Epoxy Coated Rebar Bridge Decks: Expected Service Life

Prepared for

Michigan Department of Transportation
Bridge Operations Unit

by

Brandon Boatman

Michigan Department of Transportation
Bridge Inspector Co-op

Michigan State University
Undergraduate Student

State of Michigan
Department of Transportation
Construction & Technology Division
Lansing, MI 48090

October 14, 2010

Introduction

1.1 History

The Michigan Department of Transportation (MDOT) has been designing and constructing bridges dating back to the early 1900s. Original bridge designs during these times included the use of uncoated steel rebar (commonly referred to as "black rebar") within concrete bridge decks. Around 1975 the first use of epoxy coated rebar (ECR) was implemented into concrete deck design. Adding an epoxy coat to the rebar helps establish a barrier that attempts to block the penetration of water, oxygen, and other elements that promote corrosion of the rebar. In late 1980 the Engineering Operations committee approved the use of epoxy coated rebar for all bridge decks. The committee noted in the memorandum that all jobs starting in December of 1980 will conform to this directive *(Appendix Fig 5-1)*.

1.2 Objective

The objectives of this study are as follows:

- Estimate service life of black rebar bridge decks.
- Estimate service life of ECR bridge decks.
- Review accuracy of Markov's transition probabilities.
- Identify different variables influencing deterioration of the deck surface.

The ultimate objective of this study is to accurately predict the service life of ECR bridge deck top surfaces. Currently it is unknown how long these deck surfaces will last before reaching poor condition. "Poor condition" of a deck surface is defined as a rating of 4 or below on the Bridge Safety Inspection Report (BSIR), and indicates the need for rehabilitation. If a known approximate service life was available for these decks then future overlays and preventive maintenance can be planned and budgeted accordingly.

1.3 Markov Model

Markov models use transition matrices that describe the probability that a bridge element in a known condition state at a known time will change to some other condition state in the next time period. This process assumes that the probability of changing from one state to another is a function only of the condition state and time period in which the deck is currently located. Therefore, the past performance of a bridge deck has no impact on the predicted rate of change in future performance [3]. This report reviews Markov transition probabilities for deck surface condition ratings for concrete bridge decks having "black" rebar and epoxy coated rebar (ECR). The transition probabilities are then converted to a deterioration rate using the following equation:

$$n = \frac{\log(0.5)}{\log(T)} \qquad [4]$$

where; T = Transition Probability
n = average # of years to reach next condition state.

Deterioration rates can help predict the time for a bridge deck to reach a specific condition state. With multiple year transition probabilities and deterioration rates calculated, averages from each one step transition can be averaged resulting in the most accurate results as possible.

Results

2.1 Data Set

A data set of 1,790 bridge decks was selected for use within this study. Out of this sample, 766 were ECR bridge decks, and 1,024 were black bar bridge decks. The data set was filtered down from 4,350 total bridge decks prior to analysis eliminating as many different variables as possible. The data set for both epoxy and black rebar contained only bridge decks that were labeled as monolithic concrete for the deck wearing surface (108A = 1) and contained no membrane (108B = 0). Black rebar data was filtered down to include decks that contained no deck protection (108C = 0). ECR bridge decks were filtered to only contain decks that have epoxy coated reinforcing (108C = 1). Any bridge decks that underwent reconstruction after 2003 were removed from this data set. This was done to ensure that the surface ratings were not altered due to a reconstruction or rehabilitation project. Bridges that "contained" epoxy coated rebar but built before 1980 were excluded; likewise any bridges that "contained" black rebar and built after 1980 also were excluded. There were several instances of ECR decks "built" in the late 2000's but containing deck surface ratings prior to their built date. This is more than likely a coding issue relating to bridges that have underwent rehabilitation, it appears that the year the rehabilitation occurred was labeled incorrectly as the built date. These bridges were either removed from the data set entirely or their surface ratings prior to the corresponding build date were discarded in calculating the probabilities. Figure 2-1 illustrates the filtered data population used within this study.

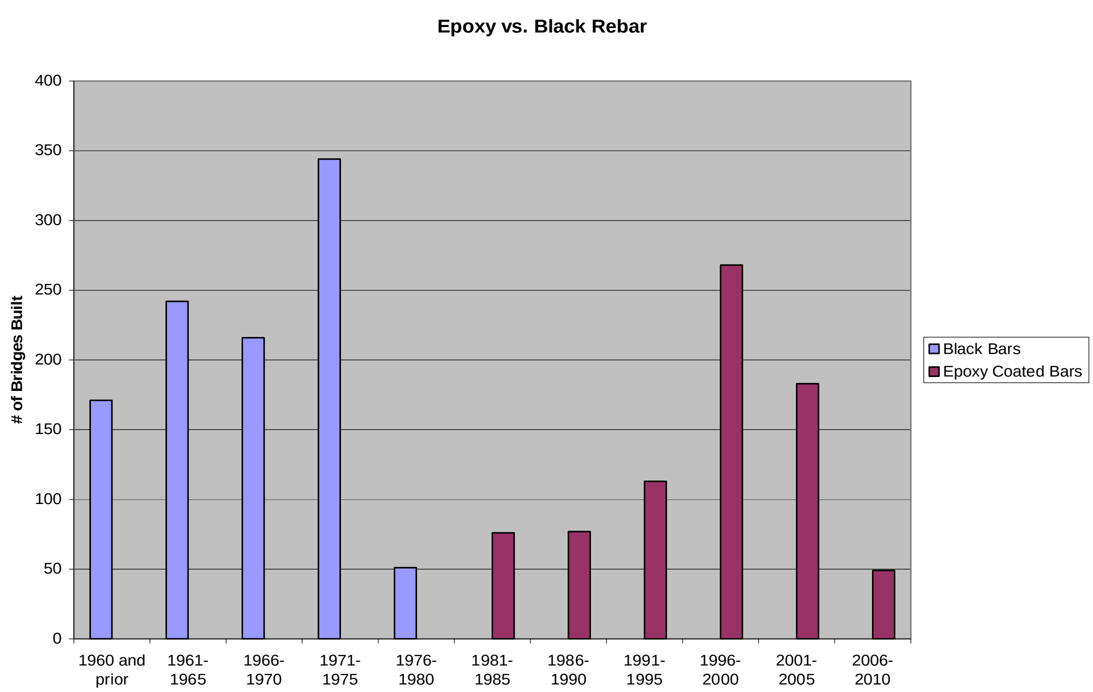

Figure 2-1: Bridge Data Population

2.2 Transition Probabilities and Deterioration Curves

Transition probabilities were calculated using bridge deck surface ratings from 2004 to 2010. These ratings were analyzed from year to year intervals, resulting in a transition probability for each year. For instance; in 2004 234 ECR bridge decks held a rating of a 7, in 2005 227 remained a rating of a 7 while the other 7 decks worsened to a rating of a 6. The transition probability is 97% that the deck will remain at a 7 and a 3% chance that the deck will lower to a 6. This was done for each deck surface rating, creating a transition probability matrix. This process was then repeated for 2005-2006, 07-08, 08-09, and 09-10 resulting in six different probability matrices *(Appendix Tables 5-1 thru 5-12)*. The probabilities were then averaged based on the six different matrices, resulting in an average transition probability matrix. Deterioration rates were calculated using the equation previously mentioned *(Section 1.3)*, the deterioration rates were then plotted along the x-axis with deck surface ratings assigned to the y-axis *(Appendix Fig 5-2 thru 5-13)*.

