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BRIDGE ELEMENT DETERIORATION RATES

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EXECUTIVE SUMMARY

The objective of this research project has been to carry out an extensive filtering / reconditioning of inspection data, identify methods to calculate deterioration rates for bridge elements and develop a computer program to calculate deterioration rates for bridge elements. Several filters have been developed and implemented to remove inspection data affected by rehabilitation, inspector subjectivity, sudden drop in ratings because of vehicle/vessel collision, and miscoding of inspection rating. In addition to filters described above, reconditioning algorithms have been developed to remove erroneous data because of reconstruction of bridge elements before the inspection data became available starting in 1981. The filtered inspection data show predominantly deteriorating behavior representing actual deterioration process. In order to investigate effects of numerous factors, e.g., AADTT, climate, DOT regions, ownership, design types, etc., on the deterioration rates, a versatile cascading approach has been developed to classify bridge elements on the basis of selected factors. The cascading approach generates classes of bridges based on the classification factors selected. These classes can be analyzed to calculate deterioration rates. A computer program has been developed to calculate deterioration rates by Markov Chain and Weibull-based approaches. The computer program uses an updateable inspection database and generates quadratic equations of desired orders for deterioration rates. A detailed case study has been carried out to compare Markov chain and Weibull-based approaches for deterioration rates. Since the Weibull-based method utilizes actual scatter in duration data for a particular rating and considers this duration as a random variable, it has been found to be more reliable for calculating deterioration rates for bridge elements. Hence, deterioration curves and equations using the Weibull-based method have been generated and are presented for use.

STATEMENT ON IMPLEMENTATION

The main outcome of this project is a computer program for the calculation of deterioration rates. The computer program generates deterioration curves in the form of condition ratings versus age in terms of polynomial equations of desired orders. These equations can be fed into the bridge management system such as “PONTIS” by the NYSDOT for effective management of bridge maintenance, inspection and rehabilitation. The inspection database used by the computer program is updatable with the new inspection data as they become available. Hence, the outcome of the project will be implemented immediately by the NYSDOT and will continue to be used for many years in future.

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16. Abstract This report describes the development of bridge element deterioration rates using the NYSDOT bridge inspection database using Markov chains and Weibull-based approaches. It is observed that Weibull-based approach is more reliable for developing bridge deterioration curves. Both Markov chains and Weibull-based approaches have been incorporated into a computer program that generates deterioration curves for specific bridge elements, based on historical NYSDOT bridge inspection data going back to 1981. A computer program has been developed to generate deterioration curves and equations for bridge elements in New York State.			
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TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION	1
1.1 Background.....	1
1.2 State-of-the-art on determination of bridge deterioration rates.....	3
1.3 Bridge Elements Analyzed	5
1.4 Grouping of Inspection Data within an Element.....	5
CHAPTER TWO: DATA FILTERING	15
2.1 Introduction.....	15
2.2 Filtering of Inspection Data.....	15
2.3 Element Specific Data Reconditioning	18
2.4 Impact of Data Reconditioning.....	20
CHAPTER THREE: BRIDGE ELEMENT CLASSIFICATION	22
3.1 Introduction.....	22
3.2 Classification Factors	22
CHAPTER FOUR: METHODS FOR DETERIORATION RATES CALCULATIONS	33
4.1. Introduction.....	33
4.2. Markov Chains Approach.....	33
4.3. Weibull-Distribution Based Approach	36
4.4. Computer Program for Deterioration Rates Calculations	38
4.5. Computer Program Interface	39
4.6. Computer Program Manual	41
4.7. Comparisons between Markov Chain and Weibull-Based Approaches	55
4.8. Deterioration Curves and Rates for Typical Bridge Elements Using Weibull- Based Approach.....	60
CONCLUSIONS	83
REFERENCES	84
APPENDIX A: K-MEAN CLUSTERING ALGORITHM	86
APPENDIX B: UPDATING THE DATABASE	87
APPENDIX C: UNINSTALLING THE COMPUTER PROGRAM	94

