test cylinders differ by more than 10 percent from the average of the three, the results of both will be discarded and the compressive strength shall be the strength of the remaining cylinder.

If approved by the Engineer, and unless otherwise specified, Arizona Test Method 318 may be used to estimate concrete strength by the maturity method. The maturity method shall not substitute for compressive strength acceptance testing (28-day test cylinder breaks). The contractor shall submit a written request to the Engineer prior to using the maturity method. If its use is approved by the Engineer, the contractor shall be responsible to develop the strength-maturity relationship and shall also be responsible to provide the maturity meter(s) and digital data loggers necessary, as well as performing all required testing, all at no additional cost to the Department.

7.02-A Quality Control Program

The contractor shall develop a Quality Control Program (QCP) for controlling, monitoring, and testing HPC. The cost of the QCP and related testing shall be the responsibility of the contractor. The QCP shall insure that HPC meets the project specifications in the plastic and hardened states. The QCP shall include the following at a minimum:

a) Incorporate QCPs from subcontractors and suppliers that are involved with the handling, placement, and finishing of the HPC.

b) Flow chart identifying the steps that will take place from the time HPC is batched until it has been completely cured and achieved its specified strength, including all construction procedures associated with the HPC.
c) A scheduled HPC pre-placement meeting with the Engineer, contractor, sub-contractors, suppliers, and other pertinent parties.
d) Name(s) of the contractor's representative who accepts or rejects HPC loads.
e) Handling and transportation methods of the HPC test samples to the independent certified testing laboratory approved by the Engineer.

The contractor shall submit the QCP to the Engineer for review and approval a minimum of 14 calendar days prior to the placement of any HPC. The engineer's approval will be based on the completeness of the QCP and the contractor's incorporation of the requirements of this specification.

Quality control of fresh HPC shall be the responsibility of the contractor. During placement of HPC, the contractor shall make concrete test cylinders to measure compressive strength at the ages of 7, 28, and 56 days. The compressive strength of HPC shall be represented by the average of three concrete cylinders tested at each age. One set of twelve test cylinders for compressive strength measurement shall be made for each truckload of HPC placed. Three test cylinders shall be tested at 7, 28, and 56 days; with three test cylinders held in reserve.

The contractor shall provide an ACI certified field and lab technician(s) to conduct the required quality control testing. Two weeks prior to placing any HPC, the names and qualifications of the certified technician(s) shall be submitted to the Engineer for review and approval.

All contractor daily test results and placement records shall be submitted to the Engineer no later than 9:00 A.M. the morning following HPC placement. The required information shall include a placement summary sheet and a certificate of compliance for each delivered load of HPC.

It shall be the contractor's responsibility to provide adequate and representative samples of fresh HPC for testing.

The contractor is responsible to hire and pay for an independent certified testing laboratory approved by the Engineer to perform field and laboratory testing of HPC as stated in this Specification.

7.03 Sampling Frequency for Concrete:

A sample of HPC concrete for the required tests, as specified in Subsection 10HPC-7.02, will be taken on a daily basis for each 50 cubic yards, or fraction thereof, of continuously placed concrete from each batch plant. Temperature, slump, and air content measurements shall be performed for each 20 cubic yards placed. An additional sample or samples for any of the required tests may be taken at an interval of less than the sampling frequency specified above, at the discretion of the Engineer on any batch or load of concrete. A sample for the required tests on daily placements of 10 cubic yards or less may be taken at the discretion of the Engineer.

7.04 Acceptance of HPC for Compressive Strength:

HPC will be accepted and paid for in accordance with the Table 10HPC-7.04-A and Subsection 10HPC-8. HPC will be paid for by the cubic yard, complete in place, except that an adjustment in the contract unit price to the nearest cent will be made for the quantity of concrete represented by the 28 day compressive strength test results less than the specified requirements listed in Table 10HPC-7.04-A.

Acceptance of HPC for compressive strength shall be based on the strength tests performed on concrete test cylinders according to Arizona Test Method 314 at 28 day. A strength test is the average of three concrete test cylinders.

The HPC is accepted if both of the following requirements are met:

1) All strength tests are above ninety five percent of the required compressive strength.
2) Every arithmetic average of any three consecutive strength test equals or exceeds the required compressive strength.

HPC failing to meet the acceptance requirements in Subsection 10HPC-7.04, or failing to meet any requirements in Subsection 10HPC-7.01, will be rejected and removed in accordance with the provisions of Subsection10HPC-9 at no additional cost to the Department, unless the contractor can submit evidence that will indicate to the Engineer that the strength, durability, service life, and quality of the concrete is such that the concrete should be considered acceptable and be allowed to remain in place.

If such evidence consists of cores, the contractor shall obtain three cores from the concrete represented by the failing cylinder strength test. The cores shall be obtained at no additional cost to the Department, under the observation of an ADOT representative, and delivered to the Engineer in time to allow complete testing of such cores within 48 days after the placement of the concrete. All cores shall be obtained and tested in accordance with the requirements of Arizona Test Method 317. Testing shall be performed by the Department and the contractor may elect to have a representative present during testing. The concrete represented by the cores will be considered for acceptance, in accordance with the requirements of Table 10HPC-7.04-A. If the average compressive strength does not meet the specified requirement, all concrete so represented shall be removed at no additional cost to the Department unless permitted to remain in place by the Engineer. Results of the core testing will be binding on both the contractor and the Department, and will replace the results of the test cylinders for that sample.

Table 10HPC-7.04-A Adjustment in Concrete Unit Price for Compressive Strength of HPC 4,500 psi and Above			
Individual Compressive Strength Tests Requirement No 1		**Average of Three Consecutive Strength Tests Requirement No 2**	
Percent of specified 28-day compressive strength attained, to the nearest one percent	Percent reduction in contract unit price (see notes 1 and 2)	Percent of the average of any three consecutive strength tests attained, to the nearest one percent	Percent reduction In contract unit price (see notes 1 and 2)
100 or More	0	100 or More	0
99	1	99	1
98	2	98	2
97	3	97	3
96	4	96	4
95	5	95	5
Less than 95	30 (see note 3)	Less than 95	30 (see note 3)
Note 1: For items measured and paid for by the cubic yard, the reduction shall not exceed $200.00 per cubic yard. Note 2: The final adjustment in unit price will be the sum of the percent reduction in contract unit price for both Requirement No 1 and Requirement No 2. Note 3: If allowed to remain in place.			

8 - Method of Measurement and Basis of Payment:

The method of measurement and basis of payment will be made as specified herein and in Section 601HPC.

9 - Unacceptable Materials:

Material not conforming to the requirements of this specification, whether in place or not, will be rejected and shall be promptly removed from the site of the work, unless otherwise directed by the Engineer. No rejected material, the defects of which have been corrected, shall be returned to the work site until such time as approval for its use has been given by the Engineer.

CONCRETE STRUCTURES USING HIGH PERFORMANCE CONCRETE
SECTION 601HPC

CONCRETE STRUCTURES
Using High Performance Concrete
SECTION 601HPC

601HPC-1 Description:

All concrete shall be High Performance Concrete (HPC) as defined and described in this specification and the project plans.

The work under this section shall consist of furnishing all materials and constructing structures or parts of structures to the forms, shapes, and dimensions shown on the project plans and to the lines and grades established by the Engineer and in accordance with the requirements of this specification. When the structures or parts of structures are precast, the work shall also include transporting and erecting the units.

Concrete structures such as cattle guards, catch basins, median barriers, headwalls, and other small miscellaneous structures of sizes which can readily be precast as units and furnished and installed in place are hereby defined as minor structures. Minor structures, at the option of the contractor, may be either constructed of cast-in-place concrete or furnished and installed as precast units providing they are fabricated in accordance with drawings submitted and approved in accordance with requirements which may be found in the Special Provisions.

601HPC-2 Materials:

601HPC-2.01 General:

All concrete materials shall conform to the requirements of Section 10HPC as shown on the project plans and described herein.

Where a concrete strength is shown on the project plans but a class of concrete is not indicated it shall be construed to mean Class H concrete having the specified compressive strength shown at 28 days.

Materials furnished for expansion joint filler and joint seal shall conform to the requirements of Section 1011.

Materials furnished for water stops shall conform to the requirements of Section 1011.

Preformed bearing pads and elastomeric bearing pads shall conform to the requirements of Section 1013.

Reinforcing steel shall conform to the requirements of Section 1003.

601HPC-3 Construction Requirements:

601HPC-3.01 HPC Construction:

The contractor shall coordinate the HPC construction operations and schedule with the Engineer according to the following:

601HPC-3.01-A HPC Preconstruction Meeting:

The HPC preconstruction meeting shall be held no later than 14 calendar days after the preconstruction conference. The contractor shall schedule the initial placement of HPC on the bridge deck no sooner than 90 days after the HPC preconstruction meeting.

The purpose of this meeting is to review HPC requirements for this project and to discuss with the contractor the impact of HPC practices and work on this project. This meeting shall include the Engineer and other designated Department personnel, contractor, sub-contractors, suppliers, and other parties who will be responsible to see that the work is implemented in accordance with the project plans, and the specifications.

601HPC-3.01-B HPC Mix Design Submittal:

The contractor shall, at least 60 days prior to any HPC placement, submit an HPC mix design in accordance with Section 10HPC-3 of the specifications for review and approval by the Engineer.

601HPC-3.01-C HPC Field Demonstration:

The contractor shall, within 14 days prior to any HPC placement, perform a HPC field demonstration (mock up) of the HPC placement of the bridge deck. The field demonstration shall include all aspects of HPC work including: the production, transportation, pumping, placement, finishing, and curing of HPC proposed for use on the bridge deck. The field demonstration shall be carried out by the same contractor's personnel that will be placing the HPC on-site, and shall use the same equipment to be used on the job, to simulate actual job conditions. The location of the field demonstration shall be at an off-site location in the immediate proximity of the job site, as approved by the Engineer.

The contractor shall place at least four cubic yards of HPC before the initial placement of HPC on the bridge deck. The contractor shall demonstrate proper batching, placement, finishing, and curing of HPC. To simulate the actual job conditions in all aspects including batch plant conditions, transit equipment, travel conditions, admixtures, forming, placement of equipment, and personnel. The field demonstrations are the responsibility of the contractor at no additional cost to the Department and shall be repeated until all processes for production, placement, finishing, pumping, and curing of HPC are acceptable and approved by the Engineer.

The contractor shall, not later than 24 hours after the field demonstration, submit a comprehensive report to the Engineer describing the outcome of the field demonstration including, but not limited to, the batching, pumping, placing, finishing, protecting, curing, sampling and testing of HPC. The Engineer will require that the contractor perform additional field demonstration(s) at no additional cost to the Department if the Engineer determines that the contractor's HPC practices in the field demonstration are not acceptable or do not meet this specification.

601HPC-3.01-D HPC Pre-Placement Meeting:

After the field demonstration, and at least seven days prior to any subsequent HPC placement, the contractor shall meet with the Engineer to discuss and obtain approval from the Engineer for all issues related to the use and placement of HPC. These issues include, but are not limited to the following:

(1) Concrete truck batch size
(2) Batching sequence
(3) Delivery details
(4) Truck routes
(5) Travel time and routes
(6) Concrete mix proportions and adjustment
(7) Pumping and associated air loss
(8) Pumping and associated slump loss
(9) HPC protection plan
(10) HPC curing plan
(11) Quality assurance and quality control programs
(12) Testing requirements by the contractor
(13) HPC acceptance criteria
(14) Deck placement schedule
(15) Finisher's certification: American Concrete Institute (ACI)
(16) Deck construction details
(17) Joint details
(18) Role of all personnel
(19) Contingency plans

In addition to the requirements of this specification, the Department may perform additional HPC testing, sampling, and instrumentation during the production, transportation, and placement of HPC for the field demonstration and the bridge deck placement. The contractor shall make all necessary provisions to allow for adequate sampling and testing of the HPC.

601HPC-3.02 Falsework and Forms:

601HPC-3.02-A Design and Drawings:

The contractor shall be responsible for designing and constructing safe and adequate falsework and forms which provide the necessary rigidity, support the loads imposed, and produce in the finished structure the lines, grades, and dimensions shown on the project plans and established by the Engineer.
Forms shall be any system of structural elements which provides horizontal support or restraint to the lateral pressure of concrete.

Falsework shall be any system of structural elements that provides temporary support for loads from plastic concrete, forms, reinforcing steel, structural steel, loads from placement operations or other related loads, and continues to provide support until the concrete has attained adequate strength and the structure is capable of self-support.

The design load for falsework shall consist of the sum of dead and live vertical loads, and an assumed horizontal load. The minimum total design load for any falsework shall be not less than 100 pounds per square foot for the combined live and dead load regardless of slab thickness.

Dead loads shall include the weight of concrete, reinforcing steel, forms, and falsework. The weight of concrete, reinforcing steel, and forms shall be assumed to be not less than 160 pounds per cubic foot for normal concrete and not less than 130 pounds per cubic foot for lightweight concrete.

Live loads shall consist of the actual weight of any equipment to be supported by falsework applied as concentrated loads at the points of contact and a uniform load of not less than 50 pounds per square foot applied over the area supported.

The assumed horizontal load to be resisted by the falsework bracing system shall be the sum of the actual horizontal loads due to equipment, construction sequence or other causes and an allowance for wind, but in no case shall the assumed horizontal load to be resisted in any direction be less than two percent of the total dead load. The falsework shall be designed so that it will have sufficient rigidity to resist the assumed horizontal load without considering the weight of the concrete.

If the concrete is to be prestressed, the falsework shall be designed to support any increased or readjusted loads caused by prestressing forces.

Falsework shall be designed by the working stress design method, and stresses under all loads shall not exceed the maximum allowable stresses provided for in the current edition of AASHTO Standard Specifications for Highway Bridges. The maximum allowable stresses provided for in the National Design Specification (NDS) for wood construction may be used as an alternate to the AASHTO specifications for timber design. The maximum allowable horizontal shear stress in timber shall not exceed 125 pounds per square inch after all applicable modification factors have been applied. No increase in allowable stresses for repetitive member uses will be allowed.

Unless otherwise specified on the plans, deflection of the falsework span due to the weight of concrete only shall not exceed 1/240 of the falsework beam span irrespective of the fact that the deflection may be compensated for by camber strips.
In the case of post-tensioned structures, the falsework deflections shall not produce stresses in the structure at any time prior to post-tensioning greater than 0.8 times the modulus of rupture for plain concrete unless approved by the Engineer.