2.2.1 Black Rebar

Table 2-1 displays the average transition probability from 2004-2010 for black rebar bridge decks. The numbers located along the left side and highlighted in bright green represent the previous year deck surface rating. The numbers located along the top and highlighted in bright green represent the following year deck surface ratings and highlighted in blue are the average transition probabilities. For instance; there is a 41% chance that a 9 will remain a 9 the following year. Deterioration rates are highlighted light green.

Table 2-1: Transition Probability Matrix for Black Rebar

				BLACK BARS						
				107=1 108a=1 108b=0 108c=0						
Average from 2004-2010				Item 58A Deck Surface Ratings						
Transition Probability Matrix							Percent			
	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0	0.059191	0.529165	0.411644
8	0	0	0	0	0	0.001208	0.014922	0.18262	0.80125	0.780926
7	0	0	0	0	0.001427	0.003758	0.095205	0.899609	3.128175	
6	0	0	0	0.0010657	0.009233	0.038784	0.950917	6.551821	3.909101	
5	0	0	0	0.0084841	0.051367	0.940149	13.7724	10.46092		
4	0	0	0	0.0445106	0.955489	11.23115	24.23332			
3	0	0	0	1	15.22343	35.46448				
2	0	0	0		50.68791					
1	0	0								

Figure 2-2 displays the deck surface ratings plotted against deterioration rates calculated in Table 2-1. According to Figure 2-2; on average a black rebar bridge deck will take 35 years to reach a rating of 4, meaning poor condition.

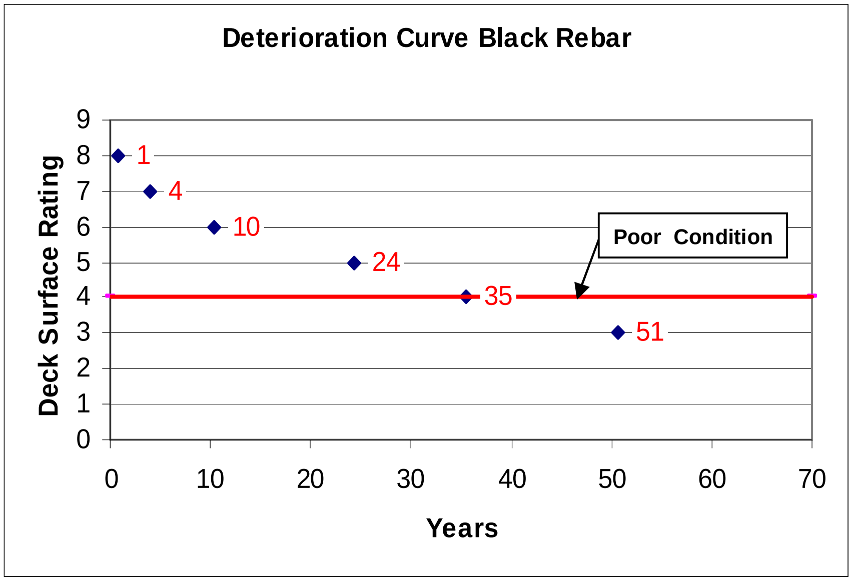

Figure 2-2: Black Rebar Bridge Deck Deterioration Curve

2.2.2 Epoxy Coated Rebar

Table 2-2: Transition Probability Matrix for ECR

EPOXY COATED BARS										
107=1 108a=1 108b=0 108c=1										
Average from 2004-2010					**Item 58A Deck Surface Ratings**					
	Transition Probability Matrix							Percent		
	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0.001792	0.071201	0.481616	0.445391
8	0	0	0	0	0	0	0.006989	0.165386	0.827625	0.857004
7	0	0	0	0	0	0.000435	0.031281	0.968284	3.663665	
6	0	0	0	0	0	0.010675	0.967974	21.50633	4.520669	
5	0	0	0	0	0	1	21.29493	26.027		
4	0	0	0	0	0	0	47.32193			
3	0	0	0	0		0				
2	0	0	0		0					
1	0	0								

Table 2-2 displays the average transition probability from 2004-2010 for ECR bridge decks. Again, transition probabilities are highlighted in blue and the deterioration rates are highlighted light green. Notice the emptiness of this matrix as compared to that of Table 2-1. Please also note that the average transition probability from a deck surface rating of a 6 to a 5 was based on two yearly transitions rather than six, due to insufficient data.

Figure 2-3 is the deterioration curve from the deterioration rates found within Table 2-2. This graph shows that an ECR deck should take 26 years to attain a deck surface rating of 6 and likewise 47 years to attain a rating of 5. Notice that deterioration rates cannot be calculated past a rating of 5. This is due to the lack of data containing deck surface ratings below a 5. To estimate the time to poor for ECR bridge deck surfaces, a straight line connecting condition state 6 and 5 was extended to condition state 4.

