EFFECT OF INITIAL SCARIFICATION AND OVERLAY TREATMENT TIMING ON CHLORIDE CONCENTRATIONS IN CONCRETE BRIDGE DECKS

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By

W. Spencer Guthrie, Ph.D. (Corresponding Author)
Associate Professor
Department of Civil and Environmental Engineering
Brigham Young University
Provo, UT 84602
(801) 422-3864 Voice
(801) 422-0159 Fax
guthrie@byu.edu

Curtis D. Nolan, E.I.T.
Engineer
Kiewit Engineering Company
Kiewit Plaza
Omaha, NE 68131
(402) 342-2052 ext. 2089 Voice
(402) 271-2874 Fax
curtis.nolan@kiewit.com

and

Dale P. Bentz
Chemical Engineer
Inorganic Materials Group
Materials and Construction Research Division
Building and Fire Research Laboratory
National Institute of Standards and Technology
100 Bureau Drive, Stop 8615
Gaithersburg, MD 20899
(301) 975-5865 Voice
(301) 990-6891 Fax
dale.bentz@nist.gov

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ABSTRACT
Scarification and overlay (SO) procedures are often performed on concrete bridge decks to minimize the corrosion of reinforcing steel due to chloride ingress. Given the need to develop guidelines for the initial timing of SO treatments, the objectives of this research were to collect information from state department of transportation (DOT) personnel about their SO procedures and, subsequently, to recommend timing of initial SO procedures on concrete bridge decks for preventing the accumulation of corrosion-inducing levels of chlorides and extending deck service life.

A questionnaire survey of state DOTs was conducted, and numerical modeling of SO treatments was performed for decks with and for decks without stay-in-place metal forms (SIPMFs). Full-factorial numerical modeling was performed through a service life of 50 years to determine the recommended initial timing of SO treatment in each case.

The research results show that, overall, bridge decks without SIPMFs can endure longer delays in SO treatment timing than those with SIPMFs; the allowable delay in SO timing ranged from 2 years to 6 years for decks with SIPMFs, while the allowable delay ranged from 6 years to 18 years for decks without SIPMFs. In addition, the results show that the allowable delay also depends on the original cover depth (OCD). On average, for each additional 0.5 in (12.7 mm) of OCD, the period of additional allowable delay for decks with SIPMFs was 2 years; however, for decks without SIPMFs, the additional allowable delay was 5 years with each additional 0.5 in (12.7 mm) of OCD.

INTRODUCTION

Corrosion of reinforcing steel due to chloride ingress is a leading cause of deterioration of bridge infrastructure in the United States (*1, 2, 3, 4, 5*). Rust, the byproduct of corrosion, is up to 600 percent more voluminous than its parent materials (*6*). The formation of rust causes tensile stresses in concrete and leads to cracking and delamination. These distresses result in eventual weakening and even failure of affected structures. Concrete bridge decks located in coastal climates and areas where deicing salts are used as a form of winter road maintenance are especially vulnerable to accelerated corrosion due to the presence of chlorides. The typical threshold value for corrosion initiation of reinforcing steel in concrete is 2 lb of chloride per cubic yard of concrete (1.19 kg of chloride per cubic meter of concrete) (*7*).

In a 2004 questionnaire survey conducted of bridge engineers and managers at 28 state departments of transportation (DOTs) nationwide, Brigham Young University (BYU) researchers inquired about decision thresholds utilized to determine if a bridge deck was in need of rehabilitation or replacement (*7*). The respondents indicated that action was needed if the deck was more than 20 to 50 percent deteriorated, with the wide range in values being associated with the different methods by which deterioration can be assessed. When action is warranted, procedures such as surface treatments, scarification and overlay (SO) treatments, cathodic protection, electrochemical chloride extraction, concrete removal and patching, and complete deck replacement are among those performed (*7, 8*), yet no standard procedure is apparently followed for determining the correct timing of deck rehabilitation.

However, research performed at BYU since the time of the 2004 survey has investigated the latest timing of deck surface treatments allowable before the corrosion threshold of 2 lb of chloride per cubic yard of concrete (1.19 kg of chloride per cubic meter of concrete) is exceeded at the level of the reinforcing steel (*9*). Depending on the presence of stay-in-place metal forms (SIPMFs) and concrete cover thickness, the recommended timing for placement of surface treatments to seal the surface and prohibit further chloride ingress from the environment ranges from 1 year to 15 years for decks similar to those evaluated in the study. As evidenced by these data, surface treatments are only beneficial during comparatively early stages of bridge deck service life. Once the deck age has exceeded the latest possible timing for surface treatments or other preventive maintenance procedures, a form of rehabilitation or reconstruction must be considered.

SO treatments are among the common forms of rehabilitation that can be performed on concrete bridge decks. Even though SO treatments are utilized by many agencies, the literature does not provide specific guidance about the initial timing of SO treatments with respect to preventing the accumulation of critical levels of chlorides at the level of the reinforcing steel in concrete bridge decks (*10*).

Derived from the need to develop guidelines for the initial timing of SO treatments, the specific objectives of this research were to collect information from state DOT personnel about their SO procedures and, subsequently, to determine the recommended timing of initial SO procedures on concrete bridge decks for preventing the accumulation of corrosion-inducing levels of chlorides and extending deck service life. The following sections provide background information, describe the research procedures, explain the results, and offer conclusions and recommendations.

BACKGROUND

The following background sections discuss the diffusion of chlorides in concrete, the effect of SIPMFs on chloride intrusion in concrete bridge decks, and the basic SO procedure on bridge decks.

Chloride Diffusion

Chloride ions enter concrete bridge decks primarily through diffusion, a process in which the ions travel through the pore water that exists within concrete. Diffusion of chloride ions in concrete is generally believed to follow Fick's second law of diffusion (*1, 11*). Diffusion begins when chloride solutions first contact the concrete surface (*5*). The rate at which these ions penetrate concrete is strongly influenced by the concentration gradient of chloride ions in the concrete and the diffusion coefficient of the concrete (*11, 12*). The diffusion coefficient is controlled by the water-to-cementitious materials ratio of the concrete mixture, tortuosity and degree of saturation of the pore structure, degree of hydration of the concrete, and external environmental factors (*3, 13*). In particular, higher diffusion coefficients are typically associated with higher water-cementitious materials ratios, lower tortuosity, higher degrees of saturation, lower degrees of hydration, and higher temperatures (*14, 15, 16*).

Over time, the accumulation of chlorides in the concrete immediately around the steel causes a breakdown of the naturally occurring protective environment that concrete provides for reinforcing steel. The otherwise passive oxide layer on the surface of the steel becomes unstable at elevated chloride concentrations and therefore becomes susceptible to corrosion. The higher the diffusion coefficient of the concrete, the quicker this transformation can occur.