LIST OF TABLES

Table 1-1: Condition Ratings for Bridge Elements in New York State	2
Table 1-2: Bridges Elements Considered for Calculating Deterioration Rates	5
Table 1-3: Bridges Inventory Database Tables Corresponding to Different Bridge Elements	6
Table 1-4: Element Grouping for Abutment Wingwall	6
Table 1-5: Element Grouping for Abutment Bearing	6
Table 1-6: Element Grouping for Abutment Joint	7
Table 1-7: Element Grouping for Pier Bearing	7
Table 1-8: Element Grouping for Pier Pedestal.	7
Table 1-9: Element Grouping for Pier Cap Top	8
Table 1-10: Element Grouping for Pier Cap	8
Table 1-11: Element Grouping for Pier Column	8
Table 1-12: Element Grouping for Pier Recommendation	8
Table 1-13: Element Grouping for Pier Joint	9
Table 1-14: Element Grouping for Primary Member	9
Table 1-15: Element Grouping for Secondary Member	10
Table 1-16: Element Grouping for Deck Curbs	10
Table 1-17: Element Grouping for Superstructure Recommendation	11
Table 1-18: Element Grouping for Side Walk or Fascia	11
Table 1-19: Element Grouping for Structural Deck	12
Table 1-20: Element Grouping for Wearing Surface	12
Table 1-21: Element Grouping for Superstructure Design Type	13
Table 1-22: Element Grouping for Material Type 1	13
Table 1-23: Element Grouping for Material Type 2	14
Table 3-1: Ownership Type Classification Based on Primary Ownership	23
Table 3-2: Sample Climate Data	25
Table 3-3: Climate Data Membership Count in 5 Clusters	27
Table 3-4: Classification and number of Bridges based on AADTT	28
Table 3-5: Classification and number of Bridges based on Functional Class Carried	28
Table 3-6: Three Cluster Centers (Average) For Snow Accumulation in Inches	29
Table 3-7: Membership of Counties in Snow Clusters	29
Table 3-8: Bridge Distribution Across Salt Usage Classes	30
Table 3-9: Membership of Counties in Salt Clusters	30
Table 3-10: Classification based on Original Wearing Surface	30
Table 4-1: Deterioration Equation for Abutment Backwall.	60
Table 4-2: Deterioration Equations for Abutment Bearing Design Types	61
Table 4-3: Deterioration Equations for Abutment Joint Design Types	62
Table 4-4: Deterioration Equations for Abutment Pedestal	63
Table 4-5: Deterioration Equations for Abutment Stem	64
Table 4-6: Deterioration Equations for Abutment Wingwall	65
Table 4-7: Deterioration Equations for Deck Curb Design Types	66
Table 4-8: Deterioration Equations for Pier Bearing Design Types	67

Table 4-9: Deterioration Equations for Pier Cap Design Types	68
Table 4-10: Deterioration Equations for Pier Cap Top Design Types	69
Table 4-11: Deterioration Equations for Pier Column Design Types	70
Table 4-12: Deterioration Equation for Pier Footing	71
Table 4-13: Deterioration Equations for Pier Joint Design Types	72
Table 4-14: Deterioration Equations for Pier Pedestal Design Types	73
Table 4-15: Deterioration Equations for Pier Recommendation Design Types	74
Table 4-16: Deterioration Equation for Pier Stem	75
Table 4-17: Deterioration Equations for Primary Member Design Types	77
Table 4-18: Deterioration Equations for Secondary Member Design Types	79
Table 4-19: Deterioration Equations for Sidewalk Fascia Design Types	79
Table 4-20: Deterioration Equations for Structural Deck Design Types	80
Table 4-21: Deterioration Equations for Superstructure Recommendation Design Types	81
Table 4-22: Deterioration Equations for Wearing Surface Design Types	82