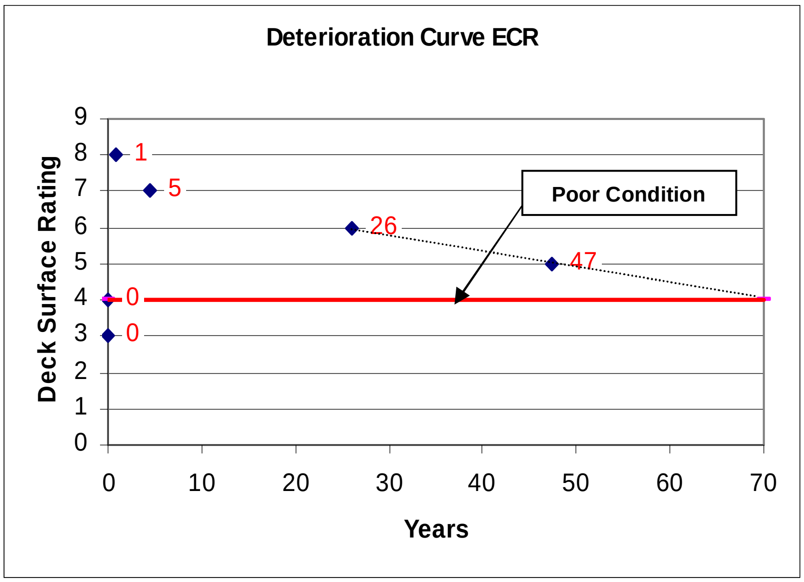

Figure 2-3: ECR Bridge Deck Deterioration Curve

2.3 Black Rebar Deck – Age Before Rehabilitation or Reconstruction

A separate data set was analyzed containing 409 bridges that contained black rebar. Each of these bridges was rehabilitated or reconstructed at some point in time. With the data set containing both a year built and a year of rehabilitation or reconstruction, an age of deck can be found at the time the work was done. These results are presented within Figure 2-4. Notice how this data represents a bell shaped probability curve. The figure displays an average age of approximately 36-40 years before an overlay is applied, meaning that the deck likely had reached poor condition during this time. The average age of overlay for the data set was found to be 38 years, which correlates very well with the time to poor calculated by using the transition probability matrix.

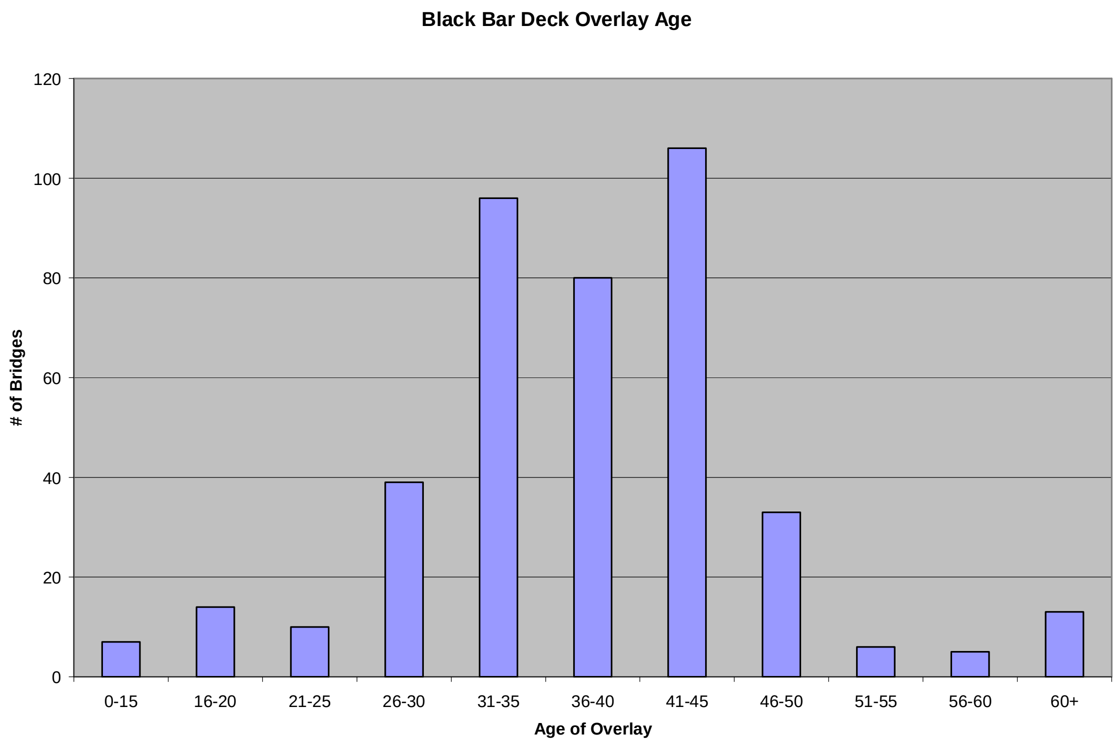

Figure 2-4: Average Age of Overlay for Black Rebar Bridge Decks

Discussion

3.1 Expected Service Life of Bridge Decks

3.1.1 Black Rebar

The current bridge deck preservation matrix is based upon black rebar decks. This matrix anticipates bridge decks to last "40+" years before a poor surface rating has been achieved *(Appendix Fig 5-14)*. This seems to be fairly accurate for decks with black rebar as compared to the results from this study. Based on the deterioration curve for black rebar decks *(Figure 2-2)* it should take approximately 35 years for the deck to reach a poor surface rating. Likewise in *Figure 2-4* the average deck age before overlay was found to be around 36-40 years based on the bell shaped curve. Over 1,000 bridge decks were evaluated containing deck surface ratings from 3 to 9. This resulted in the creation of a complete transition probability matrix *(Table 2-1)* along with a high correlation deterioration curve *(Figure 2-2)*.

3.1.2 Epoxy Coated Rebar

A sample size of 766 was used in calculating the transition probabilities for ECR bridge decks. ECR bridge deck surface ratings only ranged from 5 to 9 as compared to black rebar decks ranging from 3 to 9, resulting is an incomplete transition probability matrix *(Table 2-2)*. Notice how there is zero probability of a 5 becoming a 4. This is because no ECR bridge deck surfaces were identified that have reached a rating of poor (condition state 4 or below). *Figure 2-3* shows 26 years to achieve a rating of 6 and 47 years to achieve a rating of 5. To estimate the time to poor for ECR bridge deck surfaces, a straight line connecting condition state 6 and 5 was extended to condition state 4, resulting in a time to poor for ECR deck surfaces to be estimated at 70 years.

3.1.3 Comparison

ECR bridge decks are providing better performance than standard black rebar bridge decks. Black rebar decks have been lasting approximately 10 years before a rating of 6 is achieved *(Figure 2-2)* as compared to ECR decks lasting approximately 26 years *(Figure 2-3)*. This is a 16 year increase, taking 2 ½ times longer to achieve a deck surface rating of a 6. Comparing them at a deck surface rating of 5; black rebar will reach in 24 years, ECR will reach in 47 years. An ECR bridge deck will take nearly double the time for the deck to reach a surface rating of 5. Based on these ratios an estimation of when an ECR bridge deck becomes poor can be developed. According to the deterioration curve black rebar bridge decks take approximately 35 years to become of poor condition. A ratio of two times seems appropriate as compared to the previous ratios. This results in a range of 70 years for an ECR bridge deck to become poor, as also demonstrated by the straight line extrapolation shown in figure 2-3.