Falsework over or adjacent to roadways or railroads which are open to traffic shall be designed and constructed so that the falsework will be stable if subjected to impact by vehicles. Falsework posts which support members that cross over a roadway or railroad shall be considered as adjacent to roadways or railroads. Other falsework posts shall be considered as adjacent to roadways or railroads only if they are located in the row of falsework posts nearest to the roadway or railroad and the horizontal distance from the traffic side of the falsework to the edge of pavement or to a point 10 feet from the centerline of track is less than the total height of the falsework and forms.

The vertical load used for the design of falsework posts and towers, but not footings, which support the portion of the falsework over openings, shall be increased to not less than 150 percent of the design load calculated in accordance with the provisions for design load previously specified.

Falsework posts adjacent to roadways or railroads shall consist of either steel with a minimum section modulus about each axis of 9.5 inches cubed or sound timbers with a minimum section modulus about each axis of 250 inches cubed.

Each falsework post adjacent to roadways or railroads shall be mechanically connected to its supporting footing at its base, or otherwise laterally restrained, so as to withstand a force of not less than 2,000 pounds applied at the base of the post in any direction except toward the roadway or railroad track. Such posts also shall be mechanically connected to the falsework cap or stringer. Such mechanical connection shall be capable of resisting a load in any horizontal direction of not less than 1,000 pounds.

For falsework spans over roadways, all exterior falsework stringers and stringers adjacent to the ends of discontinuous caps, the stringer or stringers over points of minimum vertical clearance and every fifth remaining stringer, shall be mechanically connected to the falsework cap or framing. Such mechanical connections shall be capable of resisting a load in any direction, including uplift on the stringer, of not less than 500 pounds. Such connections shall be installed before traffic is allowed to pass beneath the span. For falsework spans over railroads, all falsework stringers shall be so connected to caps.

When timber members are used to brace falsework bents which are located adjacent to roadways or railroads, all connections for such timber bracing shall be of the bolted type using 5/8 inch diameter or larger bolts, or shall be connected in a manner that will equal 100 percent capacity of the smaller member connected.

The falsework shall be located so that falsework footings or piles are at least three inches clear of railing posts and barriers and all other falsework members are at least one foot clear of railing members and barriers.

Falsework bents within 20 feet of the center line of a railroad track shall be sheathed solid in the area between 3 and 17 feet above the track elevation on the side facing the track. Sheathing shall consist of plywood not less than 5/8 inch thick or lumber not less than one inch thick (nominal). Bracing on such bents shall be adequate so that the bent will resist the required assumed horizontal force or 5,000 pounds, whichever is greater.

Drawings shall be prepared in accordance with the requirements of Subsection 105.03.

The drawings shall be complete and fully detailed working drawings showing the dimensions and material for all parts, arrangement, spacing, and connections, and all provisions for adjustment and for measuring displacement. The falsework foundations, any connections or contacts with previously built structures or other works, and the means of protecting such other works from damage shall be detailed. The above data may be presented as convenient either on the drawings or in the design summary, which shall also describe the assumptions and types of calculations used in the design and the stresses and deflections found for critical points. For any embankments used, the equivalent of the above drawings and data shall be submitted, and in addition the source, classification, and compaction requirements for the material and the results of any tests performed on the material. In no case shall the embankment be compacted to less than 90 percent compaction, and the top three feet shall be compacted to a minimum of 95 percent compaction when tested in accordance with the requirements of the applicable test methods of the ADOT Materials Testing Manual, as directed and approved by the Engineer. The embankment shall be topped with a lean concrete waste slab screeded to the required grades.

Falsework design will require written approval by the Engineer prior to commencing work and shall be in accordance with the requirements of Subsection 105.03.

Except as provided for on the project plans, supports for deck falsework, forming or screed supports shall not be welded to steel girders, shear connectors, slab ties or girder stirrups.

Modification of girders to support falsework and forming will not be allowed except as approved by the Engineer. This includes connections of any type in girder webs to support deck forming. When modification of girders to support the deck falsework and forming has been approved by the Engineer, shop drawings for both the girders and the falsework and forming shall be submitted concurrently so that the review and approval of the drawings can be coordinated.

The tops of the erected girders shall be surveyed by the contractor in the field prior to placement of the deck forming falsework. This survey shall be submitted to the Engineer for evaluation. If the top of erected girder elevations are higher than the screed elevations minus the combined deck slab and the buildup thicknesses, adjustments will have to be made in the roadway profile or in the girder bearing seat elevations. Encroachment into the deck slab of up to 1/2 inch will be allowed for random occurrences.

601HPC-3.02-B Falsework Construction:

The falsework shall be constructed to conform to the falsework drawings. The materials used in the falsework construction shall be of the quality necessary to sustain the stresses required by the falsework design. The workmanship used in falsework construction shall be of such quality that the falsework will support the loads imposed on the falsework.

Falsework shall be founded on a solid footing safe against undermining and capable of supporting the loads imposed.

No concrete shall be placed in any forms supported by falsework until the contractor's professional engineer has inspected the completed falsework and has issued a properly signed and sealed certificate that the falsework has been constructed according to the approved falsework drawings.

Wedges, screws or jacks shall be used in connection with falsework to set the forms to required grade and uniform bearing prior to placing concrete.

All wedges shall be in pairs to insure uniform bearing. Laminated sections will not be permitted. If additional material is required under wedges, either single blocks or thicker wedges will be required. A sufficient number of wedges shall be used to cover the entire bearing area.

The contractor shall provide tell-tales attached to the soffit forms and readable from the ground in enough systematically placed locations to determine the total settlement of the entire portion of the structure where concrete is being placed.

If any weakness develops during the placing of the concrete or the falsework shows any undue settlement or distortion, the work shall be stopped and the falsework corrected and strengthened.

601HPC-3.02-C Forms Construction:

601HPC-3.02-C.01 General Requirements:

Forms shall be of wood, metal, or other suitable material conforming to the requirements specified herein. Forming plans for cast-in-place bridge girders shall be prepared in accordance with the requirements of Subsection 105.03.

The forms shall be mortar tight and shall be designed, constructed, braced, and maintained so that the finished concrete will be true to line and elevation and will conform to the required dimensions and contours. They shall be designed to withstand the pressure of concrete with consideration given to rate of concrete placement, temperature of the concrete, use of set-retarding admixtures or pozzolanic materials in the concrete, the effects of vibration as the concrete is being placed, and all loads incidental to the construction operations, without distortion or displacement.

Stay-in-place forming shall not be used unless specified on the plans or approved by the Engineer. Expanded metal meshes may be used to form construction joints providing:

(1) Three-inch edge cover is maintained, and

(2) Use in bridge decks is prohibited.

Forms reused shall be maintained at all times in good condition as to accuracy of shape, strength, rigidity, water-tightness, and smoothness of surface. Forms or form lumber unsatisfactory in any respect shall not be used.

Forms shall be constructed so that portions may be removed without disturbing forms that are to remain. All form joints shall be taped or caulked in an acceptable manner. Forms for this work shall be equivalent to first class pattern work.

Forms shall be filleted 3/4 inch at all exposed, sharp corners of the concrete.

All forms shall be treated with an approved form release agent before concrete is placed. Any material which will adhere to or discolor the concrete shall not be used.

Forms shall be cleaned of all dirt, sawdust, water, and other foreign material prior to placing concrete in the forms.

For narrow walls and columns where the bottom of the form is inaccessible, provisions shall be made for cleaning out extraneous material immediately before placing the concrete. The cells of box girders shall be cleared of all loose materials prior to the completion of deck forming when such forming is to remain in place. When the deck forming is to be removed, the cells of the box girders shall be cleared of all loose materials after removal of the forms.

601HPC-3.02-C.02 Wood Forms:

All lumber used for forms shall be free from defects affecting the accuracy of shape, strength, rigidity, water-tightness, and smoothness of the surface. All lumber for forms above stream bed shall be plywood. All form lumber shall be securely fastened to the studding so that cupping cannot occur. Chamfer strips shall be of selected material dressed to true line and uniform dimensions. The interior surfaces of all forms in contact with concrete surfaces which will be exposed in the finished work shall be smooth and even. No uneven or offset joints or single boards projecting so that their impressions are left in the concrete will be allowed. Forms, as far as practicable, shall be so constructed that the form marks will conform to the general lines of the structure. In general, grain of the lumber and direction of side joints shall be horizontal on wide faces and walls and vertical on narrow faces. If varying widths of panels are used, the wider panels shall be placed on the bottom and the narrower ones near the top. Panel end joints shall be staggered not less than three feet. Spreaders made of wood shall not be left in the concrete.

601HPC-3.02-C.03 Metal, Fiberglass and Other Forms:

The same provisions as specified under wood forms shall apply to metal and fiberglass forms and in addition, the following shall apply:

(1) All bolts and rivet heads shall be countersunk. Clamps, rods, pins, or other connecting devices shall be designed to hold the forms rigidly together and allow removal without injury to the concrete. Forms which do not present a smooth surface or are not properly aligned shall not be used

(2) Care shall be exercised to keep the forms free of dust, grease, or other foreign matter which will tend to discolor the concrete.

(3) Metal forms shall be used for the casting of precast I-beams, box beams, and voided or flat slabs where the contract number of units combined dictates production runs equal to or longer than

the precasting bed length. A limited number of units, having a total combined length at least one unit length less than bed length, may be cast with alternate forms, as approved by the Engineer. Dimensional tolerances using alternate forms shall conform with Subsection 601HPC-4.02-B.

(4) Waste slabs used as a part of the forms shall be finished to the appropriate grade including any camber. The finished slab shall not vary more than 1/4 inch from the theoretical grade nor more than 1/4 inch from a 10 foot straightedge in any direction.

601HPC-3.02-C.04 Internal Cells:

Internal cells or voids in pre-cast box beams shall be constructed with either wood forms conforming to Subsection 601HPC-3.02-C.02, or with solid expanded polystyrene.

When solid expanded polystyrene is used, the entire top surface of the polystyrene of the internal void shall be covered with 3/8 inch thick, exterior-grade plywood. Butt joints of the plywood sections shall be at least two feet away from any joined section of polystyrene. Polystyrene sections shall be securely held together by an adhesive recommended by the manufacturer of the polystyrene.

All wood forms or polystyrene/plywood sections shall be securely held in place by nails, waterproof adhesive, or other means approved by the Engineer. Internal cells shall be completely sealed so no plastic concrete is allowed to enter the formed cell.

601HPC-3.02-D Removal of Falsework and Forms:

No falsework or forms shall be relieved of load and no forms shall be removed without approval of the Engineer.

Falsework, excluding bridge deck cantilevered overhangs for cast-in-place prestressed structures, shall not be removed until after the prestressing steel has been tensioned and a minimum of 72 hours after the prestressing steel has been grouted. Falsework for the cantilevered bridge deck overhang shall be removed prior to prestressing but shall not be removed within seven days of concrete placement unless the concrete has attained a minimum compressive strength of 3,000 pounds per square inch. In no case shall falsework be removed within five days of concrete placement. On bridges with both transverse and longitudinal stressing, the deck and overhang falsework shall not be removed until after the transverse prestressing has been completed unless shown otherwise on the plans. The deck overhang falsework shall then be removed prior to performing the longitudinal prestressing.

Falsework for HPC shall not be removed until either:

(1) At least 10 days after the last concrete has been placed in each continuous span and until the compressive strength of all placed

concrete has attained at least 70 percent of the required 28-day compressive strength; or

(2) At least five days after the last concrete has been placed in each continuous span and until the concrete has attained the required 28-day compressive strength.

The sloped exterior girders of cast-in-place box girder bridges shall be laterally braced or supported until the top slab (deck) concrete has been placed and has attained at least 70 percent of the required 28-day compressive strength.

Side forms for footings, beams, girders, box culverts, columns, railings, curbs, or other members wherein the forms do not resist dead load bending may be removed after the concrete has set, and the contractor shall cure and protect the concrete thus exposed in accordance with the requirements of Section 10HPC. The contractor shall assume all risks and responsibility resulting from such removals. Forms for cast-in-place concrete, unless otherwise specified herein, shall not be removed until at least seven days after concrete has been placed in the forms, without the approval of the Engineer.

Placement of backfill material shall be in accordance with Subsection 203-5.03(B). Where backfill is to be placed against both sides of a structural element, the backfill elevations on one side of the element shall not exceed the backfill elevations on the opposite side of the element by more than five feet.

Forms for precast concrete shall stay in place a minimum of eight hours.

The period of time between the placement of concrete in the top slab of a standard concrete box culvert (12 foot span or less) and the removal of the slab support forms may be reduced to 48 hours if the top slab remains supported along the center line of the culvert span by a continuous beam and line of posts erected as a part of the original slab form, and which will remain in place, undisturbed, a minimum of seven days.

If the Engineer allows the removal of forms before the specified curing period has elapsed, the contractor shall cure the concrete for the remaining required curing time by one of the methods specified in Section 10HPC.

All forms shall be removed, except forms used to support the deck of box girders when no permanent access to the cells is available.
Care shall be taken in removing falsework and forms so as not to deface or damage the structure. Methods of removal likely to damage or cause overstressing of the concrete shall not be used.

All falsework shall be removed from under bridge superstructures prior to opening the structure to traffic. Falsework shall be removed in such a manner that excessive stresses are not induced into the structure. Holes shall not be drilled into the structure to facilitate removal of the falsework. Round blockouts may be used for such purpose providing the contractor can submit evidence that the blockouts are not detrimental to the structure and the Engineer approves the use of the blockouts. The maximum blockout diameter shall not exceed six inches.

601HPC-3.03 Placing Concrete:

601HPC-3.03-A General Requirements:

No concrete shall be placed in any structure until the placement of reinforcing steel and the adequacy of the forms and falsework have been approved by the Engineer.

Adequate time shall be given to the Engineer to check all form dimensions, embedded items, and placement of reinforcing steel. Concrete shall not be placed until all necessary corrections have been made by the contractor and all work required for the proposed pour has been completed.

Reinforcing steel shall be placed in accordance with the requirements of Section 605 and the project plans.

The sequence of concrete placement shall be as shown on the project plans or as approved by the Engineer when not shown on the project plans.

Concrete shall be placed and consolidated by methods that will not cause harmful segregation and will result in a dense homogeneous concrete free of honeycomb or voids.

Concrete shall be placed in horizontal layers not over 24 inches in depth unless otherwise approved by the Engineer.