LIST OF FIGURES

Figure 2-1: Histogram of Structural Deck Rating for Bridges of 70 years Age.	18
Figure 2-2: Average Duration at Rating 5, 6, and 7 Versus Maximum Number of Years in the filtering logic	18
Figure 2-3: Deterioration Curve for Structural Deck using Raw Data (without significant filtering/reconditioning)	21
Figure 2-4: Deterioration Curves for Structural Decks Using Filtered/Reconditioned Data	21
Figure 3-1: Map Showing NYSDOT Regions	23
Figure 3-2: New York State Climate Divisions defined by NOAA.	24
Figure 3-3: Climate NOAA region membership classified into 5 clusters	26
Figure 3-4: Bridge distribution in the 10 NOAA regions.	27
Figure 3-5: Screening for Element Selection and Cascading Classification	31
Figure 3-6: Cascading Classification Showing Number of Bridges Under Each Classification	32
Figure 4-1: Comparison between deterioration rate curves using first and second level Markov Chains processes.	36
Figure 4-2: Frequency Distribution of Durations for Different Condition Ratings	37
Figure 4-3: Screenshot of the Computer Program Showing Interfaces	40
Figure 4-4: Classification Workspace Interface.	41
Figure 4-5: Classification Workspace Showing Results of Classification	42
Figure 4-6: Class View Showing Selected Classes.	43
Figure 4-7: Class Analysis Workspace Window.	44
Figure 4-8: Markov Chain Plot Showing Comparisons Between Original and Fitted Data.	45
Figure 4-9: Compare Class Window.	46
Figure 4-10: Matlab Plot Showing Comparisons Between Two Classes.	46
Figure 4-11: Polynomial Fitting Window.	47
Figure 4-12: Plot Showing Polynomial Fit to Markov Chains Curve	48
Figure 4-13: Weibull Analysis View.	49
Figure 4-14: Matlab Plots Weibull Based Deterioration Curves.	50
Figure 4-15: Plot Showing Weibull Probability Distributions.	51
Figure 4-16: Curve Fitting of Weibull-Based Deterioration Curve Using Bleasdale Equation	52
Figure 4-17: Comparison Between Weibull-Based Deterioration Curves for Two Classes.	53
Figure 4-18: “More” View Window.	54
Figure 4-19: Element View Window Showing Element Ratings.	55
Figure 4-20: Deterioration plots for plate girders made of steel and weathering steel in bridges owned by NYSDOT	56
Figure 4-21: Deterioration plots for structural decks with coated and uncoated rebars in bridges owned by NYSDOT.	57
Figure 4-22: Deterioration plots for structural decks with uncoated rebars.	58
Figure 4-23: Deterioration plots for concrete pier caps in bridges owned by NYSDOT.	58

Figure 4-24: Deterioration plots of Elastomeric Abutment Bearings in Bridges Owned by NYSDOT.	59
Figure 4-25: Deterioration plots for Abutment Joints with Elastic (Filled) and compression materials	59
Figure 4-26: Deterioration curve for Abutment Backwall	60
Figure 4-27: Deterioration curve for Abutment Bearing Design Types	61
Figure 4-28: Deterioration curve for Abutment Joint Design Types	62
Figure 4-29: Deterioration curve for Abutment Pedestal	63
Figure 4-30: Deterioration curve for Abutment Stem	64
Figure 4-31: Deterioration curve for Abutment Wingwall	65
Figure 4-32: Deterioration curve for Deck Curb Design Types.	66
Figure 4-33: Deterioration curve for Pier Bearing Design Types	67
Figure 4-34: Deterioration curve for Pier Cap Design Types	68
Figure 4-35: Deterioration curve for Pier Cap Top Design Types	69
Figure 4-36: Deterioration curve for Pier Column Design Types	70
Figure 4-37: Deterioration curve for Pier Footing.	71
Figure 4-38: Deterioration curve for Pier Joint Design Types	72
Figure 4-39: Deterioration curve for Pier Pedestal Design Types	73
Figure 4-40: Deterioration curve for Pier Recommendation Design Types	74
Figure 4-41: Deterioration curve for Pier Stem	75
Figure 4-42: Deterioration curves for Primary Member Design Types	76
Figure 4-43: Deterioration curves for Secondary Member Design Types	78
Figure 4-44: Deterioration curves for Sidewalk Fascia Design Types	79
Figure 4-45: Deterioration curves for Structural Deck Design Types	80
Figure 4-46: Deterioration curves for Superstructure Recommendation Design Types	81
Figure 4-47: Deterioration curves for Wearing Surface Design Types	82

CHAPTER ONE: INTRODUCTION

1.1 Background

The deterioration of bridge elements occurs because of the combined effects of several complex phenomena, e.g., reinforcement corrosion, concrete degradation, creep, shrinkage, cracking and fatigue, etc. In the absence of a mechanistic based deterioration model that requires quantitative contribution of these complex phenomena based on environmental effects and maintenance constraints, bridge inspection data are used to determine the need of rehabilitation or replacement and prioritize the order of work. The condition assessment of the bridge infrastructure of New York State (NYS) is crucial in preparing five and ten-year capital programs for the construction and maintenance of bridges to ensure their serviceability and safety.