3.2 Accuracy of Markov Transition Probabilities

The accuracy of Markov's transition probabilities was explored using different methods of calculating expected service life of black rebar bridge decks. The transition probabilities in conjunction with the deterioration curve estimates 35 years for a black rebar deck to reach poor condition. A separate data set was used in evaluating the age of black rebar decks before rehabilitation or reconstruction. The average age of deck before overlay was calculated to be 38 years. The deck preservation matrix implies that a deck should last 40+ years. The value received from the transition probabilities resides within this data range. Therefore; Markov transition probabilities are determined to be acceptable and fairly accurate in analyzing bridge deck data.

3.3 Errors and Uncertainties

3.3.1 Data Set

The data set used contained large amounts of faulty information. Most bridges that were built in 2000s happened to be reconstructed and these reconstructions contained deck surface ratings before the year they were built. These bridges were labeled as having ECR although the previous ratings, before the reconstruction, involved black rebar. All data containing this problem were assigned no values prior to their construction date; therefore the data prior would not be analyzed. Incorrect coding for deck protection was also found in the data set, these were eliminated. All of these discrepancies were mentioned previously in Section 2.1. This data set was filtered numerous times throughout this study to eliminate as much corrupt data as possible. It is acknowledged that this data may still contain small amounts of discrepancy but the majority has been eliminated.

3.3.2 Variables

There are many different variables that can affect the condition of each bridge deck. Variables may include: location, average daily traffic, concrete mix design, preventative treatments, and the inspector. Location can be the biggest concern as both temperature and precipitation have a huge affect on the condition of bridge decks. Average daily traffic (ADT) may also have an impact on the condition of a bridge deck. Concrete mix designs differ for each bridge deck and could possibly influence surface ratings. Preventative treatments are applied accordingly pending on the condition of each bridge deck. Different treatments deteriorate at different rates and should furthermore be evaluated individually. Deck surface ratings can be dependent on the inspector's discretion. Meaning that one inspector may rate the deck surface a 7, while another inspector evaluating the same deck may believe that it appears to be a 6. These are all variables that may affect the condition of a bridge deck surface rating. Within this analysis a large population of 766 ECR bridge decks was used in order to eliminate as much variability as possible.

Conclusion

The study has yielded the following conclusions:

- The service life of a black rebar bridge deck is estimated to be 35 years.
- The service life of an ECR bridge deck is estimated to be approximately 70 years.
- Markov transition probabilities are determined to be acceptable and fairly accurate in analyzing bridge deck data.

It is important to understand that time is the largest constraint when evaluating these transition probabilities. ECR bridge decks only date back to around 30 years ago and currently there are no decks containing ECR that have reached a poor rating, which in itself is a very positive demonstration of the performance of ECR bridge decks. With a larger population of bridges containing a fair to poor deck surface rating more analysis can be done with more accurate results. At this time the service life of ECR bridge decks can only be estimated until additional data is obtained for lower surface ratings.

Appendix

5.1 Memorandum

DESIGN DIVISION

INFORMATIONAL MEMORANDUM #277-B (Revised)

October 10, 1980

Subject: Epoxy Coated Rebars for Bridge Decks

The Engineering Operations Committee has approved using epoxy-coated rebars for the bottom mat for all bridge decks. Since only a few uncoated rebars would remain in the superstructure, we will call for epoxy-coating of all superstructure reinforcement.

All jobs let starting in December 1980 will conform to this directive.

Adrianus VanKampen
Engineer—Bridge Design

DD-LOC-AVK/jg

Figure 5-1: ECR Design Memorandum

5.2 Black Rebar Transition Probabilities & Deterioration Curves

Table 5-1 2004-2005 Black Rebar Transition Probability Matrix

Bridge Condition Change Matrix 2004-2005 Number

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	26	9								4	18	4
	122	8							1	24	97	
5	294	7							30	264		
30	305	6				1	4	11	289			
24	112	5				1	5	106				
28	40	4				1	39					
17	13	3				13						
		2			0							
		1		0								
5		0										
109	912											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0.153846	0.692308	0.153846
		8	0	0	0	0	0	0	0.008197	0.196721	0.795082	0.37031
		7	0	0	0	0	0	0	0.102041	0.897959	3.022751	
		6	0	0	0	0.003279	0.013115	0.036066	0.947541	6.440053	3.393061	
		5	0	0	0	0.008929	0.044643	0.946429	12.86343	9.833114		
		4	0	0	0	0.025	0.975	12.58899	22.69655			
		3	0	0	0	1	27.37785	35.28554				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	62.66339					
		1	#DIV/0!	#DIV/0!								

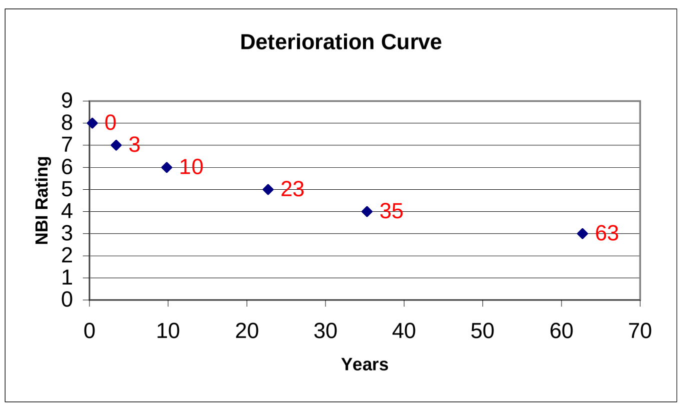

Figure 5-2: 2004-2005 Black Rebar Deterioration Curve

Table 5-2 2005-2006 Black Rebar Transition Probability Matrix

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
			Bridge Condition Change Matrix				2005-2006			Number		
0	22	9								1	2	19
	138	8						1	4	21	112	
3	322	7						1	29	292		
29	320	6					4	11	305			
15	107	5				2	4	101				
13	35	4				4	31					
8	8	3				8						
		2			0							
		1		0								
		0										
68	952											

Unrated			0	1	2	3	4	5	6	7	8	9
			Transition Probability Matrix							Percent		
		9	0	0	0	0	0	0	0	0.045455	0.090909	0.8636364
		8	0	0	0	0	0	0.007246	0.028986	0.152174	0.811594	4.7280406
		7	0	0	0	0	0	0.003106	0.090062	0.906832	3.320389	
		6	0	0	0	0	0.0125	0.034375	0.953125	7.087558	8.04843	
		5	0	0	0	0.018692	0.037383	0.943925	14.43779	15.13599		
		4	0	0	0	0.114286	0.885714	12.01122	29.57378			
		3	0	0	0	1	5.711456	41.585				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	47.29645					
		1	#DIV/0!	#DIV/0!								