Concrete shall be placed as nearly as possible in its final position and the use of vibrators for shifting the mass of fresh concrete will not be permitted. Dropping the concrete more than eight feet without the use of approved pipes or tubes will not be allowed.

Care shall be taken to fill all areas within the forms and to force the concrete under and around the reinforcement without displacing the reinforcement or other embedded items.

Conveying equipment shall be capable of providing a supply of concrete to the point of placement without segregation, or interruptions sufficient to permit loss of plasticity between successive increments.

Concrete placed in slabs and floors other than bridge decks shall be struck off by means of a screed. The screed may be self-propelled screed equipment or the type specified under Subsection 401-3.04 (D), Fixed Form-Manual Methods.

No concrete that has partially hardened or been contaminated by foreign materials shall be deposited in the structure.

The rate of concrete placement and consolidation shall be such that the formation of cold joints within monolithic sections of any structure will not occur. Any portion of any structure displaying apparent cold joints will be rejected, unless the contractor, at no additional cost to the Department, can submit evidence that will indicate that either a cold joint does not exist or that a cold joint is not detrimental to the structure. The Engineer shall be the sole judge in determining the existence of a cold joint and whether its existence is detrimental to the structure. The rate of concrete placement for major structures shall not be less than 35 cubic yards per hour unless otherwise specified or approved in writing by the Engineer. This rate shall not apply to precast concrete members.

The rate of concrete placement for the bottom slabs and girder walls of cast-in-place box girder superstructures shall not be less than 60 cubic yards per hour when the volume of concrete to be placed exceeds 300 cubic yards.

601HPC-3.03-B Bridge Deck:

HPC shall not be placed when the air temperature in the shade is above 90^{o}F. HPC shall be placed only when the rate of evaporation on the bridge deck does not exceed 0.10 pounds per square foot per hour for the entire duration of the HPC placement. The rate of evaporation is determined from the evaporation graph (Attachment A) after measuring the relative humidity, plastic concrete temperature, and wind velocity at the bridge deck.

The contractor may elect to work at night, if approved by the Engineer. If approved, night work shall be performed in accordance with Subsection 108.05 of the specifications. Fogging equipment shall be in place and in good working order prior to the placement of HPC. Windscreens will be required to be in-place when the fogging equipment alone cannot maintain the evaporation rate within acceptable limits as stated in the above paragraph and the contractor elects to continue HPC placement.

The placing of concrete will not be permitted until the Engineer is satisfied that the rate of producing and placing concrete shall be sufficient to complete the proposed pour and finishing operations within the scheduled time, that experienced concrete finishers are available to finish the deck and that all necessary finishing tools and equipment are on hand at the site of the work and are in satisfactory condition for use.
Concrete shall be placed for the full width of the panel to be poured. After the concrete has been placed it shall be consolidated and then struck off by means of self-propelled screed equipment.

Screed equipment shall be designed to operate as close as practicable to bridge curbs or other obstructions.

Screed equipment shall travel on steel rails. Rails shall be substantially supported by adjustable steel supports of adequate size securely fastened in place and spaced at sufficiently close intervals to prevent any appreciable deflection in the rails. Steel supports shall be of such types and installed in such manner that when the rail and adjustable support have been removed, there will be no void in the concrete.

The steel rails for placing and finishing equipment shall be set to the correct elevation shown on the project plans or as established by the Engineer. The rails shall extend beyond both ends of the scheduled length for placement a sufficient distance that will permit the screed and finishing equipment to reach all areas of the concrete placed.

Placement of the deck concrete shall be in accordance with the placing sequence shown on the project plans. The contractor shall submit a drawing showing the placement sequence construction joint locations, directions of the concrete placement, and any other pertinent data to the Engineer for review. The drawing shall be submitted at least four weeks prior to the date of deck placement.

Screed beams or rollers shall be made of metal, or the bottom of the beam shall be metal clad. Roller screeds shall be constructed so that there will be no sag or deflection in the screeds.

Screed assemblies shall be equipped with vibrators. The screed assemblies shall be so designed that the vibrating units do not contact any reinforcing steel. Vibration shall be transmitted to the concrete in such a manner that when the motion of the machine is stopped, all vibration will cease.

A slight excess of concrete shall be maintained in front of the screed at all times during the screeding operation. The screed shall make the minimum amount of passes over the slab to avoid overworking the surface while obtaining a uniform surface.

The contractor shall furnish a minimum of two transverse work bridges from which floating, straight edging, and curing operations may be accomplished. The work bridges shall be reasonably rigid and free of excessive deflections. The self-propelled mechanical bridge used for texturing the bridge deck may be substituted for one of the required work bridges.

The floating operation shall follow the screeding if required. The float shall have a minimum diameter of three inches and have a minimum length of 12 feet. The float shall be constructed so that the surface will be maintained true at all times.

Prior to placing concrete, the screed shall be traversed the length of the proposed pour and the clearance from the screed to the reinforcing steel and deck thickness shall be checked. The method of determining the clearance shall be approved by the Engineer prior to making such checks. The clearance shall be as indicated on the project plans with a permissible variation of ± 1/4 inch. Deflection of the screed rails as a result of the weight of the screed equipment will not be permitted. All corrections necessary as a result of this operation shall be performed prior to beginning the pour.

601HPC-3.03-B.01 Bridge Deck HPC Placement:

The following HPC deck placement practices shall be strictly followed. Delays such as waiting for concrete surface sheen to disappear, concrete surface strength development, or other reasons shall not be allowed. HPC fresh surfaces shall be continuously protected from moisture loss and surface drying by means of water fogging, moisture evaporation retarders, and windscreens until such time when HPC can be cured according to Subsection 10HP-6.

601HPC-3.03-B.01-a Deck Forms:

Prior to placement of HPC, bridge deck forms shall be kept moist for a period of at least 3 hours before receiving HPC. All freestanding water shall be removed prior to HPC placement. During concrete placement, bridge deck forms that will receive HPC shall be kept moist until HPC is placed against the bridge deck form.

601HPC-3.03-B.01-b Surface Finishing:

The rate of concrete discharge, placement, and finishing shall be maintained so that the finishing machine (Bidwell) is between five to ten feet away from the concrete deposited on the bridge deck.

Placing HPC shall be a continuous operation. As soon as HPC is placed, mechanical screeding shall take place. HPC shall be placed slightly above grade and then struck-off, screed and finished to final grade. All horizontal concrete surfaces shall be finished using vibratory screeds (equipped with the Bidwell) that ride on screed rails. The forward speed of the finishing machine (Bidwell) shall be adjusted to the average progress of the HPC production in order that the strike-off operations are as continuous and uninterrupted as possible. Hand finishing with a float may occasionally be required to produce a tight uniform surface at the edges of the bridge deck. When such hand finishing is needed, it shall be kept to a minimum to avoid overworking the surface.

601HPC-3.03-B.01-c Water Fogging :

The addition of water directly to the HPC surface during the finishing operations will not be permitted. A high-moisture area of 2 to 3 feet above concrete surface shall be maintained by an approved fogging system attached to the finishing machine until and the curing cover is placed on the concrete surface as described in Subsection 10HPC-6 of the specifications. The fogging system shall be capable of producing a fine mist fog above and over the entire surface of the freshly placed concrete surfaces.

601HPC-3.03-B.01-d Concrete Vibration:

Fresh HPC, three inches or more in thickness, shall be internally vibrated in addition to the surface vibration by the vibratory screed (Bidwell).

601HPC-3.03-B.01-e HPC Surface Evaporation and Protection:

A monomolecular film product that aids in retarding the evaporation and acts as a finishing aid may be used provided the manufacturer’s recommendations are followed and the Engineer’s approval is obtained in advance. The use of an approved monomolecular film may be allowed as an evaporation retarder after the finishing has been completed. The application of such evaporation retarder shall not be in lieu of the water fogging or protection of the surface above the HPC. The application of the evaporation retarder shall be in the form of a fine mist using a suitable sprayer. Impacting the plastic concrete surfaces with a stream shall not be allowed. The evaporation retarder shall not be mixed into the plastic concrete at any time. The use of a monomolecular film shall conform to the manufacturer's recommendations.

601HPC-3.03-B.01-f Placement Progress:

If the placement of HPC is stopped for a period of one-half hour or more, the contractor shall install a bulkhead transverse to the direction of the placement at a position where the HPC can be finished full-width up to the bulkhead. The bulkhead shall be full depth of the bridge deck and shall be installed to grade. For delays of less than one-half hour, the end of the HPC placement shall be protected from drying with wet burlap. The HPC previously placed shall be finished, covered, and cured in accordance with the specifications. Further placement is permitted only after a period of twelve hours unless a gap is left in the lane or strip. The gap shall be of sufficient width for the finishing machine to clear the transverse bulkhead installed where the HPC placement was stopped. The previously poured HPC shall be sawn back from the bulkhead, to a point designated by the Engineer, to straight and vertical edges and shall be water blasted or sandblasted before new HPC is placed.

601HPC-3.03-B.01-g Slump and Air Content:

Determination of HPC properties for acceptance and placement shall be made based on the results of testing and sampling taken at the final point of discharge of the HPC (on the bridge deck) and not at the truck discharge. The contractor shall establish the amount of air and slump losses encountered during pumping HPC and make adjustments to the HPC mix to compensate for these losses so that the final HPC slump, air content, and other HPC properties listed in Subsection 10HPC-3.01, at the point of placement are in compliance with the specifications.

601HPC-3.03-C Pumping Concrete:

Where concrete is conveyed and placed by mechanically applied pressure, the equipment shall be of suitable type and shall have adequate capacity for the work. The concrete shall not flow either over or through any piping, fittings, or equipment which is fabricated of aluminum or aluminum alloys. The operation of the pump shall be such that a continuous stream of concrete without air pockets is produced. Excessive segregation due to high velocity discharge of the concrete will not be permitted. When pumping is completed, the concrete remaining in the pipeline, if it is to be used, shall be ejected in such a manner that there will be no contamination of the concrete or segregation of the ingredients. Standby equipment shall be readily available to replace initial pumping equipment should breakdown occur.

601HPC-3.03-D Vibrating Concrete:

All concrete in structures shall be consolidated by means of approved vibrators together with any other equipment necessary to perform the work as specified herein. The minimum frequency of the internal vibrators shall be 8,000 vibration cycles per minute.

Vibration shall be applied in the area of the freshly deposited concrete. Vibrators shall penetrate to the bottom of the concrete layer and at least six inches into the preceding layer. The vibration shall be of sufficient duration and intensity to consolidate the concrete thoroughly within 15 minutes after it has been deposited in the forms.

Vibration shall not be continued at any one point to the extent that localized areas of grout are formed. Application of vibrators shall be at points uniformly spaced and not farther apart than twice the radius over which the vibration is visibly effective.

Re-vibration of concrete may be required at any time as directed by the Engineer.

The contractor shall provide sufficient equipment to ensure uninterrupted and continuous vibration of concrete.

601HPC-3.03-E Placing Concrete in Water (Tremie Concrete):

Tremie concrete shall be deposited in water only if either specified on the project plans or when directed and then only under the Engineer's supervision. When depositing in water is allowed, the concrete shall be carefully placed in a compact mass in the space in which it is to remain by means of a tremie, bottom dump bucket or other approved method that does not permit the concrete to fall through the water without adequate protection. The concrete shall not be disturbed after being deposited. No concrete shall be placed in running water and forms which are not reasonably watertight shall not be used for holding concrete deposited under water.

A head of concrete shall remain above the discharge end of the tremie tube at all times.

601HPC-3.03-F Bridge Deck Widening:

Where the roadway portion of a bridge deck widening section is more than 12 feet in width, concrete shall be placed in the roadway portion in accordance with the requirements of Subsection 601HPC-3.03-B.

Where the roadway portion of a bridge deck widening section is 12 feet or less in width, the spreading and floating of concrete in the roadway portion shall conform to the requirements of Subsection 401-3.04(D).

601HPC-3.03-G Pedestrian Rail and Fence:

This work shall consist of furnishing and constructing Combination Pedestrian-Traffic Bridge Railing, Pedestrian Fence for Bridge Railing, and Two-Tube Bridge Rail, including all hardware and materials, in accordance with the requirements of the project plans.

601HPC-3.03-H Bridge Barriers and Transitions:

This work shall consist of furnishing and constructing Bridge Concrete Barrier and Transition, including all hardware and materials, in accordance with the requirements of the project plans.

601HPC-3.03-I Approach and Anchor Slabs:

This work shall consist of furnishing and constructing reinforced concrete approach and anchor slabs for bridges, including all tools, equipment, labor, and materials. All work shall be in accordance with the details shown on the project plans and the requirements of these specifications.

601HPC-3.04 Joints in Major Structures:

601HPC-3.04-A Construction Joints:

Except as otherwise specified herein, construction joints shall be constructed at the locations specified on the project plans.

Construction joints shall be placed in the locations shown on the project plans or as approved by the Engineer. Except under emergency conditions, construction joints shall be planned and located in advance of placing concrete. All construction joints shall be perpendicular to the principal lines of stress and in general located at points of minimum shear and moment.

Construction joints shall be constructed in accordance with the details shown on the project plans or as directed by the Engineer. Before new concrete is placed against concrete which has hardened, forms shall be drawn tight against the face of the concrete, wood keys shall be removed and the exposed steel or dowels and the entire surface of the construction joint shall be thoroughly cleaned. Immediately ahead of placing fresh concrete on the construction joint, the old concrete shall be thoroughly saturated with water.

After placing of concrete has been completed to the construction joint and before placing fresh concrete, the exposed reinforcing steel and the entire surface of the construction joint shall be thoroughly cleaned of surface laitance, curing compound, and other materials foreign to the concrete and clean, coarse aggregate exposed. Surfaces of concrete that have been in place for eight hours or more shall be cleaned by abrasive blast methods. Surfaces of concrete that have been in place for less than eight hours may be cleaned with air and water jets provided that surface laitance and curing compound is removed.
After the concrete surfaces have been treated as specified, they shall be cleaned of all dust and abrasive material.

601HPC-3.04-B Deck Joint Assemblies:

601HPC-3.04-B.01 Description:

This work shall consist of furnishing and installing expansion devices including the seals, anchorage system, and hardware in conformity with the project plans and the requirements of these specifications.

601HPC-3.04-B.02 Materials:

Elastomer seals shall be of the Compression Seal or Strip Seal type and shall conform to the requirements of Subsection 1011-5.

Steel shapes and plates shall conform to the requirements of ASTM A 36 or A 588.