Stay-in-Place Metal Forms

Advantages associated with construction of bridge decks with SIPMFs include reduced labor costs, reduced construction time, and increased safety of construction workers (*12*). The forms are simple to construct on site, as they are lightweight and usually prefabricated. The SIPMFs can be quickly installed and, unlike conventional forms, are not removed after placement of the concrete. SIPMFs reduce safety hazards for bridge contractors, as bridge construction usually occurs over dangerous places such as ravines and highways (*12*).

Although decks with SIPMFs have numerous advantages over those without SIPMFs, they also have a higher potential for corrosion of reinforcing steel than decks without SIPMFs, primarily because decks with SIPMFs have higher average moisture contents than decks without SIPMFs (*6*). Higher moisture contents facilitate higher diffusion coefficients and therefore result in greater ionic conduction (*6*). The higher moisture contents are a consequence of the reduction in evaporation of water from the bridge deck due to the presence of the SIPMFs along the bottom of the deck. Previous researchers determined that decks with SIPMFs exhibited diffusion coefficients approximately twice as high as those associated with decks without SIPMFs (*9*). Because different diffusion coefficients would result in different rates of chloride accumulation, different rehabilitation practices would be expected for the different bridge deck types. Specifically, decks with SIPMFs may require earlier maintenance and rehabilitation procedures than those without SIPMFs.

Scarification and Overlays

Although more costly than traditional surface treatments, concrete overlays are a common form of deck rehabilitation performed by DOTs. Deteriorated concrete is first removed to a specified depth from the upper surface of the bridge deck through a scarification process usually involving heavy milling equipment, hydrodemolition equipment, jackhammers, or a combination of methods (*7*). The process of removing the deteriorated concrete and preparing the surface can be tedious and must be performed carefully to provide a rough but stable surface to which the new overlay can adequately bond. Poor bonding can lead to a shorter overlay service life by causing cracking and spalling.

Overlays are typically designed to exceed the performance of the pre-existing concrete and are generally categorized as high-performance concrete (HPC). HPC meets special requirements based on strength and/or durability (*17*). The mixture design for an HPC varies with geographic location and project circumstances but commonly includes silica fume or latex modifiers for bridge deck overlay applications (*18*). These additives reduce the diffusion coefficient and thereby provide enhanced protection of reinforcing steel against the ingress of chlorides into bridge decks (*19, 20, 21, 22, 23*). While previous research has validated the effectiveness of HPC as a barrier against the intrusion of chlorides into concrete, the timing at which application of treatment would protect the underlying reinforcing steel from reaching threshold levels of chloride concentrations during the service life of the deck was not considered in any of the articles identified in the literature review conducted for this study.

EXPERIMENTAL METHODOLOGY

This section describes the questionnaire survey and numerical modeling of SO treatments performed to meet the objectives of this research.

Questionnaire Survey

A questionnaire survey was conducted for the purpose of assessing the state of the practice concerning SO procedures applied to concrete bridge decks throughout the United States and to facilitate numerical modeling of typical approaches. The DOTs were chosen based on the climate of the geographic region and previous knowledge of SO treatment usage by DOT personnel. The climates of the selected states were those with winter seasons harsh enough for winter road maintenance in the form of deicing salts or chemicals. A total of 44 DOTs were contacted, and personnel in the following 40 states responded: Alaska, Arizona, Arkansas, California, Colorado, Connecticut, Delaware, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Rhode Island, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Washington, West Virginia, and Wyoming. The survey was conducted by telephone and e-mail. Participants in the survey were typically state bridge engineers or state bridge maintenance engineers. Each DOT participant was asked the following questions regarding rehabilitation procedures on concrete bridge decks:

- What is a typical range for scarification depth?
- What is a typical range for overlay thickness?
- What types of overlays are used in your specific state (HPC, low-slump, etc.)?

Based on the answers to these questions, appropriate ranges of SO depth were selected for use in the modeling process. The use of typical values ensured that the numerical modeling would have maximum utility for practitioners working in the area of bridge management.

Numerical Modeling

Numerical modeling was performed using a program developed by the National Institute of Standards and Technology (*24*). The program uses a one-dimensional, finite-difference solution for diffusion based on Fick's second law to simulate the diffusion of chlorides through concrete. The program considers several internal and external variables that contribute to the intrusion of chlorides into concrete. The internal variables that are considered in the program include concrete mixture design parameters such as water-cementitious materials ratio, air content, degree of hydration, and diffusion coefficient. Specific diffusion coefficients were used for decks with and without SIPMFs. The external variables for which the program accounts are average monthly temperature, surface chloride concentration, and unexposed boundary condition for the concrete. The unexposed boundary condition may be simulated as a "reflecting boundary" or "constant at zero" as stated in the software; these options account for the presence of decks with and without SIPMFs, respectively (*24*). Accounting for all of these variables together allows for extensive approximations of chloride concentration profiles based on the cyclic loading of chlorides on bridge decks.

The function used to represent the chloride concentration at the surface of the decks in the numerical modeling is represented by Equation 1 (*9*):

$$C = 3.38 + 1.07 \cdot \cos\left(\frac{\pi \cdot t}{6}\right) \tag{1}$$

where C = chloride concentration of pore water for month t, mol/L
t = month of year from 1 to 12 to represent January to December, respectively

Specific inputs for the program were determined from local climatic conditions (*25*) and with assistance from personnel at the National Institute of Standards and Technology and the Federal Highway Administration High Performance Concrete Technology Implementation Panel. Determined in previous BYU research, the diffusion coefficients used in this study were 2.72E-11 m^2/s and 1.30E-11 m^2/s for decks with and without SIPMFs, respectively (*9*). In the previous research, chloride concentration data were collected from 12 concrete bridge decks located within the Interstate 215 corridor in Salt Lake City, Utah. All bridge decks ranged from 16 to 21 years in age, and six of the decks were constructed using SIPMFs (*9*). For SO treatments investigated in this research, the diffusion coefficient assigned to the HPC overlay was 1.00E-12 m^2/s, suggesting that the diffusion of chlorides in HPC overlays is 27 times slower than in decks with SIPMFs and 13 times slower than in decks without SIPMFs. Table 1 contains the specific and default values used in the modeling performed in this research. The "Typical" column in the table refers to the original concrete that exists on the simulated deck prior to rehabilitation, while the "Overlay" column refers to the overlay placed on the deck following scarification. Table 2 displays the monthly temperature inputs used in the modeling process. Both tables are presented in metric units as required by the program.