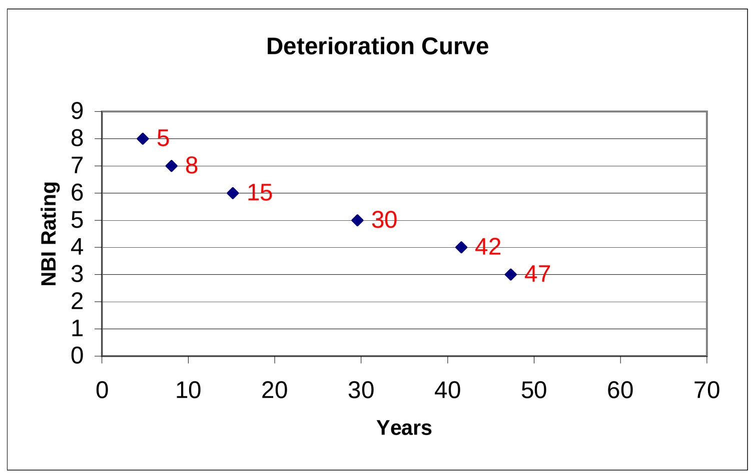

Figure 5-3: 2005-2006 Black Rebar Deterioration Curve

Table 5-3 2006-2007 Black Rebar Transition Probability Matrix

Bridge Condition Change Matrix 2006-2007 Number

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	33	9								2	20	11
	131	8							1	26	104	
4	336	7					1		23	312		
23	321	6				1	2	16	302			
18	98	5					6	92				
11	30	4					30					
4	10	3				10						
		2			0							
		1		0								
		0										
60	959											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0.060606	0.606061	0.333333
		8	0	0	0	0	0	0	0.007634	0.198473	0.793893	0.63093
		7	0	0	0	0	0.002976	0	0.068452	0.928571	3.003154	
		6	0	0	0	0.003115	0.006231	0.049844	0.94081	9.353207	3.634084	
		5	0	0	0	0	0.061224	0.938776	11.36044	12.98729		
		4	0	0	0	0	1	10.97118	24.34773			
		3	0	0	0	1	#DIV/0!	35.31891				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
		1	#DIV/0!	#DIV/0!								

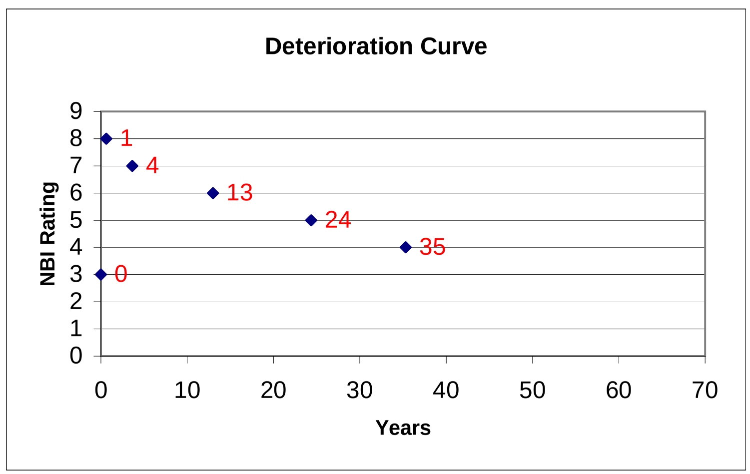

Figure 5-4: 2006-2007 Black Rebar Deterioration Curve

Table 5-4 2007-2008 Black Rebar Transition Probability Matrix

			Bridge Condition Change Matrix				2007-2008			Number		
Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	21	9								2	7	12
	140	8							2	10	128	
2	356	7					1	1	31	323		
25	316	6					3	8	305			
20	89	5				1	2	86				
3	36	4				1	35					
1	10	3				10						
		2			0							
		1		0								
		0										
51	968											

			Transition Probability Matrix							Percent		
Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0.095238	0.333333	0.5714286
		8	0	0	0	0	0	0	0.014286	0.071429	0.914286	1.2386126
		7	0	0	0	0	0.002809	0.002809	0.087079	0.907303	7.734968	
		6	0	0	0	0	0.009494	0.025316	0.96519	7.125396	8.973581	
		5	0	0	0	0.011236	0.022472	0.966292	19.56361	16.09898		
		4	0	0	0	0.027778	0.972222	20.21481	35.66258			
		3	0	0	0	1	24.6051	55.8774				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	80.48249					
		1	#DIV/0!	#DIV/0!								

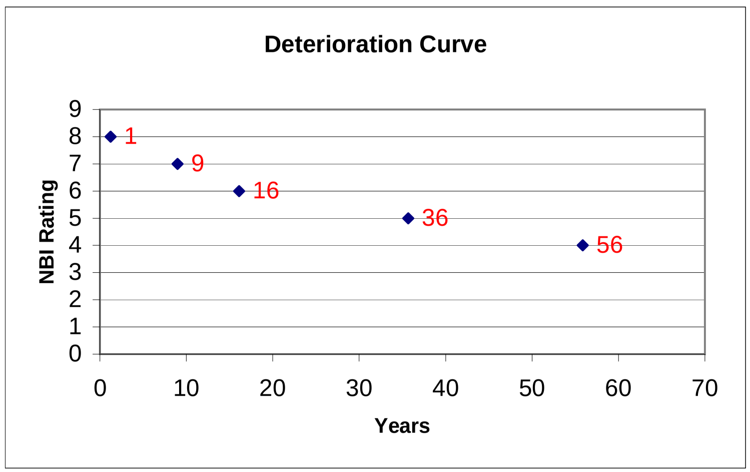

Figure 5-5: 2007-2008 Black Rebar Deterioration Curve

Table 5-5 2008-2009 Black Rebar Transition Probability Matrix

Bridge Condition Change Matrix 2008-2009 Number

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	14	9									11	3
	139	8							3	38	98	
3	364	7						1	46	317		
8	341	6					2	12	327			
10	86	5					5	81				
4	38	4					38					
3	9	3				9						
		2			0							
		1		0								
1		0										
29	991											

Transition Probability Matrix Percent

Unrated

	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0	0	0.785714	0.214286
8	0	0	0	0	0	0	0.021583	0.273381	0.705036	0.449966
7	0	0	0	0	0	0.002747	0.126374	0.870879	1.983217	
6	0	0	0	0	0.005865	0.035191	0.958944	5.013647	2.433183	
5	0	0	0	0	0.05814	0.94186	16.53409	7.44683		
4	0	0	0	0	1	11.5721	23.98092			
3	0	0	0	1	#DIV/0!	35.55302				
2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
1	#DIV/0!	#DIV/0!								