601HPC-3.04-B.03 Construction Requirements:

601HPC-3.04-B.03-a General:

Deck joint assemblies shall consist of elastomer and metal assemblies which are anchored to the concrete at the joint. The seal armor shall be cast in the concrete. The completed assembly shall be in planned position, shall satisfactorily resist the intrusion of foreign material and water and shall provide bump-free passage of traffic.

For each size of seal on a project, one piece of the material supplied shall be at least 18 inches longer than required by the project plans. The additional length will be removed by the Engineer and used for testing by ADOT Materials Group. Certificates of Compliance conforming to the requirements of Subsection 106.05 shall be submitted.

601HPC-3.04-B.03-b Shop Drawings:

Prior to fabrication, the contractor shall submit eight sets of shop drawings to the Engineer for approval in accordance with the requirements of Subsection 105.03. The shop drawings shall show complete details of the method of installation to be followed, including a temperature correction chart for adjusting the dimensions of the joint according to the ambient temperature and any additions or rearrangements of the reinforcing steel from that shown on the project plans.

Deck joint assemblies for prestressed concrete structures shall be installed at the narrowest joint opening possible to allow for long term creep.

601HPC-3.04-B.03-c Elastomer Seals:

Seals shall conform to the requirements hereinbefore specified.

601HPC-3.04-B.03-d Welding:

All welding shall be in accordance with the requirements of Subsection 604-3.06.

601HPC-3.04-B.03-e Armor:

All metal for cast-in-place seal assemblies shall be steel conforming to the requirements hereinbefore specified.

601HPC-3.04-B.03-f Galvanizing:

All metal parts of strip seal assemblies shall be galvanized after fabrication in accordance with the requirements of ASTM A 123 and A 153, unless ASTM A 588 steel is used. Bolts shall be high strength, conforming to the requirements of ASTM A 325, with a protective coating of cadmium or zinc followed by a chromate and baked organic coating according to ASTM F 1135, Grade 3, 5, 6, 7, or 8 and Color Code A.

Metal parts of compression seal assemblies do not require galvanizing, plating, or painting.

601HPC-3.04-B.03-g Joint Preparation and Installation:

The contractor shall form the joint with a secondary concrete pour. The surface of the existing concrete shall be coated prior to the concrete being placed with an approved adhesive specifically formulated for bonding new concrete to old concrete.

Joints to be sealed shall be covered or otherwise protected at all times prior to installing the elastomer portion of the assembly. The elastomer shall be installed at such time and in such manner that it will not be damaged by construction operations.

The seal element shall be installed subject to these specifications and the approval of the Engineer. Immediately prior to the installation of the seal element, the metal contact surfaces of the joint armor shall be clean, dry and free of oil, rust, paint, or foreign material. Any perforation or tearing of the seal element due to installation procedures or construction activities will be cause for rejection of the installed seal element.

601HPC-3.04-C Water Stops:

Water stops of rubber or plastic, shall be placed in accordance with the details shown on the project plans. Where movement at the joint is provided for, the water stops shall be of a type permitting such movement without injury. They shall be spliced, welded, or soldered, to form continuous watertight joints.

601HPC-3.04-D Joints in Deck Units:

After erection and at the time directed by the Engineer, the longitudinal joints or shear keys shall be thoroughly packed with a pre-packaged non-shrink grout or a sand-cement grout with an expansion agent approved by the Engineer. The contractor shall then transversely connect the deck units with the connection rods, stressing and anchoring them as shown on the project plans.

601HPC-3.05 Finishing Concrete:

601HPC-3.05-A General Requirements:

The appropriate finish, as specified herein, shall be applied to each surface of all concrete structures.

All formed surfaces will require a Class I Finish. Formed surfaces shall be finished immediately after the removal of forms in accordance with the requirements specified herein. If rock pockets or honeycomb are of such an extent and character as to affect the strength of the structure and to endanger the steel reinforcement, the Engineer may declare the concrete defective and require the removal and replacement of that portion of the structure affected at the expense of the contractor.

Formed surfaces normally in view of vehicular or pedestrian traffic, or not covered by fill material shall present a pleasing appearance of uniform color and texture commonly achieved by the use of clean, smooth plywood forms joined tightly or taped at the joints, preformed metal forms, paper tubing forms, or specially coated forms.

601HPC-3.05-B Class I Finish:

All bolts, wires, snap-ties, and rods shall be clipped and recessed one inch below the surface of the concrete. All holes, honeycomb, rock pockets, and other surface imperfections shall be cleaned to sound concrete, thoroughly moistened and carefully patched with mortar.

Mortar shall be composed of one part cement, two parts of fine sand, water, and an adhesive of a type approved by the Engineer. A portion of the required cement shall be white as required to match the color of the surrounding concrete. Small voids due to entrapped air and water in precast members need not be patched.

601HPC-3.05-C Finishing Bridge Deck:

601HPC-3.05-C.01 General Requirements:

Bridge decks that will be covered with a special riding surface or waterproofing membrane shall be lightly textured with a burlap drag during the plastic concrete state, after the finishing operation and straightedge test, as specified below, and prior to the curing process.

Bridge decks exposed directly to traffic shall be grooved or tined as specified in Subsection 601HPC-3.05-C.02.

The deck surface shall be finished to a final floated surface, free of mortar ridges, hollows, and any other projections. Water shall not be applied to the deck surface at any time during floating or finishing except that a fine fog mist may be applied as approved by the Engineer.

Fogging equipment shall be capable of applying water to the concrete in form of a fine fog mist in sufficient quantity to reduce the effects of rapid evaporation from the concrete. The fine fog mist shall be applied at a distance not to exceed 12 inches from the surface and shall not be applied directly toward the concrete surface. Application of water by brushes or any other method will not be permitted.

Excess concrete resulting from the finishing process shall not be discarded into areas of the bridge deck that will be covered by sidewalks, medians, curbs, or parapets, or otherwise incorporated into the work, but shall be removed and disposed of properly.

The finished surface of the concrete shall be tested with a 10 foot straightedge placed on the deck surface. The surface plane shall not vary by more than 1/8 inch, as measured from the bottom of the straightedge. Deck surfaces to be covered with a special riding surface or waterproofing membrane shall not vary by more than 1/4 inch, as measured from the bottom of the straightedge.

Deck surface areas tested during the plastic state that do not meet the straightedge criteria specified above shall be corrected immediately, refinished, and retested. All corrected areas shall be textured to match the finish of the surrounding deck surface.

Should the deck surface require additional corrections or repair after the concrete has cured, as determined by the Engineer, such work shall be in accordance with Subsection 105.04. If the bridge deck corrections require mechanical grinding, all corrected areas shall be re-textured with sawed grooves to match the finish of the surrounding deck surface. After such corrective grinding and re-grooving is completed, the minimum remaining cover over the reinforcing steel shall be not less than 2 1/4 inches.

601HPC-3.05-C.02 Tining and Grooving:

601HPC-3.05-C.02-a General Requirements:

Unless longitudinal grooving is specified on the plans, the contractor shall texture the bridge deck, approach slab, and anchor slab with transverse grooves.

Grooves shall be placed with a tinning broom while the concrete is still plastic; however, if an item for Bridge Deck Texturing (Sawed Grooves) is included in the bidding schedule, the bridge deck, approach slab, and anchor slab shall be textured with sawed grooves after the concrete has been cured.

A uniform textured surface of grooves shall be installed for the entire length of the bridge deck, approach slabs, and anchor slabs, except for those areas occupied by devices installed on the deck.

Widened bridge decks shall be finished to match the existing deck surface texture.

Bridge sidewalks shall be textured to a light broom finish during the plastic concrete state.

601HPC-3.05-C.02-b Broomed Tines:

Tine broom texturing shall occur after the Engineer has accepted the straightedge test of the finished surface, and during the plastic concrete state, but prior to the curing process.

The tined grooves shall terminate at 12 inches ± 3 inches from the face of curbs, bridge rails, or median dividers along each edge of the bridge deck surface. Texturing shall be stopped 9 to 12 inches from any devices installed on the bridge deck, including scuppers and expansion devices, whether perpendicular to the tined grooves or skewed.

The apparatus producing the texture grooves in the plastic concrete shall be mechanically operated from an independent self-propelled bridge. The bridge shall be used for texturing only, and shall be supported on the same steel rails used for the screed equipment. The tine brooming equipment shall be capable of producing grooves which meet the dimensional requirements specified in Subsection 601HPC-4.01.

The timing of the texture operation in the plastic concrete is critical. The texturing shall be completed before the surface is torn or unduly roughened by the texturing operation. Grooves that close following the texturing will not be permitted.

Hand tine brooms shall be provided and available at the job site at all times when texturing plastic concrete.

601HPC-3.05-C.02-c Sawed Grooves:

(1) **General Requirements:**

Sawed groove texturing shall occur after the Engineer has accepted the finished surface, and after the concrete has cured for at least fourteen days, but before the roadway is opened to traffic. Grooving shall occur prior to the application of any concrete sealer if a sealer is specified in the contract documents.

A self-propelled texturing machine built for grooving of concrete surfaces shall be used for making the sawed grooves. The saw grooving equipment shall be capable of producing grooves which meet the dimensional requirements specified in Subsection 601HPC-4.01.

Sawed groove texturing shall terminate at 12 inches ± 3 inches from the face of curbs, bridge rails, or median dividers along each edge of the bridge deck surface. Texturing shall be stopped 9 inches to 12 inches from any devices installed on the bridge deck, such as scuppers and expansion devices that are perpendicular to the grooves.

For skewed expansion devices on the bridge deck, the direction of the grooves as specified above shall not be altered, and texturing shall terminate no closer than six inches nor farther than four feet from the joint armor. The maximum gap in texturing, from one side to other of skewed expansion devices, shall not exceed five feet.

Overlapping of grooves by succeeding passes shall not be allowed.

(2) **Equipment:**

The self-propelled texturing machine shall have diamond-tipped circular saw blades mounted on a multi-blade arbor, and shall have a depth control device that detects variations in the deck surface and adjusts the cutting head height to maintain the specified depth of the groove. The texture machine shall also include devices to control alignment. Single blade equipment may be authorized by the Engineer where multi-blade assemblies are not capable of sawing to within one foot of obstructions. Flailing or impact type grooving equipment shall not be used.

The grooving equipment shall be equipped with vacuum slurry pickup equipment which shall continuously pick up water and sawing dust, and pump the slurry to a collection tank.

(3) **Construction:**

The contractor shall submit a plan detailing the proposed layout of the texturing to the Engineer for approval at least seven days prior to the grooving operations. Spacing dimensions at the starting and ending point of each pass shall be noted. A description of the saw cutting equipment shall be included.

Prior to grooving operations, the contractor shall provide two gauges, designed for verification of groove depth, to the Engineer for approval. The gauges shall be accompanied by the manufacturer’s instructions for their use. During grooving operations the contractor shall check the groove dimensions, under the observation of the Engineer, at random locations. If the minimum groove depth has not been achieved, the grooving operation shall stop and the necessary adjustments shall be made.

At the beginning of each work shift, the contractor shall furnish a full complement of saw blades for each texturing machine that are capable of cutting grooves of the specified width, depth, and spacing.

If during the work a single grooving blade on a machine becomes incapable of cutting a groove, the contractor shall continue work for the remainder of the work shift. The contractor will not be required to cut the groove omitted resulting from the failed blade. If two or more grooving blades on a machine become incapable of cutting grooves, the contractor shall cease operating the machine until it is repaired.

The contractor shall continuously remove all slurry from the equipment throughout the grooving operations with a vacuum pickup, and shall dispose of the slurry at an approved off-site location, and in accordance with applicable laws and ordinances for disposal. All textured areas shall be flushed with clear water as soon as possible to remove any slurry material not collected by the vacuum pickup. Flushing shall be continued until all surfaces are clean and accepted by the Engineer.

The contractor shall repair all damage to the expansion devices caused by the grooving operation in a manner satisfactory to the Engineer. If the Engineer determines that the expansion device cannot be repaired in a manner which will allow proper functioning of the system, the contractor shall replace the device at no additional cost to the Department. The replacement shall be a new expansion device equal in all respects to the expansion device being replaced.

Damage to any other portion of the bridge deck, or to anything attached or embedded in the bridge deck, that is attributable to the contractor’s operations shall be repaired in a manner satisfactory to the Engineer at no additional cost to the Department.

601HPC-3.02 Curing Concrete:

Curing HPC shall be in accordance with the requirements of Subsection 10HPC-6.

601HPC-3.03 Supporting, Handling, Transporting, and Precast Concrete Items:

After prestressing, precast members for major structures shall be handled or supported at or near the final bearing points for storage.

Precast items shall be supported during transporting in a manner that will allow reasonable conformity to the proper bearing points. At all times, the items shall be handled or supported securely in an upright position.

Items that have been damaged in shipment will be rejected at the point of delivery.

Lifting devices shall not project above the surface of the item after placement unless they will be embedded in a subsequent concrete pour, will have a minimum concrete cover of two inches, and will not interfere with the placement of reinforcing steel or concrete.

601HPC-3.04 Backfilling:

Structure backfill shall be placed in accordance with the requirements of Subsection 203-5.03(B).

601HPC-3.05 Vertical Restrainers:

601HPC-3.05-A Description:

The contractor shall furnish and install restrainer units consisting of cables and assemblies and associated materials or components in conformance with the details shown on the project plans, and in accordance with these specifications.
Components required for each restrainer unit type will be detailed on the project plans and shall include various combinations of the following: cables, clips, No. 11 rebar, duct tape, expanded polystyrene, hardboard, and incidentals.

601HPC-3.05-B Materials:

Cables shall be 3/4 inch diameter preformed, 6 by 19 wire strand core, or independent wire rope core (IWRC), galvanized ASTM A 603 Class A coating, right regular lay, manufactured of improved plow steel with a minimum breaking strength of 21 tons. Two certified copies of mill test reports of each manufactured lengths of cable used shall be furnished to the Engineer.

Free ends of cable restrainer units shall be securely wrapped at each end to prevent separation.

The cable assemblies shall be shipped as a complete unit.

A minimum of one test loop assembly per bridge or one test loop assembly for every 40 cable assemblies, whichever is greater, shall be furnished to the Engineer for testing. The test loop assembly shall be fabricated from the same lot of material, wire rope, and fittings or clips as the cable assemblies. The test loop assembly shall be not less than 27 inches or more than 33 inches long when pulled taut.