The various treatments selected for modeling were based on the responses received in the questionnaire survey conducted in this study. Specific scarification depths chosen for numerical modeling were 0.5 in. (12.7 mm), 1.0 in. (25.4 mm), and 1.5 in. (38.1 mm), while overlay depths of 1.5 in. (38.1 mm) and 2.0 in. (50.8) were chosen. The depths for SO were combined in a full-factorial experimental design to form all possible combinations, producing a total of six unique treatments. Original cover depths (OCDs) of 2.0 in. (50.8 mm), 2.5 in. (63.5 mm), and 3.0 in.

(76.2 mm), as measured from the surface of the deck to the top layer of reinforcing steel, were used to simulate different bridge design practices (*7*), and simulations involving decks with and without SIPMFs were also performed. In all, fully crossing all the levels of these various factors produced a total of 36 unique scenarios.

The numerical modeling for each scenario was carried out to a total simulated service life of 50 years. Modeling times were chosen to start at a simulated deck age of 2 years and advanced at 2-year increments through a service life of 20 years. Beginning at year 20, modeling was performed at 5-year increments through a service life of 50 years. First, modeling of the decks without treatment was performed. Second, the modeling process was performed for each combination of treatment and timing. The latest scheduled time of SO treatment that resulted in a chloride concentration, at the level of the reinforcing steel, that most nearly approached the threshold level of chloride concentration of 2 lb of chloride per cubic yard of concrete (1.19 kg of chloride per cubic meter of concrete) without exceeding it during the 50 year service life was chosen as the latest recommended initial timing of the SO treatment. To limit the number of required simulations and to present the data clearly, the modeling was performed for three treatment times before and three treatment times after the threshold concentration of chlorides was reached. This approach facilitated determination of the most effective initial timing of SO treatment and analysis of the chloride concentrations in the decks associated with premature and delayed treatment.

RESULTS

The results of the questionnaire survey and numerical modeling are presented in the following sections.

Questionnaire Survey

Of the 40 DOTs that responded to the questionnaire survey, 20 use a scarification depth between 0.5 in. (12.7 mm) and 1.5 in. (38.1 mm), and 27 use an overlay depth between 1.5 in. (38.1 mm) and 2.0 in. (50.8 mm). All of the DOTs reported using HPC that resulted in a lower permeability and/or higher density, meaning that the diffusion rate is significantly lower than normal concrete. The most common types of HPC used are silica-fume (SF) and latex-modified concrete (LMC). Table 3 presents the typical scarification and overlay depths reported by each responding state DOT, along with the type of HPC used. The Connecticut, Massachusetts, and New Hampshire DOT respondents stated that they place hot mix asphalt on their decks and do not perform concrete overlays. The Rhode Island DOT participant reported that SO procedures are rare and that deck replacements are typically specified instead. The New Mexico DOT engineer provided the same response, citing a low benefit-cost ratio associated with overlays in that state.

Numerical Modeling

As an aid in understanding the process of data organization and reduction, an example is presented. In Figure 1, chloride concentration profiles for an 8-in. (203 mm)-thick deck with SIPMFs and an OCD of 3.0 in. (76.2 mm) are presented for a scenario in which an SO treatment was applied at year 6 of the deck life in the month of October. The scarification and overlay depths specified for this simulation were 1.0 in. (25.4 mm) and 2.0 in. (50.8 mm), respectively. Each series of points, which were obtained directly from the software program utilized in this research, represents a specific year ranging from year 2 through year 50. In the process of data analysis, the chloride concentration at the depth of the reinforcing steel, 3.0 in. (76.2 mm), was determined from the graph through year 6 and recorded in a spreadsheet. At year 6, the SO treatment was simulated and is taken into account in the data produced for the next simulated year, which is year 8. At this year, the chloride concentration was determined from the graph at a depth of 4 in. (101.6 mm) for recording in the same spreadsheet. In this example, although the position of the steel did not change, its depth relative to the surface of the concrete increased because the 1.0-in. (25.4 mm) scarification and subsequent 2.0-in. (50.8 mm) overlay resulted in an increase in cover thickness of 1.0 in. (25.4 mm).

From year 8 to year 50, the chloride concentrations were then determined from the graph at the 4.0-in. (101.6 mm) depth and recorded similarly. All of these recorded concentrations were then plotted in Figure 2 under the series named "Treatment at 6 years," and this process was repeated for every other treatment timing displayed in the figure. Then, again with reference to Figure 2, the series with the maximum chloride concentration over the 50-year service life that was most nearly equal to but not exceeding 2 lb of chloride per cubic yard of concrete (1.19 kg of chloride per cubic meter of concrete) was identified as the latest recommended timing for initial SO procedures; in this example, the "Treatment at 6 years" series was selected. Year 6 was then entered in Table 4 in the correct row and column. This process was continued for each SO treatment combination and OCD. The process was the same for decks with and without SIPMFs.

Overall, as shown in Table 4, the bridge decks without SIPMFs could endure delays in SO treatments for a greater amount of time than those with SIPMFs. For example, with an OCD of 3.0 in. (76.2 mm), a scarification depth of 1.5 in. (38.1 mm), and an overlay thickness of 2.0 in. (50.8 mm), the deck with SIPMFs did not experience critical chloride concentrations at the level of the reinforcing steel until 6 years of service life, while the deck without SIPMFs did not experience critical chloride concentrations until 18 years of service life. In all cases, the absence of SIPMFs extended the amount of time before an SO treatment was needed.

The results of this research indicate that, on average, the additional period of delay allowed before an SO treatment was required for decks with SIPMFs was 2 years with each additional 0.5 in. (12.7 mm) of OCD. For decks without SIPMFs, the presence of a greater OCD had a more pronounced effect on the latest recommended timing of treatment than for decks with SIPMFs; an average additional delay period of 5 years was obtained with each additional 0.5 in. (12.7 mm) of OCD on decks without SIPMFs.

At the times recommended for most of the SO treatments, the chloride concentrations at the level of the reinforcing steel were not at the threshold value of 2 lb of chloride per cubic yard of concrete (1.19 kg of chloride per cubic meter of concrete). Though maintenance procedures may initially seem premature at this stage, the SO treatment must take place. The chlorides not removed by the SO treatment may be sufficient to cause corrosion-inducing levels of chlorides at the depth of reinforcing steel in the future, due to diffusion, even if no additional chlorides enter the deck.