Currently, more than 31% of bridges in the United States are considered deficient [Better Roads, Nov. 1997]. In recognition of this state of the national bridge infrastructure, congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991 mandating bridge management system (BMS) as part of activities of all state departments of transportation. Hence, the bridge management program package, PONTIS, sponsored by the Federal Highway Administration (FHWA), was developed in 1992 under the guidance of a task force of AASHTO and adopted by several states [Thompson et al (1998)]. Another software package, BRIDGIT, was developed in 1997 for smaller DOTs having insufficient staffs to maintain a BMS [Hawk and Small (1998)]. Both these packages have in-built capabilities of calculating bridge deterioration rates using Markov Chains Model to predict the probability of transition from one condition state (rating) to another condition state. However, a number of states, including New York, Pennsylvania and Indiana, developed their own BMS. This project is focused on element level deterioration versus overall bridge deterioration curves. Without an effective system to determine deterioration rates, maintenance, repair and rehabilitation (MR&R) decisions for aging bridges will be seriously hampered. The objectives of this project have been to develop a computer program to calculate bridge element deterioration rates for typical bridge elements. This objective is achieved through pre-processing of NYS Bridge Inspection Database to remove erroneous or incompatible data, classify data according to geographical area, NYSDOT Regions, bridge/design types, etc., and develop a computer program to calculate deterioration rates.

In the United States, condition ratings¹ are used for standardized reporting of visual inspections of bridges. The *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* provides instructions for coding of condition rating for bridge superstructures [U.S. DOT (1995)]. New York State Department of Transportation bridge inspection manual provides guidelines for inspection and condition rating of bridges in New York State [NYSDOT (1997)]. The New York State Department's ratings use ordinal, integer-values scales that indicate relative health of bridge elements, but do not identify specific type of deterioration. Rather, they are correlated with general condition of bridge elements and nonspecific maintenance functions. NYS system rates bridge elements on a scale of 1 (failed) to 7 (new) with 5 defining a state "functioning as originally designed" and 3 defining a state "not functioning as designed"; even numbers 6, 4 and 2 denote intermediate conditions to shade between 7 and 5, 5 and 3, and 3 and 1, respectively. In addition to this, ratings 8 and 9 are

¹ Inspection ratings are called condition ratings.

assigned to cases “not applicable” and “condition and/or existence unknown”. Table 1 shows the definition of condition ratings [NYSDOT (1997)]. The overall Bridge Condition rating is computed by weighted average of the integer element condition ratings and is a function of selected weights. The selection of appropriate weights is driven by sound engineering reasons, such as the importance of primary members and decks to the overall structural integrity of the bridge. In accordance with New York State and Federal regulations [NYSDOT (1997)], components in all spans of the bridge are inspected at least once every two years.

Table 1-1: Condition Ratings for Bridge Elements in New York State.

Rating	Description
9	Condition and/or Existing Unknown
8	Not Applicable
7	New Condition, No deterioration
6	Used to shade between ratings of 5 and 7
5	Minor deterioration, but functioning as originally designed
4	Used to shade between ratings of 3 and 5
3	Serious deterioration, or not functioning as originally designed
2	Used to shade between ratings of 1 and 3.
1	Totally deteriorated, or in failed condition.

The bridge inspection program at the New York State Department of Transportation started in 1981. The New York State Department of Transportation (NYSDOT) maintains an inventory of over 17,000 highway bridges across the state. These bridges are inspected biennially, or more often as necessary. For each span of a bridge, an inspection will rate up to 25 components per span, in addition to the general components common to all bridges. Using the inspection data collected since 1981, deterioration models can be developed to estimate deterioration rates. The historical bridge inspection data can also be used to develop models that can predict future bridge conditions and life-cycle predictions for long-term planning of MR&R activities. The deterioration models using historical bridge inspection data can be linked to explanatory variables, such as age, traffic, and weather, to assess impact of these factors on element, component and overall bridge deterioration rates. For a network of bridges, deterioration rates and the mean service life reveal the performance of elements, and the durability of protections and maintenance actions. These models can be updated and re-calibrated with the availability of new inspection data. Development, updating and re-calibration of deterioration models are essential for any effective BMS.

Specific objectives of this project have been to:

- (i) Develop criteria to filter out erroneous or incompatible inspection data, classify filtered data according to climate and/or geographical location, DOT regions, bridge ownership, material types, design and bridge types, etc., and develop algorithms to calculate deterioration rates for classified bridge elements, major structural components and the overall bridge system.
- (ii) Develop a fully automated computer program based on Windows environment for determining the deterioration rates of individual bridge elements, major structural components and the overall bridge.

The obvious benefits of this research are the availability of new and continuously updatable deterioration rate curves for the New York State Bridge Management System (BMS). The

deterioration curve, i.e., condition ratings as a function of time are output in the form of equations, and in spreadsheet form. These equations can be input into a BMS system, such as Pontis, for effective bridge management operations.