Tempered hardboard shall conform to Federal Specification LLL-B-810, Type II, smooth one side, plain. Hardboard shall be 1/8 inch minimum thickness, unless shown or specified otherwise.

Expanded polystyrene shall be a commercially available polystyrene board. Expanded polystyrene shall have a flexural strength of 35 pounds per square inch minimum determined in accordance with ASTM C 203, and a compressive strength of between 16 and 40 pounds per square inch, at five percent compression. When shown on the plans, surfaces of expanded polystyrene shall be faced with hardboard.

Other facing materials may be used provided they furnish equivalent protection. All boards shall be held in place by nails, waterproof adhesive, or other means approved by the Engineer.

601HPC-3.05-C Construction Requirements:

Restrainers shall be installed as indicated on the project plans.

The contractor shall provide means of holding the cable assemblies in their planned positions.

The contractor shall be responsible for determining the required length of the cable assemblies.

601HPC-4 Tests on Finished Structures:

601HPC-4.01 Surface Texture:

The grooves for decks exposed directly to traffic shall have a rectangular section and shall be 1/8 inch ± 1/32 inch deep by 1/8 inch ± 1/32 inch wide. Spacing between the grooves shall be 3/4 inches ± 1/8 inch center to center. The textured groove depth shall be measured in accordance with the requirements of Arizona Test Method 310.

601HPC-4.02 Dimensional Tolerances:

601HPC-4.02-A Cast-in-Place Concrete:

The maximum allowable tolerances or deviations from dimensions shown on the project plans or the approved shop drawings shall be as follows:

(1) Variation from plumb in the lines and surfaces of columns, piers, abutment and girder walls:

In any 10-foot-or-less length: 3/8 inch
Maximum for the entire length: 1 inch

(2) Variation in cross-sectional dimensions of columns, piers, girders, and in the thickness of slabs and walls:

+ 1/4 inch
- 1/8 inch

(3) Girders alignment (deviation from straight line parallel to center line of girder measured between diaphragms):

1/8 inch per every 10 feet in length

(4) Variation in footing cross sectional dimensions in project plans:

+ 2 inches
- 1/2 inch

(5) Variation in footing thickness:

*Greater than specified: No Limit

Less than specified: 5 percent of specified thickness up to a maximum of one inch

*Does not apply to reinforcing steel placement.

(6) Subgrade Tolerances:

Slab poured on subgrade excepting footing thickness:

+ 1/4 inch
- 3/4 inch

(7) Girder Bearing Seats:

Deviation from plane surface (flatness):

± 1/8 inch in ten feet.

Deviation from required elevation:

- 1/4 inch
+ 1/8 inch

(8) Cast-In-Place concrete box girder superstructures:

Deviation in overall depth:

+ 1/4 inch
- 1/8 inch

Deviation in slab and wall thickness:

+ 1/4 inch
- 1/8 inch

Deviation of post-tensioning ducts:

± 1/4 inch

601HPC-4.02-B Precast Concrete Structures:

601HPC-4.02-B.01 General:

Precast units that do not comply with the dimensional tolerances specified herein will be rejected. Precast units that show evidence of cracks, pop outs, voids, or other evidence of structural inadequacy or imperfections that will reduce the aesthetics of the unit after final placement will be rejected.

601HPC-4.02-B.02 Precast Concrete I-Beams:

The maximum allowable tolerances of deviations from dimensions and details shown on the project plans or the approved shop drawings shall be as follows:

(a) Length: ± 3/4 inch

(b) Width (flanges and fillets): + 3/8 inch, - 1/4 inch

(c) Depth (overall): + 1/2 inch, - 1/4 inch

(d) Width (web): + 3/8 inch, - 1/4 inch

(e) Depth (flanges and fillets): ± 1/4 inch

(f) Bearing plates (ctr. to ctr.): ± 1/8 inch per 10, but not greater than ± 3/4 inch

(g) Horizontal alignment (deviation from straight line parallel to center-line of member): 1/8 inch per every 10 feet in length

(h) Stirrup bars (deviation from top of beam): + 1/4 inch
- 3/4 inch

(i) Tendon position: ± 1/4 inch c.g. of strand group and individual strands

(j) Horizontal position of deflection points for deflected strands: ± 10 inches

(k) Position of handling devices: ± 6 inches

(l) Bearing plates (ctr. to end of beam): ± 1/4 inch

(m) Side inserts (ctr. to ctr. and ctr. to end): ± 1/2 inch

(n) Exposed beam ends (deviation from square or designated skew):

Horizontal: ± 1/4 inch

Vertical: ± 1/8 inch per foot of beam depth

(o) Bearing area deviation from plane: ± 1/8 inch

(p) Stirrup bars (longitudinal spacing): ±1 inch

(q) Position of post-tensioning duct: ±1/4 inch

(r) Position of weld plates: ± 1 inch

601HPC-4.02-B.03 Precast Concrete Box Beams and Flat Slabs:

The maximum allowable tolerances or deviations from dimensions and details shown on the project plans or the approved shop drawings shall be as follows:

(a) Length: ± 3/4 inch

(b) Width (over-all): ± 1/4 inch

(c) Depth (over-all): ± 1/4 inch

(d) Width (web): ± 3/8 inch

(e) Depth (top slab): ± 1/4 inch

(f) Depth (bottom slab): + 1/4 inch, - 1/8 inch

(g) Horizontal alignment (deviation from straight line parallel to center line of member): 1/8 inch per every 10 in length

(h) Camber differential between adjacent units:

Not greater than 3/4 inch

(i) Position of tendons: ± 1/4 inch c.g. of strand group

(j) Longitudinal spacing of stirrup bars: ± one inch

(k) Position of handling devices: ± 6 inches

(l) Slab Void position: ± 1/2 inch from end of void to center tie hole + 1 inch adjacent to end block

(m) Square ends (deviation from square): ± 1/2 inch

(n) Skew ends (deviation from designated skew): ± 1/2 inch

(o) Beam seat bearing area (variation from plane surface when tested with a straightedge through middle half of member):

± 1/8 inch

(p) Dowel tubes (spacing between the centers of tubes and from the centers of tubes to the ends and sides of members):

± 1/2 inch

(q) Tie rod tubes (spacing between the center of tubes and from the centers of tubes to the end of the member): ± 1/2 inch

(r) Tie rod tubes (spacing from centers of tubes to the bottom of the beams):

± 3/8 inch

(s) Total width of deck: Theoretical width ± 1/2 per joint

(t) Position of side inserts: ± 1/2 inch

(u) Position of weld plates: ± 1 inch

601HPC-4.02-B.04 Precast Minor Structures:

The maximum allowable tolerances or deviations from the dimensions shown on the drawings shall be as follows:

(a) Over-all dimensions of member: ± 1/4 inch per 10 feet; maximum of ± 3/4 inch

(b) Cross-sectional dimensions:

Sections six inches or less: ± 1/8 inch

Sections 18 inches or less and over 6 inches: ± 3/16 inch

Sections 36 inches or less and over 18 inches: ± 1/4 inch

Sections over 36 inches: ± 3/8 inch

(c) Deviations from straight line:

Not more than 1/4 inch per 10 feet

All exposed, sharp corners of the concrete shall be filleted 3/4 inch with a maximum allowable deviation of ± 1/8.

601HPC-4.03 Compressive Strength and Acceptance:

Sampling and testing for compressive strength and acceptance for compressive strength will be in accordance with the requirements of this section and Subsection 10HPC-7.

601HPC-4.04 Opening to Traffic:

No traffic (construction or non-construction) shall be allowed on the bridge deck before the end of the curing period. The HPC bridge deck may be opened to traffic at the end of the specified curing period provided HPC has achieved its specified compressive strength and the bridge deck has been grooved and approved by the Engineer.

Prior to opening to traffic, the new HPC bridge deck shall be examined by the Engineer, visually and by other means as deemed appropriate by the Engineer. Any area that displays cracks, which are visible without magnification, will be marked by the Engineer and shall be repaired or replaced by the contractor as specified, at no additional cost to the Department. If the Engineer agrees that the cracks may remain in place and be repaired, these cracks shall be filled and sealed completely with approved epoxy, methyl methacrylate, or high molecular weight methacrylate crack filler as approved by the engineer and in accordance with the manufacturer's recommendations. The Engineer shall approve the repair work, including materials, application, and related issues. The Engineer shall have sole discretion in determining the extent of cracking that will require repair, or if the cracked area should be removed and replaced.

601HPC-5 Method of Measurement:

Bridge deck slab grooving will be measured by the square yard of deck surface grooved and accepted. The quantity of grooved surface will be determined by multiplying the width times the length of the grooved area. No deduction will be made for grooving omitted at joints, drainpipe, notches, or other similar installations in the bridge deck surface.

HPC will be measured to the nearest cubic yard placed. Measurement will include the total quantity of HPC that is acceptably placed as bridge deck replacement and related concrete retrofit work as shown on the retrofit details of the project plans. No deduction will be made for the volume occupied by reinforcing steel embedded in the concrete.

When concrete is to be paid for by the cubic yard, measurement will be made in accordance with the dimensions shown on the plans or such other dimensions as may be ordered in writing by the Engineer. No deduction will be made for the volume occupied by reinforcing steel, structural steel, prestressing materials, or pile ends embedded in the concrete.

The quantity of precast, prestressed structural members shall be measured to the nearest linear foot for each type and size of girder, box beam, or voided slab, as shown on the bidding schedule, installed in place, complete and accepted. Each member shall include the concrete, steel reinforcement and prestressing steel, enclosures for prestressing steel, anchorages, plates, nuts, elastomeric bearing pads, and such other materials contained within or attached to the unit.

Deck joint assemblies will be measured by the linear foot. Measurement will be made along the center line of the joint and at the surface of the roadway or sidewalk from face-of-curb or barrier to face-of-curb or barrier. Measurement will be to the nearest linear foot. No measurement will be made for that portion of the deck joint assembly required by plan details to extend through the face-of-curb or barrier, such being considered as incidental to the sealing of the joint.

Measurement for vertical restrainers will be made for each restrainer acceptably installed in place for each bridge.

Combination Pedestrian-Traffic Bridge Railing will be measured to the nearest linear foot from the outside dimensions of the parapet. Pedestrian Fence for Bridge Railing and Two-Tube Bridge Rail will be measured to the nearest linear foot from end-post to end-post.

Bridge Concrete Barrier and Transition will be measured to the nearest linear foot.

Reinforced Concrete Approach Slab will be measured to the nearest square foot.

Reinforced Concrete Anchor Slab will be measured to the nearest square foot. No measurement will be made for the reinforced concrete anchor lugs.

No measurement or direct payment will be made for texturing of the bridge deck with a burlap drag or by tine brooming, the cost being considered as included in contract items.

Bridge Deck Texturing (Sawed Grooves), when included in the bidding schedule, will be measured to the nearest square yard. The area will be determined by the length of the bridge, approach slabs, and anchor slabs, multiplied by the width of the roadway between the face of curb or bridge rail on each side, less 2.0 feet. The quantity shown on the bidding schedule shall be considered final and will not be re-measured unless changes are specified by the Engineer, or if the Engineer or contractor determines that the constructed area varies by an amount greater or less than two percent of the quantity shown on the bidding schedule. Such adjustments, if required, shall be in accordance with Subsection 104.02.

No measurement or direct payment will be made for the temporary bracing of erected girders, or for preparation of the girder bracing plan, the costs being considered as included in contract items.

601HPC-6 Basis of Payment:

The accepted quantity of the bridge deck grooving, measured as provided above will be paid for at the contract unit price per square yard, which price shall be full compensation for the work, complete in place, as specified herein.

The accepted quantity of HPC will be paid for in accordance with the Subsections 10HPC-7.04 and 10HPC-8. HPC will be paid for by the cubic yard, complete in place, except that an adjustment in the contract unit price to the nearest cent will be made for the quantity of concrete represented by the 28 day compressive strength test results less than the specified requirements listed in Table 10HPC-7.04-A.

The contract unit price paid for HPC, shall include full compensation for furnishing all labor and materials, tools, equipment, stay-in-place metal forms, HPC preconstruction meeting, HPC mix design and HPC mix design submittals, HPC field demonstration, HPC pre-placement meeting, quality control program, testing, and related items including the furnishing and applying of water for curing, placing, finishing, and curing of HPC; as well as the required cleanup work and other related activities necessary for the work to be complete in-place and meeting the approval of the Engineer.

A partial payment for HPC will be paid after the Field Demonstration(s) is completed as stated in this specification, and approved by the Engineer. The amount paid for the partial payment will be 20 percent of the contract unit price multiplied by the total quantity for HPC.

The accepted quantities of deck joint assemblies, measured as provided above, will be paid for at the contract unit price per linear foot complete in place, including the seal, anchorage system, galvanizing, equipment and labor.

The accepted quantities of Vertical Restrainers, as measured above, will be paid for in accordance with the provisions of Subsection 109.10, Lump Sum Payment for Structures.

Payment for minor structures will be made under the various sections of the specification covering that particular minor structure.