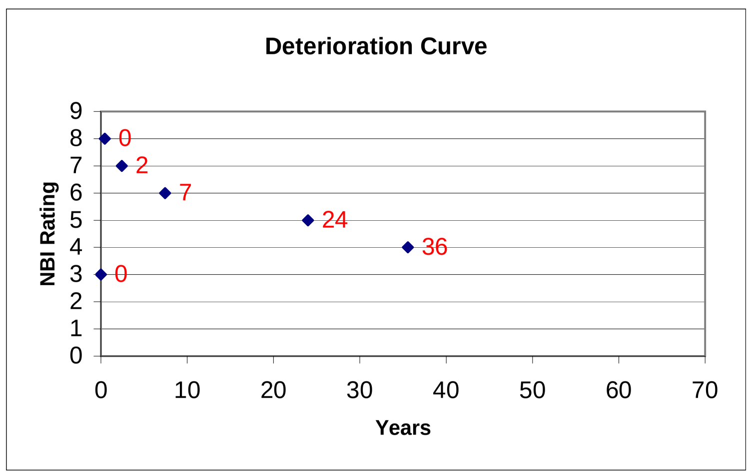

Figure 5-6: 2008-2009 Black Rebar Deterioration Curve

Table 5-6 2009-2010 Black Rebar Transition Probability Matrix

Bridge Condition Change Matrix 2009-2010 Number

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	6	9									4	2
	113	8							1	23	89	
5	360	7					1	5	35	319		
19	366	6					3	19	344			
12	83	5				1	7	75				
5	40	4				4	36					
4	6	3				6						
		2			0							
		1		0								
		0										
45	974											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0	0.666667	0.333333
		8	0	0	0	0	0	0	0.00885	0.20354	0.787611	0.63093
		7	0	0	0	0	0.002778	0.013889	0.097222	0.886111	2.903217	
		6	0	0	0	0	0.008197	0.051913	0.939891	5.732614	3.534146	
		5	0	0	0	0.012048	0.084337	0.903614	11.18129	9.266761		
		4	0	0	0	0.1	0.9	6.838975	20.44806			
		3	0	0	0	1	6.578813	27.28703				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	33.86584					
		1	#DIV/0!	#DIV/0!								

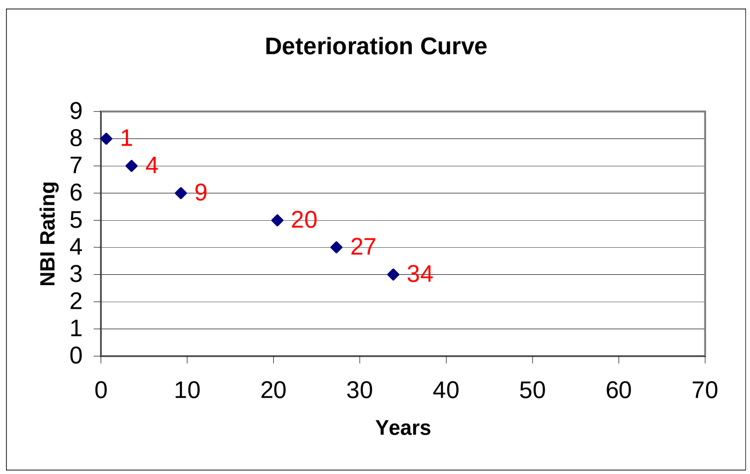

Figure 5-7: 2009-2010 Black Rebar Deterioration Curve

5.3 Epoxy Coated Rebar Transition Probabilities & Deterioration Curves

Table 5-7 2004-2005 Epoxy Coated Rebar Transition Probability Matrix

Bridge Condition Change Matrix 2004-2005 Number

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	93	9							1	18	44	30
4	270	8							2	43	225	
15	234	7							7	227		
13	47	6							47			
1	2	5						2				
		4					0					
		3				0						
		2			0							
		1		0								
6		0										
39	646											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0.010753	0.193548	0.473118	0.322581
		8	0	0	0	0	0	0	0.007407	0.159259	0.833333	0.612644
		7	0	0	0	0	0	0	0.029915	0.970085	3.801784	
		6	0	0	0	0	0	0	1	22.82259	4.414428	
		5	0	0	0	0	0	1	#DIV/0!	27.23702		
		4	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!			
		3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
		1	#DIV/0!	#DIV/0!								

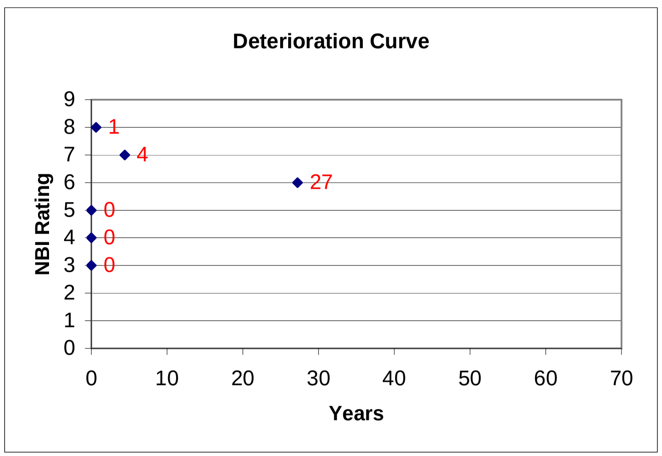

Figure 5-8: 2004-2005 Epoxy Coated Rebar Deterioration Curve

Table 5-8 2005-2006 Epoxy Coated Rebar Transition Probability Matrix

Bridge Condition Change Matrix 2005-2006 Number

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	49	9								4	18	27
2	292	8							1	54	237	
6	295	7							11	284		
5	53	6						2	51			
	3	5						3				
		4					0					
		3				0						
		2			0							
		1		0								
2		0										
15	692											

Transition Probability Matrix Percent

Unrated		0	1	2	3	4	5	6	7	8	9
	9	0	0	0	0	0	0	0	0.081633	0.367347	0.55102
	8	0	0	0	0	0	0	0.003425	0.184932	0.811644	1.163031
	7	0	0	0	0	0	0	0.037288	0.962712	3.321362	
	6	0	0	0	0	0	0.037736	0.962264	18.24018	4.484393	
	5	0	0	0	0	0	1	18.0196	22.72457		
	4	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	40.74418			
	3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
	2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
	1	#DIV/0!	#DIV/0!								