As an illustration of this point, Figure 3 shows the chloride concentration profile for a deck without SIPMFs and an OCD of 3.0 in. (76.2 mm) at year 18 just before the application of an SO treatment involving scarification and overlay depths of 0.5 in. (12.7 mm) and 2.0 in. (50.8 mm), respectively. The chloride concentration at the level of the reinforcing steel is noted in the figure as being 1.9 lb of chloride per cubic yard of concrete (1.13 kg of chloride per cubic meter of concrete), which is below the threshold at which corrosion would be expected to begin. However, after application of the SO treatment at year 18, the chloride concentration at the level of the reinforcing steel, now at a depth of 4.5 in. (114.3 mm) as shown in the figure, increased to

2.3 lb of chloride per cubic yard of concrete (1.36 kg of chloride per cubic meter of concrete) by year 20. The reason that the threshold was exceeded is that the chlorides in the pre-existing concrete, not removed by the SO treatment, continued to diffuse through the concrete and resulted in elevated chloride concentrations at the level of the reinforcing steel.

A correct timing of the SO treatment ensures that chloride concentrations at the level of the reinforcing steel always remain below 2.0 lb of chloride per cubic yard of concrete (1.19 kg of chloride per cubic meter of concrete). In the scenario just described, application of an SO treatment at 16 years is appropriate for this reason. Figure 4 shows the chloride concentration profile for the same deck at year 16 just before the SO treatment, at which time the chloride concentration at the level of the reinforcing steel is just 1.5 lb of chloride per cubic yard of concrete (0.89 kg of chloride per cubic meter of concrete). In this case, although the chloride concentration does increase by year 18 to 1.9 lb of chloride per cubic yard of concrete (1.13 kg of chloride per cubic meter of concrete) as shown in Figure 4, the value is still below the threshold, and it remains below the threshold through the entire 50 years of simulated deck life.

Scarification depth played a greater role than overlay depth when reductions in chloride concentration at the level of the reinforcing steel were considered. Due to the low diffusion rate of the HPC overlay, the two different overlay depths of 1.5 in. (38.1 mm) and 2.0 in. (50.8 mm) were not distinguishable; they both provided sufficient obstruction against intrusion of chlorides into the concrete during the simulated service life of 50 years. These findings demonstrate that HPC is an effective barrier against the ingress of chlorides in bridge decks.

CONCLUSION

Given the need to develop guidelines for the initial timing of SO treatments, the specific objectives of this research were to collect information from state DOT personnel about their SO procedures and, subsequently, to determine the recommended timing of initial SO procedures on concrete bridge decks for preventing the accumulation of corrosion-inducing levels of chlorides and extending deck service life. A questionnaire survey of state DOTs was conducted, and numerical modeling of SO treatments was performed. The resulting SO treatment schedule proposed in this research is only for the initial application of the treatment. As overlays are not permanent, repeated treatments may be necessary in practice to ensure that critical concentrations of chlorides do not accumulate in the concrete deck.

The research results show that, overall, bridge decks without SIPMFs can endure longer delays in SO treatment timing than those with SIPMFs. For decks with SIPMFs, the allowable delay in SO timing ranged from 2 to 6 years, while on decks without SIPMFs the allowable delay in SO timing ranged from 6 to 18 years. These delays are only 1 to 3 years longer than allowable delays associated with placement of surface treatments investigated in previous BYU research (*9*).

On average, the period of additional delay allowed before an SO treatment is required for decks with SIPMFs was 2 years with each additional 0.5 in. (12.7 mm) of OCD. For decks without SIPMFs, the presence of a greater OCD had a more pronounced effect on the latest recommended timing of treatment than for decks with SIPMFs; an average additional delay period of 5 years was obtained with each additional 0.5 in. (12.7 mm) of OCD on decks without SIPMFs.

Scarification depth played a greater role than overlay depth when reductions in chloride concentration at the level of the reinforcing steel were considered. Due to the low diffusion rate of the HPC overlay modeled in this research, the two different overlay depths of 1.5 in. (38.1

mm) and 2.0 in. (50.8 mm) were not distinguishable; they both provided sufficient obstruction against intrusion of chlorides into the concrete during the simulated service life of 50 years. These findings demonstrate that HPC is an effective barrier against the ingress of chlorides in concrete bridge decks.

Using the findings of this research and the specific properties of the bridge deck under scrutiny, engineers can determine the appropriate timing of SO procedures for their particular application to prevent corrosion of the steel reinforcement in the deck and ensure the usability of the deck structure for its intended service life. However, SO treatments should be considered only after determining that a less expensive surface treatment would prove to be unsuccessful, and engineers should realize that the window of opportunity is narrow between the application of a surface treatment and an SO treatment. Decks with conditions beyond those appropriate for SO treatment may require complete replacement, which is generally the most expensive option. Although the conditions studied in this research were consistent with bridges located in the state of Utah, bridge decks that exist in similar environments and that are subjected to similar treatments of deicing salts as part of winter maintenance could exhibit similar properties to the decks simulated in this research.

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TABLE 1 Computer Program Input Values

Property	Value	
	Typical	Overlay
Beginning Month of Exposure	October	
Member Thickness (m)	0.203	
Water Cementitious Material ratio, w/cm	0.44	0.39
Degree of Hydration	0.8	
Volume Fraction of Aggregate (%)	65	62
Air Content (%)	6	
Initial Chloride Concentration of Concrete (g Chloride/ g Cement)	0	
Initial Diffusion Coefficient, D_i	0	
Empirical Coefficient, m	0.6	
Ratio of Surface-to-Bulk Diffusion Coefficients	1	
Thickness of Surface Layer (mm)	0	
Activation Energy for Diffusion (kJ/mol)	40	
Langmuir Isotherm Alpha Constant	1.67	
Langmuir Isotherm Beta Constant	4.08	
Rate Constant of Binding (s^{-1})	1.00E-07	
C_3A Content of Cement (%)	5	
C_4AF Content of Cement (%)	5	
Rate Constant for Aluminate Reations with Chloride (s^{-1})	1.00E-08	

TABLE 2 Monthly Temperature Input Values

Month	Temperature (^oC)
January	-2.3
February	1.2
March	5.4
April	9.8
May	14.9
June	20.6
July	25.5
August	24.2
September	18.4
October	11.8
November	4.9
December	-1.3