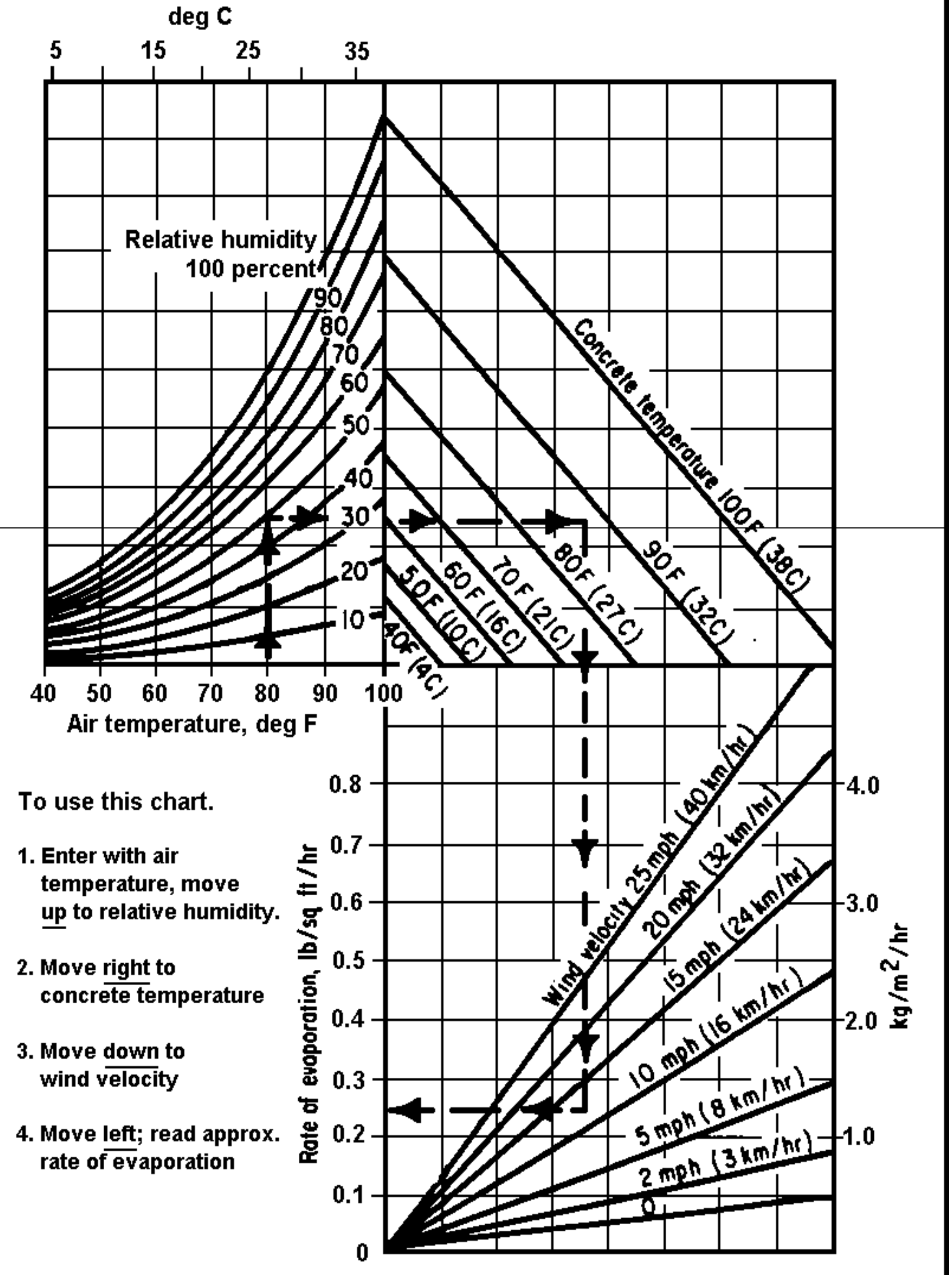
The accepted quantities of Combination Pedestrian-Traffic Bridge Railing, Pedestrian Fence for Bridge Railing, and Two-Tube Bridge Rail, measured as provided above, will be paid at the contract unit price, complete in place, including all concrete, reinforcing steel, rail, other materials, and labor. Reinforcing steel embedded below the parapet shall be included in the bridge railing.

The accepted quantities of Bridge Concrete Barrier and Transition, measured as provided above, will be paid at the contract unit price, complete in place, including all concrete, reinforcing steel, rail, other materials, and labor. Reinforcing steel embedded below the barrier or transition shall be included in the barrier and transition.

The accepted quantities of Reinforced Concrete Approach Slab, measured as provided above, will be paid for at the contract unit price, complete in place, including all concrete, reinforcing steel, labor, tools, equipment, and incidentals.

The accepted quantities of Reinforced Concrete Anchor Slab, measured as provided above, will be paid for at the contract unit price, complete in place, including all concrete, reinforcing steel, labor, tools, equipment, and incidentals. No payment will be made for furnishing all materials and constructing reinforced concrete anchor lugs, the cost being considered as included in the contract bid item for the reinforced concrete anchor slab.

The accepted quantities of sawed groove texturing, measured as provided above, will be paid for at the contract unit price, complete in place, including all labor, tools, equipment, and incidentals.



Note: Example shown by dashed lines is for an air temperature of 80°F, relative humidity of 50 percent, concrete temperature of 87°F, and a wind velocity of 12 miles per hour. This result is a rate of evaporation of 0.24 pounds per square foot per hour.

Evaporation Rate of Surface Moisture

Attachment A

APPENDIX D:
DRAFT BRIDGE DECK OVERLAY SPECIFICATIONS USING SILICA FUME CONCRETE IN ARIZONA

Bridge Deck Overlay Specifications
Using Silica Fume Concrete in Arizona

ITEM "924XXX" – MISCELLANEOUS WORK SILICA FUME CONCRETE OVERLAY:

1 - Description:

The work under this item shall consist of furnishing all materials and constructing bridge deck overlays using silica fume concrete at locations on existing bridge deck to the dimensions shown on the project plans and to the lines and grades established by the Engineer and in accordance with the requirements of the specifications.

Overlay concrete shall be silica fume concrete defined as concrete with a minimum specified 28-day compressive strength of 4,500 psi that includes silica fume and have a maximum rapid chloride permeability of 1,200 coulombs at 56 days.

All materials and work performed shall be in accordance with Section 1006 and 601 of the specifications unless noted herein.

2 - Materials:

Silica Fume concrete shall consist of a mixture of hydraulic cement, flyash, silica fume, fine aggregate, coarse aggregate, and water. It may also contain air-entraining admixtures, chemical admixtures, and fiber reinforcement.

2.01 Hydraulic Cement:

Hydraulic cement shall consist of either Portland cement or Portland-pozzolan cement.

Portland cement shall conform to the requirements of ASTM C 150 for Type I, II, or V, and shall be low alkali cement containing not more than 0.60 percent total alkali (Na_2O equivalent).

2.02 Supplementary Cementitious Materials:

Fly ash and natural pozzolan shall conform to the requirements of ASTM C 618 for Class F mineral admixture, except that the loss on ignition shall not exceed 3.0 percent.

2.03 Aggregates:

The fine aggregate and coarse aggregate shall conform to the requirements of Section 1006 of the specifications.

2.04 Silica Fume

Silica fume shall conform to the requirements of ASTM C 1240. Only densified silica fume shall be permitted. Dissolved bagged silica fume or interground silica fume with cement will not be acceptable. Silica fume in bulk or bagged form shall be kept dry.

2.05 Fiber Additive:

Fiber additive for overlay concrete shall conform to the requirements of ASTM D7508 and ASTM C1116. Fiber additive shall be polymeric, made from 100% virgin materials, non-corrosive, non-magnetic, and 100% alkali free.

Only fiber additives that are on ADOT's Approved Products List (APL) can be used. Copies of the most current version of the APL are available on the internet from the ADOT Research Center through its Product Evaluation Program.

Fiber additive shall have a length of 1.5 inches or larger and have a configuration that allows for maximum bond and dispersion in the concrete. A minimum rate of 3 pounds of fiber per cubic yards of concrete shall be added at the plant during concrete batching. The concrete batch shall be mixed with a minimum of 100 revolutions at mixing speed before discharge on site.

3 - Silica fume concrete Mixtures:

3.01 Design Criteria:

Silica fume concrete shall be proportioned in accordance with Subsection 5.3 of ACI 318, and shall be consistent with the mix design guidelines listed in Table 3.01-A.

TABLE 3.01-A
Silica Fume Concrete Mix Design Requirements

Minimum 28-Day Compressive Strength Required = 4,500 psi			
Material	Min.	Max.	Unit
Hydraulic Cement	450	475	Lbs/CY
Fly Ash	110	150	Lbs/CY
Silica Fume (by weight of Hydraulic Cement)	5	6	Percent
Water	230	260	Lbs/CY
Coarse and Fine Aggregates (see note 1)			
Water Reducers (see note 2)			
Air-Entraining Admixture (see note 2)			
Air Content, (see note 3)	4.5	7.5	Percent
Fiber Additive (see note 4)			Lbs/CY
Water/Cementitious Materials Ratio	0.40	0.42	

Note 1:

- The amount of coarse aggregates, the amount of fine aggregates, and the combined aggregate gradation shall be provided by the contractor, subject to

approval by the Engineer.
Note 2: • The type and amount of chemical and air-entraining admixtures shall be provided by the contractor, subject to approval by the Engineer.
Note 3: • The air content requirements are waived when the concrete overlay is placed at an elevation below 3,000 feet.
Note 4: • When fiber additive is required in the project plans, the type and amount of fiber additive shall be provided by the contractor, subject to approval by the Engineer.

The contractor is responsible for the submittal of silica fume concrete mix design(s) to the Engineer for review and approval in sufficient time so that a delay of work will not occur. The mix design shall be submitted to the engineer at least 60 days prior to any silica fume concrete placement and in sufficient detail to be reproducible in the laboratory and the field. Both the source and proportion of the materials shall be provided. No proprietary mixes will be accepted.

The mix design shall be submitted with the following test data (at a minimum) demonstrating the properties of the silica fume concrete mix:

j) Compressive strength @ 28-day.
k) Water/cementitious material ratio.
l) Paste content percent calculation.
m) Slump before and after pumping.
n) Air content before and after pumping.
o) Concrete temperature before and after pumping.
p) Air voids analysis of hardened concrete, determined in accordance with the requirements of ASTM C 457.
q) Rapid Chloride Permeability (RCP), determined in accordance with the requirement of ASTM C 1202.
r) Shrinkage potential, determined in accordance with the requirements of ASTM C 157.

Silica fume concrete shall meet the properties and performance criteria in Table 3.01-B for trial batches made in the field/batch plant prior to placement, and shall be documented in the mix design submittal.

TABLE 3.01-B **Silica Fume Concrete Properties and Performance Criteria**		
Concrete Properties	Minimum	Maximum
28-Day Compressive Strength	4,500 psi	-
Ratio of 28-day/7-day compressive strength	1.65	-
Water/Cementitious Material Ratio	0.40	0.42
Slump, at point of placement	4 in.	6 in.
Air Content, at point of placement (Note 1)	4.5%	7.5%
Concrete Temperature, at point of placement	50ºF	90ºF
Paste Content (cementitious materials + water)	22%	28%
Air void parameters in hardened concrete shall be in compliance with ACI 212, Chapter 2, “Air-Entraining Admixtures”. When tested in accordance with the requirements of ASTM C 457, the air void parameters shall have the following properties: • Spacing factor of 0.008 inches or less. • Specific surface of 600 in^2/in^3 or greater.		
Rapid Chloride Permeability (RCP), when tested in accordance with the requirements of ASTM C 1202 shall be: • Maximum of 1,200 coulombs at 56 days.		
Shrinkage Potential, when tested in accordance with the requirements of ASTM C 157 (standard curing conditions),shall be: • Maximum of 0.04 percent at 28 days.		
Note 1: • The air content requirements are waived when concrete overlay is placed at an elevation below 3,000 feet.		

The contractor shall perform a full scale trial batch of the proposed silica fume concrete at the batch plant before submitting the silica fume concrete mix design for review.

The Engineer is the sole authority to determine compliance of silica fume concrete mix design with the requirements of the specifications. Review and approval by the Engineer will not relieve the contractor of the responsibility to provide silica fume concrete conforming to the specifications.

The coarse aggregate size designation for silica fume concrete shall be chosen by the contractor and approved by the Engineer and shall conform to the size designation and grading requirements of AASHTO M 43. In choosing the size designation, the maximum size of coarse aggregate shall not be larger than one third the smallest thickness of the overlay.

3.02 Mixing:

3.02-A General Requirements:

Mixing of the silica fume concrete shall be performed in accordance with the material supplier's recommendations and shall be approved by the Engineer. Water reducers shall be added during batching, and if necessary, on-site. When air-entraining admixtures are used, they shall be added during batching, and if necessary on-site to restore any air loss in concrete.

Testing for slump and air content shall commence before silica fume concrete is placed and shall be performed as frequently as necessary to maintain required concrete properties and field control. The minimum and maximum allowable slump at point of placement shall be as defined in Table 3.01-B. All loads of concrete shall be consistent to within ± one (1) inch slump. When slump maintenance or adjustment are needed, it shall be accomplished only by the addition of water reducers, conforming to the requirements of ASTM C494.

Water shall not be added to the silica fume concrete after it is batched and placed in the truck for delivery to the project site. Water to rinse the chute and fins, after the addition of admixtures will not be allowed unless such water is accounted for on the approved silica fume concrete mix design and shall not exceed the maximum water/cementitious material ratio stated in Table 3.01-A.

The concrete may be mixed in a stationary mixer, either at a central mixing plant or at the site, or it may be mixed in a truck mixer, either at a central mixing plant or at the site. Each batch plant shall be equipped to control the time when the water enters the mixer during the mixing cycle. Batch and mixing time shall be from the time hydraulic cement is combined with water.

4 - Silica Fume Concrete Construction Requirements:

The contractor shall coordinate the silica fume concrete construction operations and schedule with the Engineer in accordance with the following:

4.01 Preconstruction Meeting:

A silica fume concrete preconstruction meeting shall be held before any silica fume concrete overlay placement. The purpose of the preconstruction meeting is to review silica fume concrete requirements for the project and to discuss with the contractor the impact of silica fume concrete practices and work on the project. This meeting shall include the Engineer and other designated Department personnel, contractor, sub-contractors, suppliers, and other parties who will be responsible to see that the work is implemented in accordance with the project plans, and the specifications.

4.02 Concrete Mix Submittal:

Prior to any silica fume concrete placement, the contractor shall submit a silica fume concrete mix design that meets the requirements in Subsection 3 for review and approval by the Engineer. The mix design submittal shall also include the results of the trial batches made in the field or at the batch plant. The results of the trial batch must meet all of the performance criteria listed in Table 3.01-B prior to mix design approval.

4.03 Field Demonstration:

The contractor shall, within 14 days prior to any silica fume concrete placement, perform a silica fume concrete field demonstration (mock up) of the silica fume concrete placement of the bridge overlay. The field demonstration shall include the production, transportation, pumping, placement, finishing, and curing of silica fume concrete proposed for use on the bridge deck. To simulate the job conditions during the actual silica fume concrete overlay placement, all aspects of the work shall be duplicated including batching, transportation, travel conditions, placement, equipment, protection, and curing. The field demonstration shall be carried out by the same contractor's personnel that will be placing the silica fume concrete on-site, and shall use the same equipment to be used on the job. The location of the field demonstration shall be at an off-site location in the immediate proximity of the job site, as approved by the Engineer.

The contractor shall place at least four cubic yards of silica fume concrete before the initial placement of silica fume concrete on the bridge deck. The contractor shall demonstrate proper batching, placement, finishing, and curing of silica fume concrete. The silica fume concrete shall be tested on site and meet the slump and air content at the final point of discharge of the placement. The field demonstrations are the responsibility of the contractor at no additional cost to the Department. If necessary they shall be repeated until all processes for production, placement, finishing, pumping, and curing of silica fume concrete are acceptable and approved by the Engineer.