1.2 State-of-the-art on determination of bridge deterioration rates

Bridge management systems (BMS) have been developed to help optimize maintenance, rehabilitation, and replacement (MR&R) decisions for bridge networks under financial constraints. The quality of these decisions depends, to a great extent, on the ability to predict the future condition of bridges. This is why AASHTO has prescribed a bridge-deterioration model as one of the minimum requirements of any BMS [e.g., AASHTO (1993)]. By definition, “a facility deterioration model links a measure of facility condition to a vector of explanatory variables” [Ben-Akiva and Gopinath (1995)]. Explanatory variables, such as age, traffic, and weather, are defined as factors that affect facility deterioration and can be observed or measured. Several models have been developed since the early 1970s to assist decision-makers in predicting the future condition of a network of facilities (particularly pavement), and consequently, optimizing the allocation of scarce resources on MR&R needs. These models can be grouped into three categories that are not mutually exclusive: deterministic models, stochastic models, and artificial intelligence models.

Deterministic models [Veshosky et al (1994), Yanev (1996, 1997, 1998), Yanev and Chen (1993), Sanders and Zhang (1994), Jiang and Sinha (1989)] describe the relationship between factors affecting facility deterioration (e.g., bridge age) and the condition using a simple statistical calculations, such as mean, standard deviation, regression, etc. These models calculate the predicted conditions deterministically by ignoring the random error prediction and have several limitations, e.g., (i) they neglect the uncertainty due to inherent stochasticity of infrastructure deterioration and the existence of unobserved explanatory variables [e.g., Jiang and Sinha (1989), Madanat et al (1995)], (ii) they predict the average condition of a family of facilities regardless of the current condition and the condition history of individual facilities [Shahin et al (1987), Jiang and Sinha (1989)], (iii) they estimate facility deterioration for the “no maintenance” strategy only because of the difficulty of estimating the impacts of various maintenance strategies [Sanders and Zhang (1994)], (iv) they disregard the interaction between deterioration of components such as bridge deck and deck joints [Sianipar and Adams (1997)], and (v) they are difficult to update when new data is obtained (unless entire exercise of calculating deterioration rates is repeated).

Stochastic models treat the facility deterioration process as one or more random variables that capture the uncertainty and randomness of this process. These models can be classified either as discrete-time, state-based or discrete-time, time-based models [Mauch and Madanat (2001)]. In discrete-time, state-based models, such as Markov chains, the deterioration process is modeled through a probability of transition from one condition state to another in a discrete time, given that the deterioration process is dependent on a set of explanatory variables such as AADT, climate, age, etc. Markovian models have been used extensively in modeling the deterioration rates of infrastructure facilities, e.g., pavement prediction model [Butt et al (1987)], storm water pipe deterioration [Micevski et al (2002)], bridge types and components [Jiang et al (1988), Cesare et al. (1992)]. These models use the Markov decision process that is based on the concept of defining states of facility condition transition from one state to another during one transition period [Jiang et al (1988), Jiang and Sinha (1989)]. Chase and Gaspar (2000) investigated load capacity of highway bridges with age using Markovian Decision Process. They

have done this by first determining the relationship between bridge condition rating and load rating through linear regression (nonlinear regression could be used if data fits better), determining the relationship between bridge deterioration and age using Markovian process and then combining the two to get a relationship between bridge load rating to age. Their study is based on 409,741 bridges in the NBI database and the Hungarian Bridge Databank. Although Markovian models have addressed two problems in deterministic models by capturing the uncertainty of the deterioration process and accounting for the current facility condition in predicting the future one, they still suffer from the following limitations: (i) they assume discrete transition time intervals, constant bridge population, and stationary transition probabilities, which are sometimes impractical [Collins (1972)], (ii) Markovian models currently implemented in advanced BMS such as Pontis and BRIDGIT use the first-order Markovian Decision Process that assumes state independence for simplicity [DeStefano and Grivas (1998)], i.e., the future facility condition depends only on the current facility condition and not on the facility condition history, which is unrealistic [Madanat et al (1997)]; (iii) transition probabilities assume that the condition of a facility can either stay the same or decline so that the difficulty of estimating transition probabilities for facilities where treatment actions are performed is avoided [Madanat and Ibrahim (1995)]; (iv) Markovian models cannot efficiently consider the interactive effects between deterioration mechanisms of different bridge components [Sianipar and Adams (1997)], and transition probabilities require updates when new data are obtained.