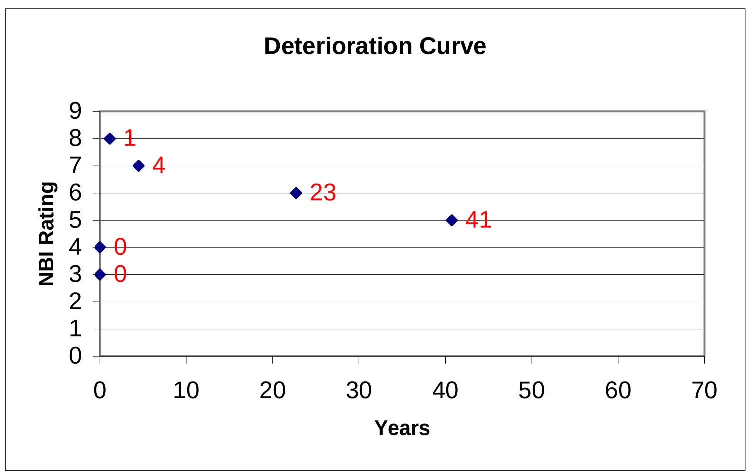

Figure 5-9: 2005-2006 Epoxy Coated Rebar Deterioration Curve

Table 5-9 2006-2007 Epoxy Coated Rebar Transition Probability Matrix

Bridge Condition Change Matrix 2006-2007 Number

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	37	9								1	19	17
1	269	8								56	213	
3	344	7							8	336		
2	61	6							61			
1	4	5						4				
		4					0					
		3				0						
		2			0							
		1		0								
		0										
7	715											

Transition Probability Matrix Percent

Unrated		0	1	2	3	4	5	6	7	8	9
	9	0	0	0	0	0	0	0	0.027027	0.513514	0.459459
	8	0	0	0	0	0	0	0	0.208178	0.791822	0.891273
	7	0	0	0	0	0	0	0.023256	0.976744	2.969538	
	6	0	0	0	0	0	0	1	29.4574	3.860811	
	5	0	0	0	0	0	1	#DIV/0!	33.31821		
	4	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!			
	3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
	2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
	1	#DIV/0!	#DIV/0!								

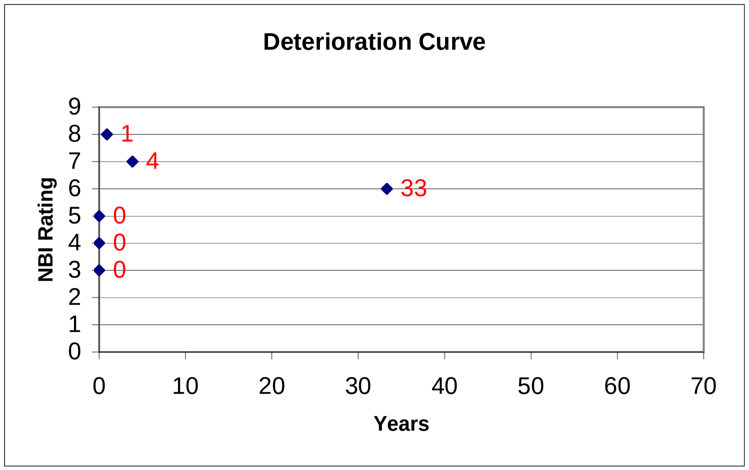

Figure 5-10: 2007-2008 Epoxy Coated Rebar Deterioration Curve

Table 5-10 2007-2008 Epoxy Coated Rebar Transition Probability Matrix

Bridge Condition Change Matrix 2007-2008 Number

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	28	9									13	15
3	237	8								16	221	
14	380	7							14	366		
4	66	6							66			
	4	5						4				
		4					0					
		3				0						
		2			0							
		1		0								
		0										
21	715											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0	0.464286	0.535714
		8	0	0	0	0	0	0	0	0.067511	0.932489	1.110538
		7	0	0	0	0	0	0	0.036842	0.963158	9.916632	
		6	0	0	0	0	0	0	1	18.46525	11.02717	
		5	0	0	0	0	0	1	#DIV/0!	29.49242		
		4	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!			
		3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
		1	#DIV/0!	#DIV/0!								

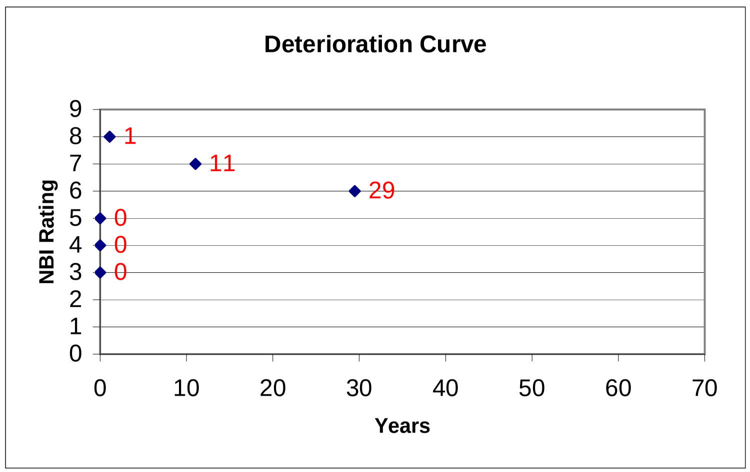

Figure 5-11: 2007-2008 Epoxy Coated Rebar Deterioration Curve

Table 5-11 2008-2009 Epoxy Coated Rebar Transition Probability Matrix

Bridge Condition Change Matrix 2008-2009 Number

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	21	9									12	9
3	253	8							1	45	207	
3	383	7						1	13	369		
4	76	6						2	74			
1	3	5						3				
		4					0					
		3				0						
		2			0							
		1		0								
		0										
11	736											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0	0.571429	0.428571
		8	0	0	0	0	0	0	0.003953	0.177866	0.818182	0.818068
		7	0	0	0	0	0	0.002611	0.033943	0.963446	3.454152	
		6	0	0	0	0	0	0.026316	0.973684	18.6138	4.27222	
		5	0	0	0	0	0	1	25.99148	22.88602		
		4	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	48.8775			
		3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
		1	#DIV/0!	#DIV/0!								