The contractor shall, submit a final comprehensive report after the field demonstration, submit a comprehensive report to the Engineer describing the outcome of the field demonstration including, but not limited to, the batching, pumping, placing, finishing, protecting, curing, sampling, and testing of silica fume concrete. The Engineer will require that the contractor perform additional field demonstration(s) at no additional cost to the Department if the Engineer determines that the contractor's silica fume concrete practices in the field demonstration are not acceptable or do not conform to the specifications. Engineer must approve the field demonstration before concrete overlay placement can proceed.

4.04 Pre-Placement Meeting:

After the field demonstration, and at least seven days prior to any subsequent silica fume concrete placement, the contractor shall meet with the Engineer to discuss and obtain approval from the Engineer for all issues related to the placement of silica fume concrete. These issues include, but are not limited to the following:

a) Concrete truck batch size
b) Batching sequence
c) Delivery details
d) Truck routes
e) Travel time
f) Concrete mix proportions and adjustment
g) Pumping and associated air loss
h) Pumping and associated slump loss
i) Concrete protection plan
j) Concrete curing plan
k) Quality assurance and quality control programs
l) Testing requirements by the contractor
m) Silica fume concrete acceptance criteria
n) Deck placement schedule
o) Finisher’s certification: American Concrete Institute (ACI)
p) Deck construction details
q) Joint details
r) Role of all personnel
s) Contingency plans

The Department may perform additional concrete testing, sampling, and instrumentation during the production, transportation, and placement of silica fume concrete during the field demonstration and the overlay placement. The contractor shall make all necessary provisions to allow for adequate sampling and testing of the silica fume concrete.

Placement of the overlay concrete shall be in accordance with the placing sequence shown on the project plans or as approved by the Engineer. The contractor shall submit a drawing showing the placement sequence, construction joint locations, directions of the concrete placement, and any other pertinent data to the Engineer for approval. The drawing shall be submitted to the Engineer at least four weeks prior to the date of overlay placement

4.05 Concrete Placement:

4.05-A General Requirements:

Silica fume concrete shall be placed as a single monolithic layer conforming to the specified depth of the overlay unless otherwise approved by the Engineer.

The rate of concrete placement and consolidation shall be such that the formation of cold joints within monolithic sections of the overlay will not occur. Any portion of the overlay which displays apparent cold joints will be rejected, unless the contractor, at no additional cost to the Department, can submit evidence that indicates that either a cold joint does not exist or that a cold joint is not detrimental to the overlay. The Engineer shall be the sole judge in determining the existence of a cold joint and whether its existence is detrimental to the overlay.

4.05-B Overlay Placement:

The overlay placement practices outlined in the specifications shall be strictly followed. Delays such as waiting for concrete surface sheen to disappear, concrete surface strength development, or other reasons shall not be allowed.

Silica fume concrete shall not be placed when the air temperature in the shade is above 90^{o}F. Silica fume concrete shall be placed only when the rate of evaporation on the bridge deck does not exceed 0.10 pounds per square foot per hour for the entire duration of the concrete placement. The rate of evaporation is determined from the evaporation monograph (Attachment A) after measuring the air temperature, relative humidity, concrete temperature, and wind velocity at the bridge deck.

The contractor may elect to work at night, if approved by the Engineer. If approved, night work shall be performed in accordance with Subsection 108.05 of the specifications. Fogging equipment shall be in place and in good working order prior to the placement of silica fume concrete. Windscreens will be required to be used when the fogging equipment alone cannot maintain the specified evaporation rate and the contractor elects to continue silica fume concrete placement.

The placing of concrete will not be permitted until the Engineer is satisfied that the rate of producing and placing concrete shall be sufficient to complete the proposed pour and finishing operations within the scheduled time, that experienced concrete finishers are available to finish the deck, and that all necessary finishing tools and equipment are on hand at the site and are in satisfactory condition for use.

The contractor shall furnish a minimum of two transverse work bridges from which, straight edging, concrete protection, placement of curing membrane, and curing operations may be accomplished. The work bridges shall be reasonably rigid and free of excessive deflections. The self-propelled mechanical bridge used for texturing the bridge deck overlay may be substituted for one of the required work bridges.

4.05-C Deck Surface Preparation:

The final surface of the prepared concrete deck shall be free from oil, grease, rust, and other foreign material that may reduce the bond of the silica fume concrete to the existing deck slab. These contaminants shall be removed by detergent cleaning, sandblasting, waterblasting, or other removal methods as approved by the Engineer.

Any area of the final surface of the prepared concrete deck contaminated by any materials detrimental to the overlay bond to the concrete deck and could not be cleaned shall be removed to such depth as required at the discretion of the Engineer. Such removal work shall be at the contractor's expense.

Exposed reinforcing steel shall be cleaned of rust and corrosive products including oil, dirt, concrete fragments, loose scale and other coating, or any other products which may interfere or adversely inhibit the bond between the existing and new concrete.
Rust or contamination which may form on the reinforcing steel within seven calendar days following the concrete removal will cause the engineer to reject the reinforcing steel unless the contractor cleans the steel and remove any trace of rust or contamination products. The cleaning may include sandblasting or shot blasting when necessary at the contractor's expense with no adjustment in contract time or price.

When reinforcing steel is expected to be exposed to the elements for more than seven calendar days prior to encasement in concrete, adequate measures shall be taken by the contractor, as approved by the Engineer, to protect the steel from contamination or corrosion. Reinforcing steel contaminated or corroded as the result of the contractor's failure to provide adequate protection as stipulated herein, shall be rejected unless the contractor cleans the steel and remove any trace of rust or contamination products. The cleaning may include sandblasting or shot blasting when necessary at the contractor's expense with no adjustment in contract time or price.

Construction equipment shall not be on any portion of the areas being overlaid, that has undergone final preparation for placing concrete, unless approved the Engineer. An effort shall be made to prevent contamination of the prepared surface. Such contamination would include the dripping of petroleum products and contamination tracked onto the concrete surface by equipment or pedestrians. The contractor shall place a material, such as polyethylene film, on the deck surface used by equipment. If the deck surface does become contaminated, the contractor will be required to clean the surface as described herein.

Prior to placement of overlay concrete, existing concrete shall be kept moist for a period of at least 24 hours before receiving fresh concrete. This shall be achieved by thoroughly wetting the surface prior to placement and maintaining it in a continuous moist condition until placement. Acceptable means of maintaining a moist condition are covering the concrete surface with visqueen and/or the use of fog spray or soaker hoses, provided that complete moisture coverage is attained. All freestanding water shall be removed prior to overlay placement. Any standing water in depressions, holes or low areas shall be blown out with compressed air.

4.05-D Bonding Coat:

A bonding coat, consisting of a portion of the overlay mix, shall be delivered and deposited on the deck where it shall be scrubbed by brooming onto the saturated surface dry concrete surface. Care shall be exercised to ensure that all surfaces receive a thorough, even coating. Coarse and fine aggregates remaining after the brushing operation shall be collected, removed from the deck, and disposed of properly.

The progress rate of the scrubbing of the bonding coat shall be limited to no more than ten feet ahead of the screed so the brushed coating does not dry before it is covered with overlay concrete. Materials intended for brushing which have started to dry or show loss of paste shall be removed and replaced. The rate of application of the bond coat shall be adjusted if drying or the loss of the bonding coat occurs.

4.05-E Placement Progress:

The rate of concrete discharge, placement, and finishing shall be maintained so that the concrete deposited on the bridge deck is not more than 10 feet ahead of the finishing machine (Bidwell).

Concrete placement shall be a continuous operation. As soon as the concrete is placed, mechanical screeding shall take place. The concrete shall be placed slightly above grade and then struck-off, screeded, and finished to final grade. All horizontal concrete surfaces shall be finished using vibratory screeds (equipped with the Bidwell) that ride on rails. The forward speed of the finishing machine (Bidwell) shall be adjusted to the average progress of the overlay production in order that the strike-off operations are as continuous and uninterrupted as possible. Hand finishing with a float may occasionally be required to produce a tight uniform surface at the edges of the finishing machine. When such hand finishing is needed, it shall be kept to a minimum to avoid overworking the surface.

If the placement of the overlay concrete is stopped for a period of one-half hour or more, the contractor shall install a bulkhead, which is transverse to the direction of the placement and at a position where the overlay can be finished full-width up to the bulkhead. The bulkhead shall be full depth of the overlay. The overlay previously placed shall be protected, finished, covered, and cured in accordance with the specifications. Further placement is permitted only after a period of twelve hours unless a gap is left in the lane or strip. The gap shall be of sufficient width for the finishing machine to clear the transverse bulkhead installed where the concrete placement was stopped. The previously poured concrete shall be sawn back from the bulkhead, to a point designated by the Engineer, to straight and vertical edges and shall be water blasted or sandblasted before new concrete is placed. For delays of less than one-half hour, the end of the overlay placement shall be protected from drying with wet burlap.

4.06 Concrete Vibration:

When the concrete overlay is three inches or more in thickness, it shall be internally vibrated in addition to the surface vibration by the vibratory screed.

Vibration shall not be continued at any one point to the extent that localized areas of grout are formed. Application of vibrators shall be at points uniformly spaced and not farther apart than twice the radius over which the vibration is visibly effective.

5 - Finishing Silica Fume Concrete Overlay:

5.01 General Requirements:

Final finishing of the bridge deck overlay shall be accomplished by lightly texturing the concrete surfaces with burlap or pan drag attached to the finishing screed. This shall take place while concrete is still plastic, and after the concrete surface has been brought to its final elevation. Concrete protection and curing process should commence immediately after final finishing of the concrete surfaces has been completed.

The deck surface shall be finished to a final surface, free of mortar ridges, hollows, and any other projections. Water shall not be applied to the deck surface at any time during placement or finishing except through fogging in accordance with Subsection 6.01.

5.02 Tining and Grooving:

5.02-A General Requirements:

Unless longitudinal grooving is specified on the plans, the contractor shall texture the bridge deck, approach slab, and anchor slab with transverse grooves.

The contractor shall submit a plan detailing the proposed layout of the texturing to the Engineer for approval at least seven days prior to the grooving operations. Spacing dimensions at the starting and ending point of each pass shall be noted.

5.02-B Broomed Tines:

Tine broom texturing shall occur after the Engineer has accepted the straightedge test of the finished surface, and during the plastic concrete state, but prior to the curing process.

The timing of the texture operation in the silica fume overlay concrete is critical. The texturing shall commence immediately after the overlay surface has been brought to final elevation and has received the burlap or pan drag. Grooves that close following the texturing will not be permitted.

Immediately after silica fume concrete overlay is tined, it shall be covered with curing medium as specified in Subsection 7.02.

6 - Silica Fume Concrete Protection:

All concrete surfaces shall be protected from drying from the time concrete is discharged and deposited on the bridge deck until the silica fume concrete surfaces are covered with the curing medium specified in Subsection 7.02-A and water curing starts in accordance with the requirements of Subsection 7.02-B.These requirements apply to both finished and unfinished concrete.

6.01 Water Fogging:

Immediately after the silica fume concrete is placed and brought to grade, the area of 2 to 3 feet immediately above the silica fume concrete surfaces shall be continuously kept in a state of high moisture conditions by applying a fog mist as described in Subsection 6.02. The mist from the nozzles shall not be pointed directly toward the overlay surfaces and shall not be allowed to accumulate on the silica fume concrete surface in a quantity sufficient to cause an accumulation, a flow, or wash the surface. Application of water by brushes or any other method will not be permitted.

6.02 Fogging Equipment

Fogging equipment shall consist of a mechanically operated pressurized system using triple headed nozzles or equivalents. Each nozzle shall be capable of producing a fine fog mist atomizing water flow so that a mist rather than a spray is formed. The nozzles shall be pointing horizontally, parallel to the surface of the concrete and at a distance not to exceed 36 inches above the concrete surface.

The fogging equipment shall be mounted on the finishing equipment. Controls shall be designed to vary the volume of water flow, shall be easily accessible, and shall immediately shut off the water when in the off position. Hand-held fogging equipment will not be allowed

6.03 Evaporation Retarding:

A monomolecular film product that aids in retarding the evaporation may be used provided the manufacturer's recommendations are followed and the Engineer's approval is obtained in advance. The use of an approved monomolecular film may be allowed as an evaporation retarder after the concrete finishing has been completed. The application of such evaporation retarder shall not be in lieu of the water fogging or protection of the concrete surface. The application of the evaporation retarder shall be in the form of a fine mist using suitable sprayers. Impacting the plastic concrete surfaces with a stream will not be allowed.

The concrete surface shall not be re-finished or manipulated after the addition of the evaporation retarder nor shall the evaporation retarder be mixed into the plastic concrete at any time.

6.04 Windscreens:

Windscreens shall be used as supplementary tools to reduce the evaporation rate when the fogging equipment alone is not sufficient to maintain the evaporation rate within acceptable limits. Windscreens shall project at least six feet, or as deemed appropriate, depending upon weather conditions, above the prepared bridge deck surface. Windscreens may be made of any construction material that would provide sufficient strength to resist the force of the wind.

7 - Curing Silica Fume Concrete:

7.01 General Requirements:

All silica fume concrete shall be wet cured for a minimum period of 14 curing days. A curing day is defined as a calendar day when the temperature taken in the shade away from artificial heat is above 50°F for at least 19 hours; or if satisfactory provisions are made to maintain the temperature of overlay concrete surfaces above the minimum curing temperature of 40°F for the entire 24 hours.

The contractor shall submit a proposed curing plan to the Engineer for review and approval. The contractor’s curing plan shall detail the proposed methods, include proper equipment and material in adequate amounts, and be approved by the Engineer prior to placing silica fume concrete.

Immediately prior to placing the silica fume concrete overlay, the contractor shall demonstrate to the Engineer on-site the materials, equipment, process and all elements of the curing plan and procedures are in place and functional as described in Subsection 7.02-B for the Engineer’s approval. An inadequate curing plan shall be cause for the Engineer to delay or stop all silica fume concrete placements on the job until remedial action is taken.

Vehicles are not permitted on the overlay concrete until the specified curing time is satisfied and until the concrete has obtained the specified compressive strength when tested in accordance with the requirements of AASHTO T22 or as approved by the Engineer.