TABLE 3 Results of Questionnaire Survey

State	Typical Range for Scarification Depth (in.)	Typical Range for Overlay Depth (in.)	Type of HPC Overlay
Alaska	3.5 - 4.0	3.5 - 4.0	SF
Arizona	1.5 - 2.0	1.5 - 2.0	SF, Polymer Epoxy
Arkansas	0.5	0.5	LMC
California	1.0 - 1.5	0.75 - 3.0	Polyester
Colorado	0.25	0.375 - 2.0	SF
Delaware	1.5	1.5	SF, LMC
Idaho	1.5	1.5	SF
Illinois	0.25 - 0.375	0.375 - 2.5	SF, LMC, Polymer
Indiana	0.25	1.75	LMC
Iowa	0.25	1.75	High Density/Low Slump
Kansas	2.0 - 3.0	1.5	SF
Kentucky	2.5	2.5	LMC
Maryland	2.0	2.0	LMC
Michigan	1.5 - 2.0	2.75	SF, LMC
Minnesota	0.25 - 1.5	2.0	Low Slump
Missouri	0.25	0.25 - 2.25	SF, LMC, Epoxy Polymer
Montana	0.75	1.5 - 2.0	LMC
Nebraska	0.5	2.0	SF
Nevada	0.25	0.75	Polyester, Epoxy
New Jersey	1.5	1.5	SF, LMC
New York	0.25 - 0.5	2.0	SF
North Carolina	0.5 - 1.5	0.5 - 1.5	LMC, High Early Strength
North Dakota	0.5	1.5	Portland Cement Concrete
Ohio	1.0 - 1.5	1.5 - 2.0	LMC
Oklahoma	0.375	1.5	High Early Strength
Oregon	0.25	1.5	SF
South Dakota	0.25	2.0	Low Slump
Tennessee	1.0	1.25	LMC
Texas	1.0	1.5 - 2.0	LMC
Utah	1.0 - 1.5	1.25 - 3.0	SF
Vermont	3.5	3.5	Portland Cement Concrete
Virginia	1.25	1.5	LMC
Washington	0.5	1.5	SF, LMC, Fly Ash
West Virginia	1.5	1.5	LMC
Wyoming	0.25	1.25	SF

(1 in. = 25.4 mm)

TABLE 4 Recommended Latest Timing of Initial SO Procedures

Decks with SIPMFs				
		Scarification Depth (in.)		
Original Cover	Overlay Depth	0.5	1.0	1.5
Depth (in.)	(in.)	Recommended Deck Age for Treatment (yr)		
2.0	1.5	2	2	2
2.0	2.0	2	2	2
2.5	1.5	2	4	4
2.5	2.0	2	4	4
3.0	1.5	4	6	6
3.0	2.0	4	6	6
Decks without SIPMFs				
		Scarification Depth (in.)		
Original Cover	Overlay Depth	0.5	1.0	1.5
Depth (in.)	(in.)	Recommended Deck Age for Treatment (yr)		
2.0	1.5	6	6	6
2.0	2.0	6	6	6
2.5	1.5	10	10	10
2.5	2.0	10	10	10
3.0	1.5	16	18	18
3.0	2.0	16	18	18

(1 in. = 25.4 mm)

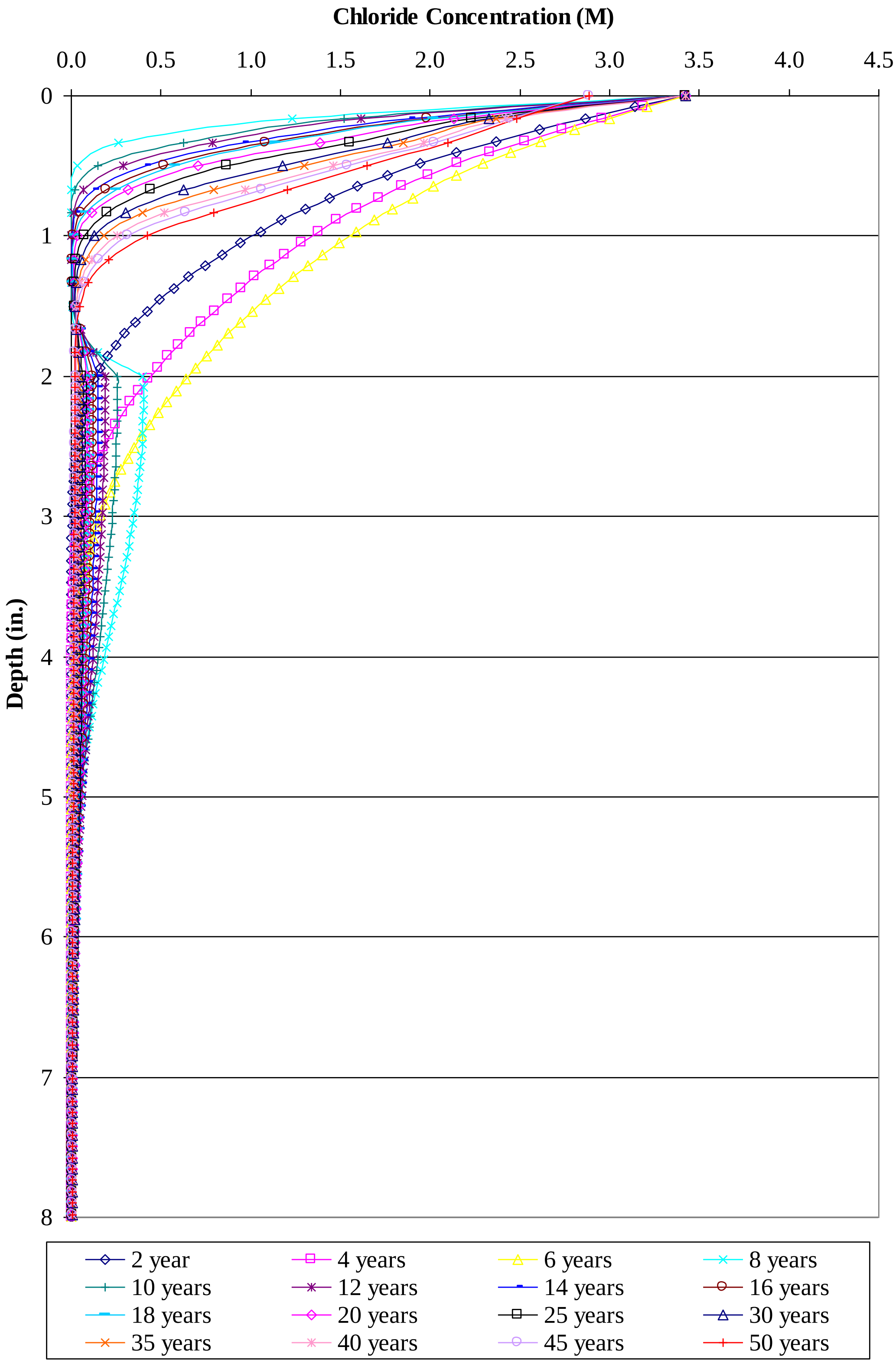


FIGURE 1 Chloride concentrations of decks with SIPMFs and a 3.0-in. (76.2 mm) OCD and a 1.0-in. (25.4 mm) scarification and 2.0-in. (50.8 mm) overlay treatment applied at 6 years.