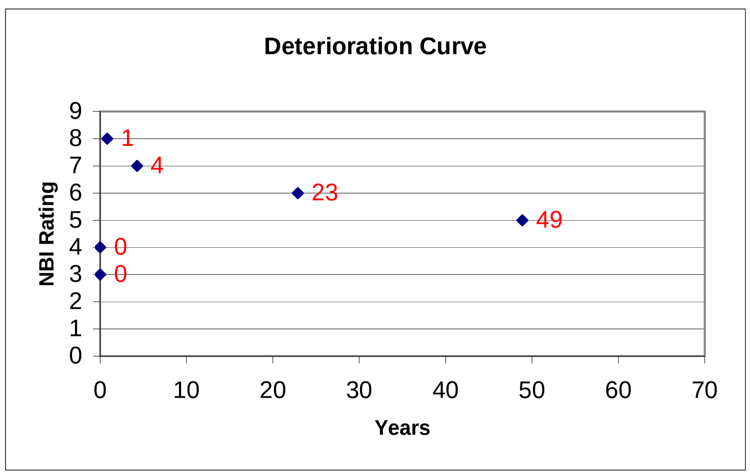

Figure 5-12: 2008-2009 Epoxy Coated Rebar Deterioration Curve

Table 5-12 2009-2010 Epoxy Coated Rebar Transition Probability Matrix

Bridge Condition Change Matrix 2009-2010 Number

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	16	9								2	8	6
2	221	8							6	43	172	
2	416	7							11	405		
12	76	6							76			
1	5	5						5				
		4					0					
		3				0						
		2			0							
		1		0								
		0										
17	734											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0.125	0.5	0.375
		8	0	0	0	0	0	0	0.027149	0.19457	0.778281	0.706695
		7	0	0	0	0	0	0	0.026442	0.973558	2.765198	
		6	0	0	0	0	0	0	1	25.86544	3.471893	
		5	0	0	0	0	0	1	#DIV/0!	29.33734		
		4	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!			
		3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
		1	#DIV/0!	#DIV/0!								

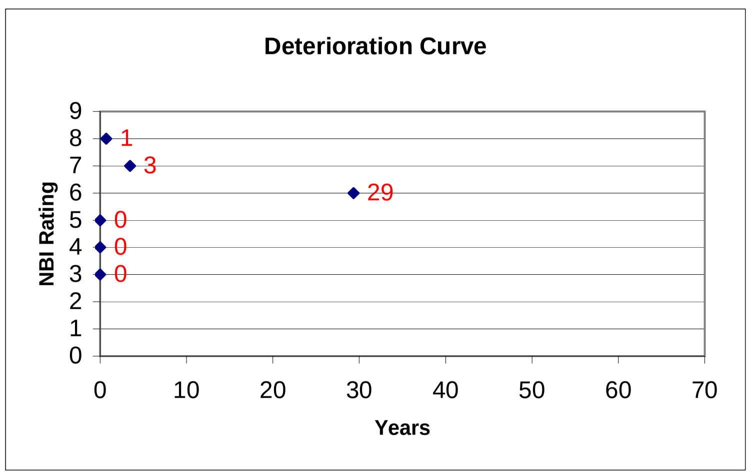

Figure 5-13: 2009-2010 Epoxy Coated Rebar Deterioration Curve

5.4 Preservation Matrix

BRIDGE DECK PRESERVATION MATRIX

DECK CONDITION STATE				REPAIR OPTIONS	POTENTIAL RESULT TO DECK BSIR		NEXT ANTICIPATED EVALUATION
Top Surface		Bottom Surface					
BSIR #58a	Deficiencies % (a)	BSIR #58b	Deficiencies % (b)		Top Surface BSIR #58a	Bottom Surface BSIR #58b	
≥ 5	N/A	N/A	N/A	Hold (c) Seal Cracks/Healer Sealer (d)	No Change	No Change	1 to 8 years
	≤ 5%	> 5	≤ 2%	Epoxy Overlay	8, 9	No Change	10 to 15 years
	≤ 10%	≥ 4	≤ 25%	Deck Patch (e)	Up by 1 pt.	No Change	3 to 10 years
4 or 5	10% to 25%	5 or 6	≤ 10%	Deep Concrete Overlay (h)	8, 9	No Change	25 to 30 years
		4	10% to 25%	Shallow Concrete Overlay (h, i)	8, 9	No Change	10 to 15 years
				HMA Overlay with water-proofing membrane (f, h, i)	8, 9	No Change	8 to 10 years
		2 or 3	> 25%	HMA Cap (g, h, i)	8, 9	No Change	2 to 4 years
≤ 3	>25%	> 5	< 2%	Deep Concrete Overlay (h)	8, 9	No Change	20 to 25 years
		4 or 5	2% to 25%	Shallow Concrete Overlay (h, i)	8, 9	No Change	10 years
				HMA Overlay with water-proofing membrane (f, h, i)	8, 9	No Change	5 to 7 years
		2 or 3	>25%	HMA Cap (g, h, i)	8, 9	No Change	1 to 3 years
				Replace Deck	9	9	40+ years

(a) Percent of deck surface area that is spalled, delaminated, or patched with temporary patch material.
(b) Percent of deck underside area that is spalled, delaminated or map cracked.
(c) The "Hold" option implies that there is on-going maintenance of filling potholes with cold patch and scaling of incipient spalls.
(d) Seal cracks when cracks are easily visible and minimal map cracking. Apply healer sealer when crack density is too great to seal individually by hand. Sustains the current condition longer.
(e) Crack sealing can also be used to seal the perimeter of deck patches.
(f) Hot Mix Asphalt overlay with waterproofing membrane. Deck patching required prior to placement of waterproofing membrane.
(g) Hot Mix Asphalt cap without waterproofing membrane for ride quality improvement. Deck should be scheduled for replacement in the 5 year plan.
(h) If bridge crosses over traveled lanes and the deck contains slag aggregate, do deck replacement.
(i) When deck bottom surface is rated poor (or worse) and may have loose or delaminated concrete over traveled lanes, an in-depth inspection should be scheduled. Any loose or delaminated concrete should be scaled off and false decking should be placed over traveled lanes where there is potential for additional concrete to become loose.

Bridge Deck Preservation Matrix March 12, 2008 Rev.

Figure 5-14: Bridge Deck Preservation Matrix

References

[1] Hyde, Charles K. *Historic Highway Bridges of Michigan.* Detroit, MI: Wayne State University Press, 1993. Print.

[2] Arnold, C. J. and McCrum, R.L. *Evaluation of Simulated Bridge Deck Slabs Using Uncoated, Glavanized, and Epoxy Coated Reinforcing Steel.* Lansing, MI: Michigan Department of Transportation, 1993. Print.

[3] Devaraj, Dinesh, and Fu, Gongkang. *Methodology of Homogeneous and Non-Homogeneous Markov Chains for Modeling Bridge Element Deterioration.* Detroit, MI: Wayne State University Press, 1998. Print

[4] Juntunen, Dave. *BMS: Domestic Scan on Bridge Management.* Lansing, MI: Michigan Department of Transportation, 19 Nov 2009. Powerpoint.