All exposed surfaces of the silica fume concrete shall be kept wet continuously for the entire curing period. Water used for curing that stains or leaves an unsightly residue shall not be used.

7.02 Curing Equipment and Material:

7.02-A Wet Curing Medium:

Curing medium shall be capable of temporarily accepting and holding moisture, then gradually releasing that moisture to the concrete surface in contact. Acceptable curing mediums include: burlap, burlap/plastic combination, or an approved equal by the engineer.

7.02-B Wet Curing Method:

All concrete overlay surfaces shall be wet cured in accordance with to the wet curing method specified herein. Curing shall begin immediately after fresh concrete has been finished and brought to final grade.

A curing medium as specified in Subsection 7.02-A shall be used to maintain continuously-moist concrete surfaces for the entire curing period. Application of the curing medium shall take place immediately at the end of the concrete surface protection specified in Subsection 6. The curing medium shall be applied manually from the work bridge and shall be carefully placed without marring the surface of the plastic concrete.

Wet curing shall begin immediately after the concrete surface protection described in Subsection 6. Wet curing shall begin no later than 10 minutes after the silica fume concrete surface has been screeded or when the finished surface of silica fume concrete is not more than ten feet behind the finishing machine whichever comes first.

Wet curing shall consist of keeping the silica fume concrete surfaces continuously wet by maintaining a layer(s) of curing medium specified in Subsection 7.02A continuously wet and in direct contact with the fresh concrete surfaces for the entire curing period. The curing medium shall be wetted down (without dripping) prior to being placed over the silica fume concrete surfaces. Continuous wetting shall be accomplished by supplying water with intermittent flow (directly on a porous type curing medium such as burlap) or through pre-fabricated holes made in the burlap/plastic combination sheets. The curing medium shall be weighted down adequately to provide continuous contact with all silica fume concrete surfaces.

Regardless of the type of medium used, wet curing shall not be interrupted anytime during the entire curing period.

8 - Quality Control Program

The contractor shall develop a Quality Control Program (QCP) for controlling, monitoring, and testing silica fume concrete. The cost of the QCP and related testing shall be the responsibility of the contractor. The QCP shall ensure that silica fume concrete meets the project specifications in the plastic and hardened states. The QCP shall include the following at a minimum:

f) QCPs from subcontractors and suppliers that are involved with the handling, placement and finishing of silica fume concrete.
g) Flow chart identifying the construction steps that will take place from the time silica fume concrete is batched until it has been completely cured and achieved the specified strength.
h) A scheduled silica fume concrete pre-placement meeting with the Engineer, contractor, sub-contractors, suppliers, and other pertinent parties.

i) Name(s) of the contractor's representative(s) on-site who is (are) authorized to accept or reject silica fume concrete loads.
j) Handling and transportation methods of the silica fume concrete test samples to the independent certified testing laboratory approved by the Engineer.

The contractor shall submit the QCP to the Engineer for review and approval a minimum of 14 calendar days prior to the placement of any silica fume concrete. The Engineer's approval will be based on the completeness of the QCP and the contractor's incorporation of the requirements of the specifications.

Quality control of fresh silica fume concrete shall be the responsibility of the contractor. During placement of silica fume concrete, the contractor shall make and test concrete cylinders to determine compressive strength at the ages of 7, 28, and 56 days. The compressive strength of silica fume concrete shall be represented by the average of three concrete cylinders tested at each age. One set of twelve test cylinders for compressive strength measurement shall be made for each truckload of silica fume concrete placed. Three test cylinders shall be tested at the ages of 7, 28, and 56 days; with three test cylinders held in reserve.

The contractor shall provide an ACI certified field and lab technician(s) to conduct the required quality control testing. Two weeks prior to placing any silica fume concrete, the names and qualifications of the certified technician(s) shall be submitted to the Engineer for review and approval.

All contractor daily test results and placement records shall be submitted to the Engineer within 3 days. The required information shall include a placement summary sheet and a certificate of compliance for each delivered load of silica fume concrete.

It shall be the contractor's responsibility to provide adequate and representative samples of fresh silica fume concrete for testing.

The contractor is responsible to hire and pay for an independent certified testing laboratory which has been approved by the Engineer to perform field and laboratory testing of silica fume concrete as stated in the specifications.

9 - Acceptance Sampling and Testing:

Acceptance sampling and testing for temperature, slump, air content, and compressive strength shall conform to the requirements of Section 1006-7 for Class S concrete, except as modified below:

Determination of concrete properties for acceptance and placement shall be made based on the results of testing and sampling taken at the final point of discharge of the concrete (on the bridge deck) and not at the truck discharge. The contractor shall establish the amount of air and slump losses encountered during pumping and make adjustments to the concrete mix to compensate for these losses so that the final concrete slump, air content, and other properties at the point of discharge are in compliance with those listed in Table 3.01B.

10 - Testing Overlay:

10.01 General requirements:

At the end of the curing time and after the concrete has attained the specified required compressive strength and curing requirements have been satisfied, the entire overlay shall be tested in accordance with Subsections 10.02, 10.03, and 10.04

10.02 Bond Strength Testing:

The bond strength between the overlay and the existing concrete shall be tested in accordance with the requirements of ASTM C1583. The bond strength shall be the average of three pull out bond tests taken at different locations throughout the overlay surface area. The test locations shall be selected by the Engineer. A bond strength test (an average of three tests) shall be performed for each 5,000 square feet of overlay surface area.

The strength measured when the failure plane takes place at the interface between the existing base concrete and the overlay shall represent the bond strength. This bond strength shall be a minimum of 300 psi at 28 days.

Bond strength shall be considered acceptable if the failure plane occurs within the existing bridge deck base concrete.

Results of the bond strength test shall be discarded and a new test shall be performed at other locations when the failure plane is within the concrete overlay itself or at the interface between the overlay and the test disk.

All costs related to the bond testing shall be borne by the contractor with no additional cost to the Department. Concrete areas where bond testing was performed shall be repaired using Rapid Set Patch or Epoxy Resin Grout Patch Material conforming to the requirements of Section 402 of the Standard Specifications in accordance with the latest ADOT Approved Product List and with the approval of the Engineer

10.03 Bond Uniformity Testing:

The entire overlay surface shall be tested in accordance with the requirements of the chain drag procedure in ASTM D 4580 to test for bond uniformity and the existence of any delamination between the newly placed concrete overlay and the existing bridge deck concrete. A report presenting the procedure, the equipment, and the results of the drag tests in accordance with ASTM 4580 shall be submitted to the engineer for approval.

10.04 Concrete Cracking Testing:

The new overlay shall be examined by the Engineer, visually and by other means as deemed appropriate by the Engineer. Any area that displays cracks will be marked by the Engineer and shall be repaired or replaced by the contractor as specified, at no additional cost to the Department

10.05 Acceptance of Overlay:

Concrete in unbonded areas, as tested in Subsection 10.03, or in areas where bond did not meet strength requirements as tested in Subsection 10.02, shall be removed and replaced at no additional cost to the department, unless the contractor can submit evidence that will indicate to the Engineer, and the Engineer approves such evidence, that the strength, uniformity, durability, service life, and quality of the overlay is such that the concrete overlay should be considered acceptable and be allowed to remain in place. The contractor shall submit a repair plan which includes proposed materials, application, and related issues to the Engineer for review and approval. The Engineer shall have sole discretion in determining the extent of overlay area that will require repair.

If the Engineer agrees that the cracks observed in Subsection 10.04 may remain in place and be repaired, these cracks shall be filled and sealed completely with a crack sealer/healer approved by the Engineer and in accordance with the manufacturer's recommendations. The contractor shall submit a repair plan which includes proposed materials, application, and related issues to the Engineer for review and approval. The Engineer shall have sole discretion in determining the extent of cracking that will require repair, or if the cracked area should be removed and replaced.

11 - Opening to Traffic:

No traffic (construction or non-construction) shall be allowed on the bridge deck before the end of the curing period. The bridge deck may be opened to traffic at the end of the specified curing period provided the overlay concrete has achieved its specified compressive strength and is approved by the Engineer.

12 - Unacceptable Materials:

Material not conforming to the requirements of the specifications, whether in place or not, will be rejected and shall be promptly removed from the site of the work at no additional cost to the department, unless otherwise directed by the Engineer. No rejected material, the defects of which have been corrected, shall be returned to the work site until such time as approval for its use has been given by the Engineer; or, material which has been rejected and removed shall be replaced with material which meets the specified requirements.

13 - Method of Measurement:

Concrete will be measured to the nearest cubic yard placed. Measurement will include the total quantity of concrete that is acceptably placed as overlay as shown on the project plans. No deduction will be made for the volume occupied by reinforcing steel embedded in the concrete.

No measurement or direct payment will be made for texturing of the bridge overlay with a burlap drag or by tine brooming. Such cost is included in the contract items.

14 - Basis of Payment:

The accepted quantity of silica fume concrete, measured as provided above will be paid for by the cubic yard, complete in place, except that an adjustment in the contract unit price to the nearest cent will be made for the quantity of concrete represented by the 28 day compressive strength test results less than the requirements specified in Subsection 1006-7.06 (B).

The contract unit price paid for overlay using silica fume concrete shall include full compensation for furnishing all labor and materials, tools, equipment, preconstruction meeting, concrete mix design and submittals, field demonstration, pre-placement meeting, quality control program, testing, placing, finishing, curing, as well as performing the required cleanup and other related activities necessary to complete the work and meeting the approval of the Engineer.

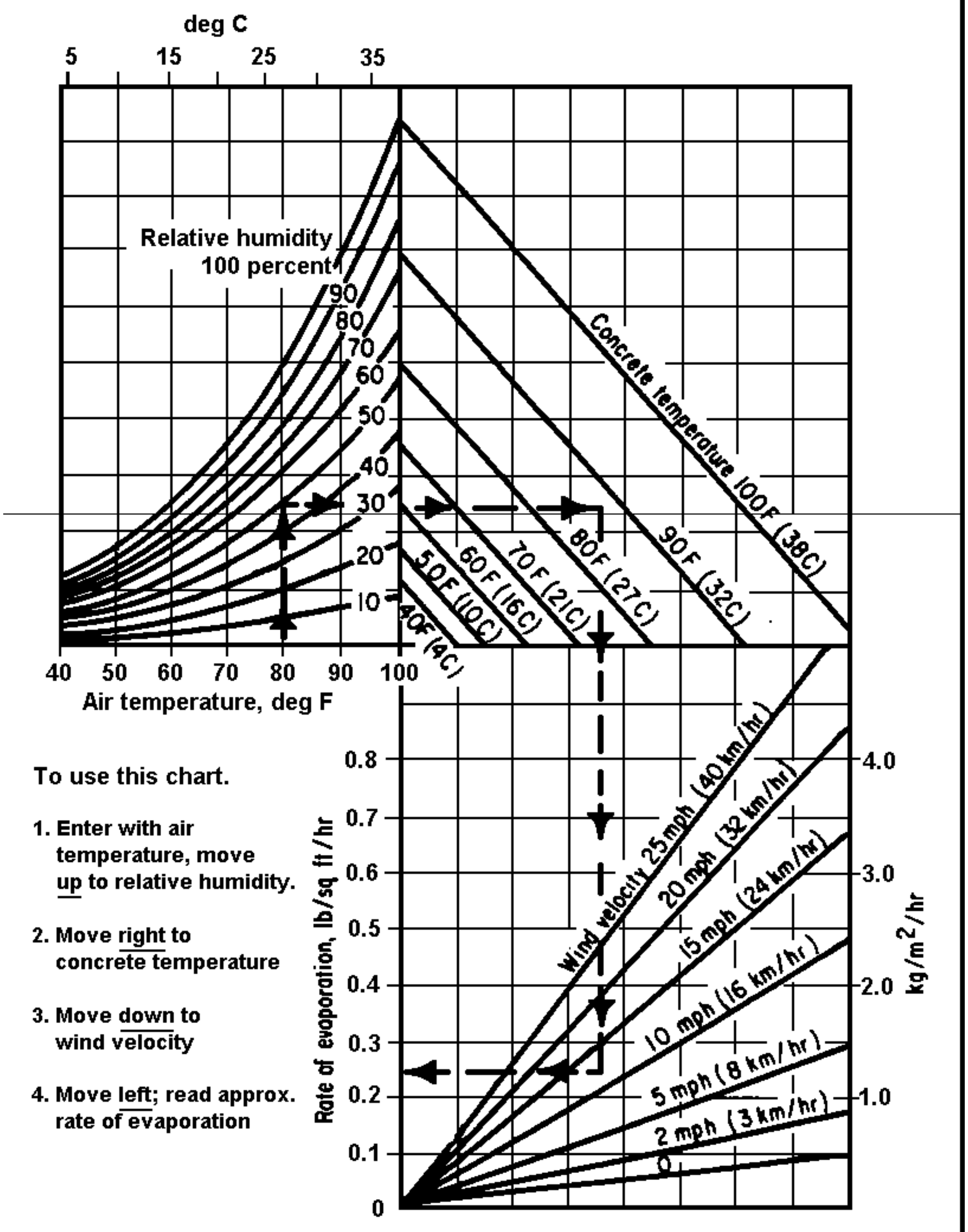
A partial payment for overlay concrete will be paid after the field demonstration(s) is completed as stated in Subsection 4.03, and approved by the Engineer. The partial payment will be (20%) twenty percent of the contract unit price multiplied by the total quantity for silica fume concrete.

Footnote:

There are two issues to consider with regard to the effect of adjacent traffic on bridge deck overlay repairs:

*1. **The integrity of the overlay concrete itself:** This should be considered only for the period from the start of concrete placement until final concrete set time. This is usually the period from the time of the delivery of the first concrete load until 4-6 hours after the final concrete had been placed. Deck movement and vibration from adjacent traffic should be minimized to avoid damage to the concrete during its early strength development.*

*2. **The bond of the overlay concrete to the existing deck**: Consideration should be given on a case by case basis taking into account potential vertical movement of the repaired deck resulting from adjacent heavy traffic. This is mainly for the period after final concrete set time and during the early ages of concrete strength development and until the new overlay concrete has developed its specified compressive strength or adequate bond to the existing concrete to prevent debonding.*



Note: Example shown by dashed lines is for an air temperature of 80°F, relative humidity of 50 percent, concrete temperature of 87°F, and a wind velocity of 12 miles per hour. This result is a rate of evaporation of 0.24 pounds per square foot per hour.

Attachment A- Evaporation Rate of Surface Moisture