Despite several limitations of the Markov process described above, it is the most widely used approach. Statistical appropriateness of Markovian process for bridge deterioration modeling has been shown in Madanat and Ibrahim (1995). The most commonly used approach for the estimation of transition probabilities is the linear regression method [Carnahan et al. (1987), Jiang et al. (1988)]. This method starts by segmenting infrastructure facilities into groups of homogeneous explanatory variables to capture the fact that transition probabilities are functions of these variables. Subsequently, for each group, a deterioration model with the condition state as the dependent variable and age as the independent variable is estimated by linear regression. Finally, a transition probabilities matrix is estimated for each group by minimizing the sum of absolute (or squared) difference between the expected value of the condition state predicted by the regression model and the theoretical value derived from the Markov transition probabilities [e.g., Carnahan et al (1987), Jiang et al (1988)]. However, the linear regression based approach fails to capture the deterioration process because the change in condition within an inspection period is not explicitly modeled, segmentation into age groups results in a small sample size within each group of classified data, and element condition ratings are discrete in nature. Madanat and Ibrahim (1995) proposed a solution to these problems by calculating transition probabilities by Poisson regression model or negative binomial model. In discrete-time, time-based models, the duration that a bridge element remains at a particular state (condition rating) is modeled as a random variable using Weibull-based probability density functions to characterize the deterioration process, given its dependence on the same set of explanatory variables described above [Mishalani and Madanat (2002), DeLisle et al (2004)].

In order to model deterioration behavior of structures more realistically, several researchers have proposed to combine probabilistic models (e., Markov chain approach) and mechanistic models (e.g., corrosion induced deterioration model) [Lounis and Madanat (2002), Roelfstra et al. (2004) and Morcouc and Lounis (2007)]. Artificial intelligence (AI) models exploit computer techniques that aim to automate intelligent behaviors. AI techniques comprise expert systems, artificial neural networks (ANN) [Sobanjo (1997), Tokdemir et al (2000)], case-based reasoning

(CBR) [Morcoux et al. (2000, 2002)].

For the calculation of deterioration rates using the NYSDOT inspection data, the authors have carried out an extensive investigation of different approaches and have chosen to use both Markov chains and Weibull based approaches in the computer program to calculate deterioration rates. Detailed description of these two methods, including features of the computer program, is presented in Chapter 4.

1.3 Bridge Elements Analyzed

Based on detailed discussions with NYSDOT, elements shown in Table 1-2 below have been included in the computer program to calculate deterioration rates. Additionally, “Superstructure Recommendation” (a rating of the entire system comprising of “Superstructure Elements” to best describe the inspector’s opinion of system’s condition and ability to function) and “Pier Recommendation” (a rating of the entire system comprising of “pier elements” to best describe the inspector’s opinion of system’s condition and ability to function) condition ratings are also included for the deterioration rate calculation.

Table 1-2: Bridges Elements Considered for Calculating Deterioration Rates.

Bridge Elements	Span Elements	
Beg/End Bearings	Pier Bearing	Structural Deck
Beg/End Backwall	Pier Pedestal	Deck Wearing Surface
Beg/End Abutment Stem	Pier Top or Cap Beam	Monolithic Deck Surface
Beg/End Wingwall	Superstructure Joint	Pier Stem
Beg/End Abutment Seat/Pedestal	Primary Member	Pier Cap Beam
Beg/End Abutment Joint	Secondary Member	Pier Column
	Deck Curbs	Pier Footing
	Deck Sidewalk/Fascia	Deck Railings & Parapets

1.4 Grouping of Inspection Data within an Element

Bridge elements shown in Table 1-2 above are identified from different Tables in NYSDOT’s Bridge Inventory Database, as shown in Table 1-3 below. The Table 1-3 also shows span number for each element. During the calculation of deterioration rates, inspection data for a particular element should only be taken for the span number listed in Table 1-3.

In the Table 1-3 below, Table RC02 contains information about the bridge that is not span-specific and therefore for those elements that retrieve the inventory grouping information from RC02, the span number is not applicable.

For those that retrieve the inventory information from RC15, the Span Number is critical, as RC15 has an inventory record for each span of each bridge. The span number used for the inventory data needs to be the same as the span number used for the inspection data for the corresponding element.