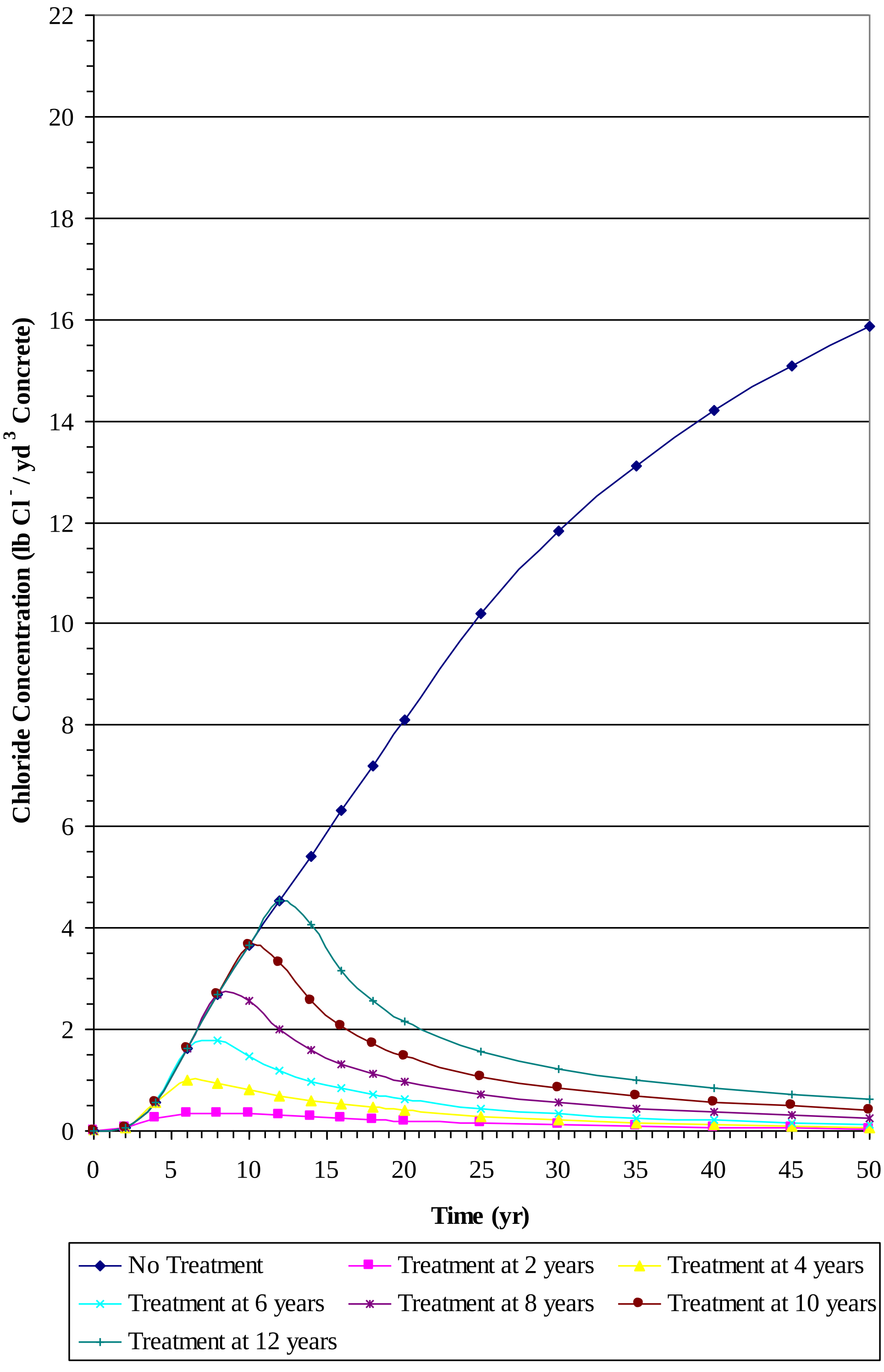
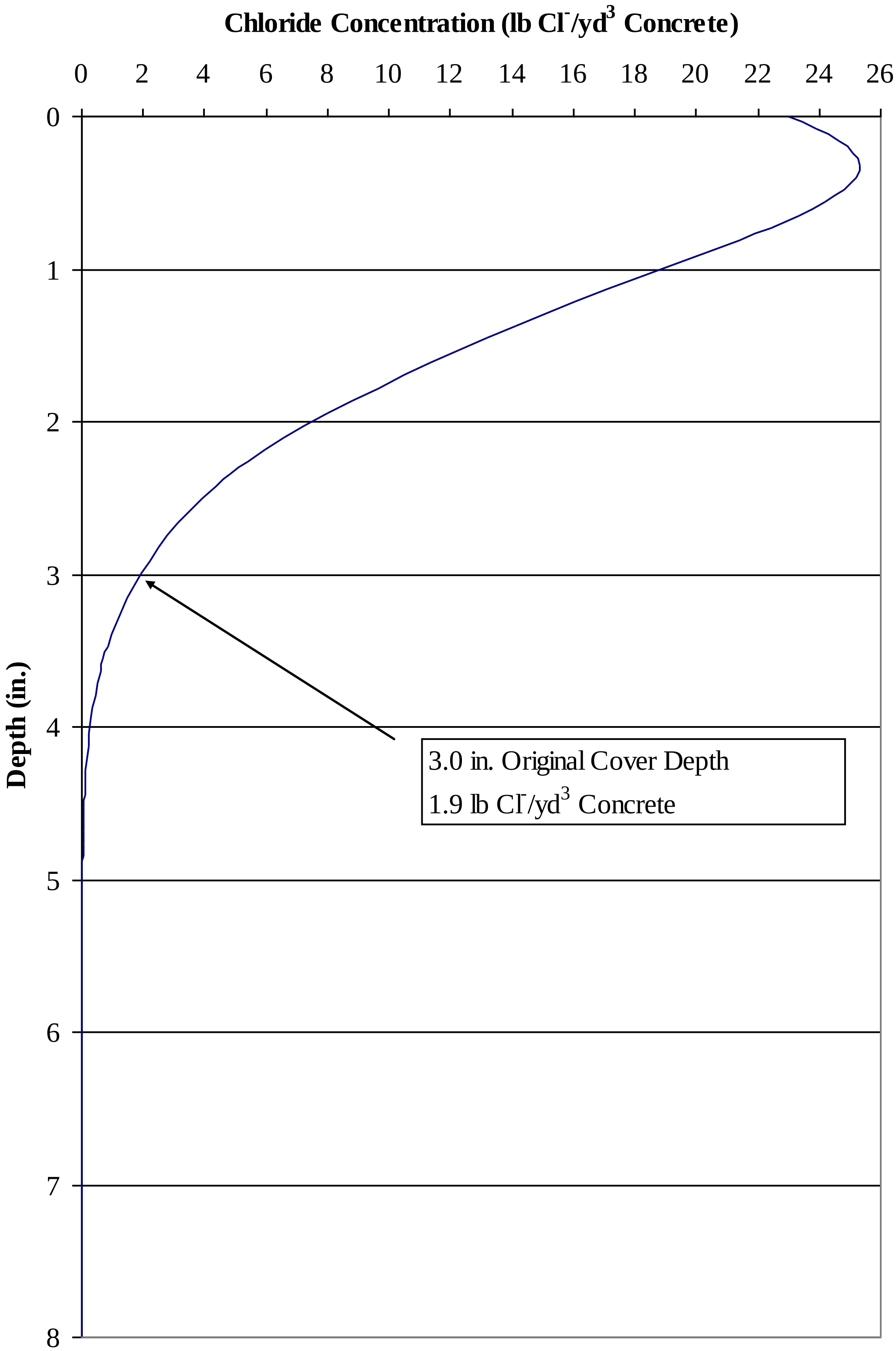
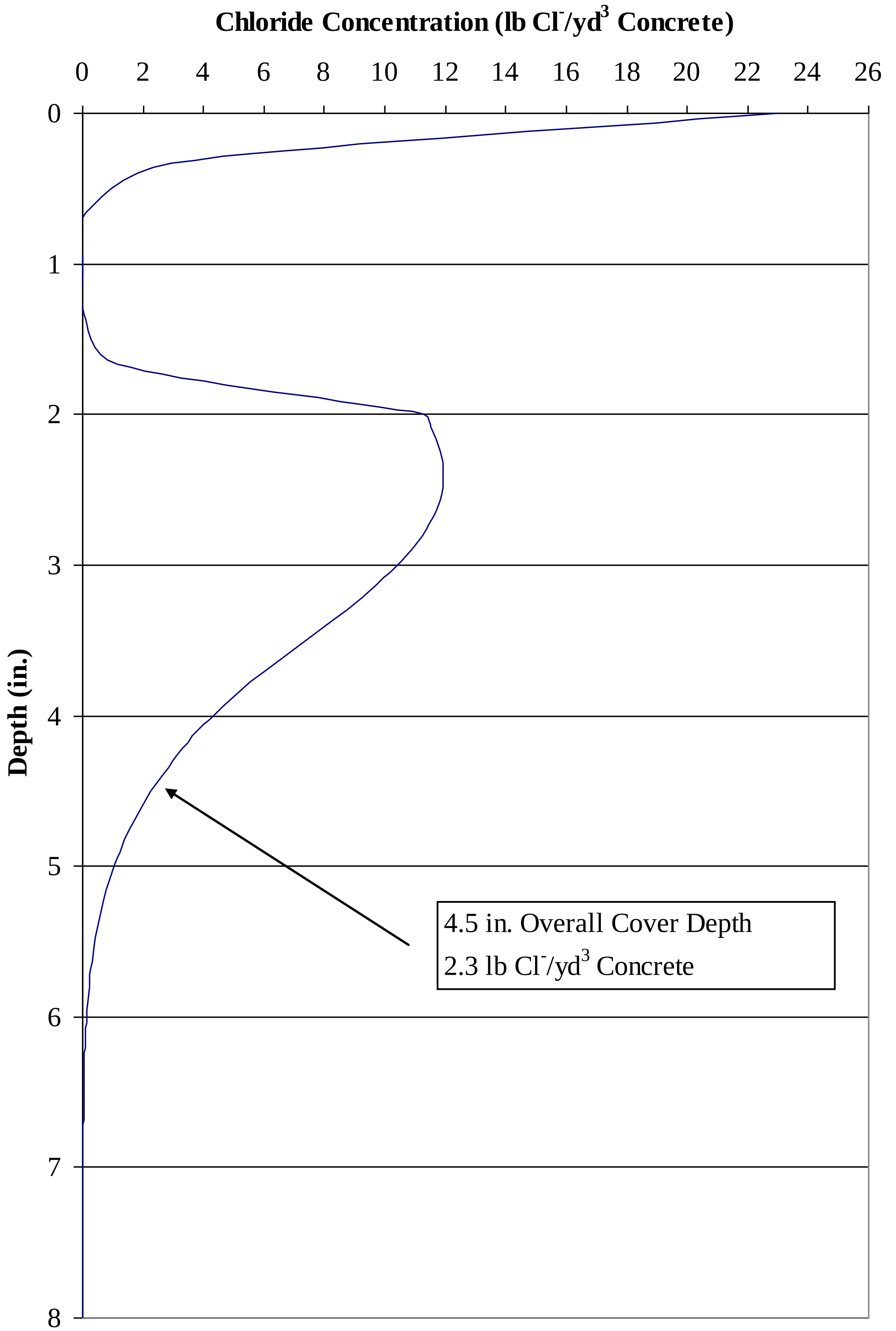