For those that retrieve the inventory information from RC15, the Span Number is critical, as RC15 has an inventory record for each span of each bridge. The span number used for the inventory data needs to be the same as the span number used for the inspection data for the corresponding element. The span number used for the inventory data needs to be the same as the span number used for the inspection data for the corresponding element.

Table 1-3: Bridges Inventory Database Tables Corresponding to Different Bridge Elements.

Element	NYSDOT Inventory Tables	Span*	Element	NYSDOT Inventory Tables	Span*
Abutment Backwall	RC02	N/A	Pier Footing	RC15	N/A
Abutment Bearings	RC15	1	Pier Joints	RC15	1
Abutment Joints	RC02	N/A	Pier Pedestal	RC15	1
Abutment Pedestal	RC02	N/A	Pier Recommendation	RC15	1
Abutment Stem	RC02	N/A	Pier Stem	RC15	1
Abutment Wingwall	RC02	N/A	Primary Members	RC15	Varies
Deck Curbs	RC02	N/A	Secondary Members	RC15	Varies
Pier Bearings	RC15	1	Sidewalk Or Fascia	RC02	N/A
Pier Cap Top	RC15	1	Structural Decks	RC15	Varies
Pier Cap	RC15	1	Superstructure Rec.	RC02	
Pier Column	RC15	1	Wearing Surface	RC15	

* The program matches the span number in the inventory database to that in the historical inspection database to retrieve element condition ratings for a further analysis.

Using bridge inventory information described in Table 1-3 above, elements are analyzed as both as a whole and subgroups within the element, as per the grouping below provided by the NYSDOT.

Abutment Backwall – [RC02] Group all together

Abutment Stem – [RC02] Group all together

Abutment Wingwall [RC02, BA Wingwall Type]

Table 1-4: Element Grouping for Abutment Wingwall.

Abutment Wingwall [RC02, BA Wingwall Type]	NYSDOT Design Type Coding
No Wingwall	1
Wingwall Exists	2, 3, 4, 5, 7
Reinforced Earth Wingwall	8
Others	0, 6

Abutment Bearing

Table 1-5: Element Grouping for Abutment Bearing.

Abutment Bearing [RC15, Begin Bearing Type]	NYSDOT Design Type Coding
None	01, 51
Steel	02, 03, 04, 05, 06, 07, 22, 64, 52, 53
P.T.F.E.	08
Multi-Rotational	09, 10, 11, 12, 60, 61
Elastomeric	13, 14, 15, 16, 17, 18, 19, 20, 21, 55, 54, 56, 57, 58, 59, 23, 63, 62
Others	00, 65

Abutment Pedestal – [RC02] Group all together

Abutment Joint

Table 1-6: Element Grouping for Abutment Joint.

Abutment Joint [RC02, BA Joint Type]	NYSDOT Design Type Coding
None	01
Open	05, 06, 23
Finger	02
Sliding Plate	03
Filled Elastic Material	04, 22
Preformed Elastomeric Seals	07, 27, 08, 24
Strip Seal	15, 31, 16, 32, 17, 33, 18, 34
Sawed and Filled	21
Compression (including armored)	12, 29, 13, 30
Modular	14
Unknown or Other	09, 25, 10, 26
Armored	11, 28

Pier Bearing [RC15, End Bearing Type]

Table 1-7: Element Grouping for Pier Bearing.

Pier Bearing [RC15, End Bearing Type]	NYSDOT Design Type Coding
None	01, 51
Steel	02, 03, 04, 05, 06, 07, 22, 51, 64, 52, 53
P.T.F.E.	08
Multi-Rotational	09, 10, 11, 12, 60, 61
Elastomeric	13, 14, 15, 16, 17, 18, 19, 20, 21, 55, 54, 56, 57, 58, 59, 23, 63, 62
Others	00, 65

Pier Pedestal [RC15, Pier Type]

Table 1-8: Element Grouping for Pier Pedestal.

Pier Pedestal [RC15, Pier Type]	NYSDOT Design Type Coding
No Pier	01
Concrete	02, 04, 05, 06, 08, 10, 13, 14
Masonry	03
Steel	07, 09, 11, 12, 16
Timber	15, 17

Pier Cap Top [RC15, Pier Type]

Table 1-9: Element Grouping for Pier Cap Top.

Pier Cap Top [RC15, Pier Type]	NYSDOT Design Type Coding
No Pier	01
Concrete	02, 04, 05, 06, 08, 10, 13, 14
Masonry	03
Steel	07, 09, 11, 12, 16
Timber	15, 17

Pier Cap [RC15, Pier Type]

Table 1-10: Element Grouping for Pier Cap.