FIGURE 2 Chloride concentrations at the level of reinforcing steel in decks with SIPMFs and a 3.0-in. (76.2 mm) OCD for 1.0-in. (25.4 mm) scarification and 2.0-in. (50.8 mm) overlay treatments (depth of reinforcing steel is 3.0 in. (76.2 mm) for no-treatment case and 4.0 in. (101.6 mm) for treatment cases).



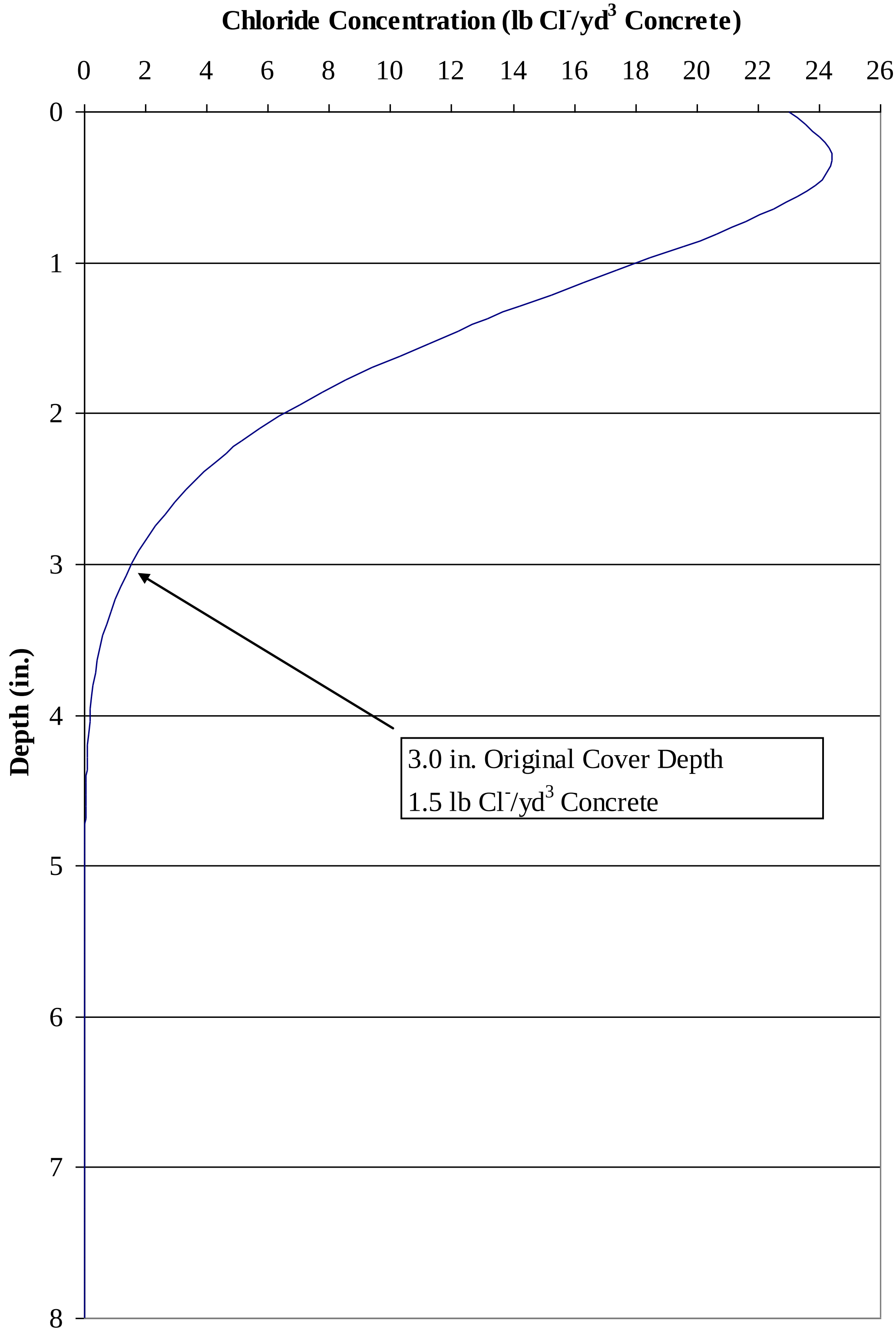
(a)

FIGURE 3 Scenario of deck with SIPMFs: (a) at year 18 (before treatment) and (b) at year 20 (after treatment).



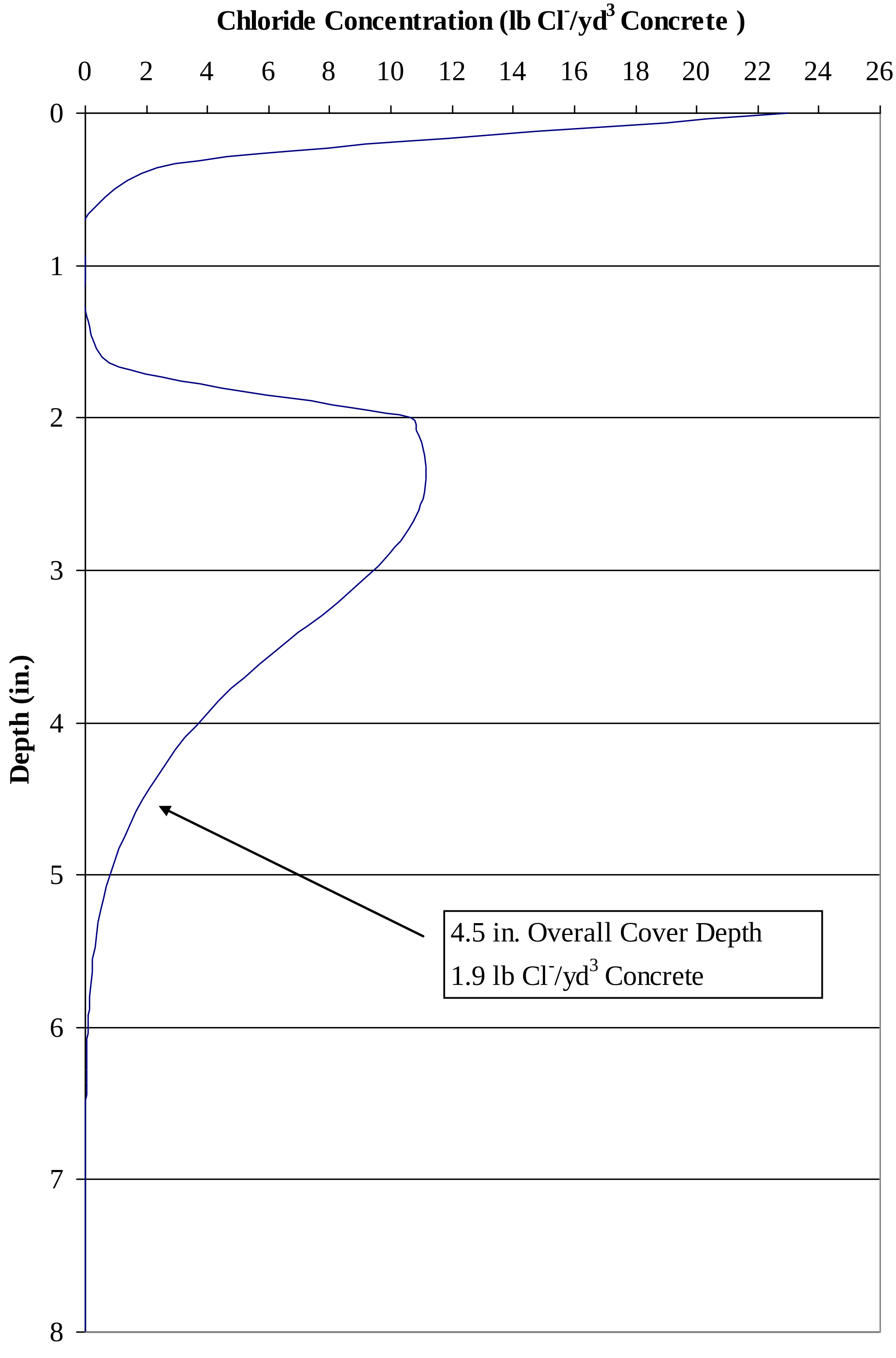
(b)

FIGURE 3 Scenario of deck with SIPMFs: (a) at year 18 (before treatment) and (b) at year 20 (after treatment), continued.



(a)

FIGURE 4 Scenario of deck with SIPMFs: (a) at year 16 (before treatment) and (b) at year 18 (after treatment).



(b)

FIGURE 4 Scenario of deck with SIPMFs: (a) at year 16 (before treatment) and (b) at year 18 (after treatment), continued.