Pier Cap [RC15, Pier Type]	NYSDOT Design Type Coding
No Pier	01
Concrete	02, 04, 05, 06, 08, 10, 13, 14
Masonry	03
Steel	07, 09, 11, 12, 16
Timber	15, 17

Pier Stem –[RC16, Pier Stem] Group all together

Pier Column [RC15, Pier Type]

Table 1-11: Element Grouping for Pier Column.

Pier Column [RC15, Pier Type]	NYSDOT Design Type Coding
No Pier	01
Concrete	02, 04, 05, 06, 08, 09, 10, 13, 14
Masonry	03
Steel	07, 11, 12, 16
Timber	15, 17

Pier Footing – [RC15, Pier Footing] Group all together

Pier Recommendation [RC15, Pier Type]

Table 1-12: Element Grouping for Pier Recommendation.

Pier Column [RC15, Pier Type]	NYSDOT Design Type Coding
No Pier	01
Concrete	02, 04, 05, 06, 08, 09, 10, 13, 14
Masonry	03
Steel	07, 11, 12, 16
Timber	15, 17

Pier Joint [RC15, Pier Joint Type]

Table 1-13: Element Grouping for Pier Joint.

Pier Joint [RC15, Pier Joint Type]	NYSDOT Design Type Coding
Open	05, 06, 23
Finger	02
Sliding Plate	03
Filled Elastic Material	04, 22
Preformed Elastomeric Seals	07, 27, 08, 24
Strip Seal	15, 31, 16, 32, 17, 33, 18, 34
Sawed and Filled	21
Compression (including armored)	12, 29, 13, 30
Armored	11, 28
Modular	14
Unknown or Other	09, 25, 10, 26
None	01

Primary Member [RC15, Design Type]

Table 1-14: Element Grouping for Primary Member.

Primary Member [RC15, Design Type]	NYSDOT Design Type Coding
Slab , Box or Box/Channel	01, 02, 03, 04, 07
Tee or I beam	05, 06
Segmental Box	08
Rolled Beam	09, 10, 11, 12
Plate Girder	13, 14, 15, 16
Truss	17, 18, 19, 20, 21
Thru Arch	22, 23
Deck Arch	24, 25
Metal Pipe Arch	26
Frame	27, 28
Movable	29, 30, 31
Orthotropic	32
Inverset	35, 36
Suspension	37
Box Culvert	40, 43
Pipe Culvert	41, 42
Timber Beam	44
Other	XX
Unknown	UU

Secondary Member [RC15, Design Type]

Table 1-15: Element Grouping for Secondary Member.

Secondary Member [RC15, Design Type]	NYSDOT Design Type Coding
Slab , Box or Box/Channel	01, 02, 03, 04, 07
Tee or I beam	05, 06
Segmental Box	08
Rolled Beam	09, 10, 11, 12
Plate Girder	13, 14, 15, 16
Truss	17, 18, 19, 20, 21
Thru Arch	22, 23
Deck Arch	24, 25
Metal Pipe Arch	26
Frame	27, 28
Movable	29, 30, 31
Orthotropic	32
Inverset	35, 36
Suspension	37
Box Culvert	40, 43
Pipe Culvert	41, 42
Timber Beam	44
Other	XX
Unknown	UU

Deck Curbs [RC02, Curb Type LEFT]

Table 1-16: Element Grouping for Deck Curbs.

Deck Curbs [RC02, Curb Type LEFT]	NYSDOT Design Type Coding
No Curb	01
Granite or Stone	03, 04
Steel Plate	05
Molded Asphalt	06
Timber	07
Other	00
Concrete	02

Superstructure Recommendation [RC02, GTMS – Type]

Table 1-17: Element Grouping for Superstructure Recommendation.

Superstructure Rec. [RC02, GTMS – Type]	NYSDOT Design Type Coding
Slab	01
Stringer/Multi-Beam or Girder	02
Girder and Floorbeam System	03
Tee Beam	04
Box Beam or Box Girders	05, 06
Frame	07
Orthotropic	08
Deck Truss	09
Thru Truss	10
Deck Arch	11
Thru Arch	12
Suspension	13
Stayed Girder	14
Moveable Bridge	15, 16, 17
Tunnel	18
Culvert	19
Segmental Box Girder	21
Channel Beam	22
Other or None Dominant	20, 00

Sidewalk or Fascia [RC02, Sidewalk Type LEFT]

Table 1-18: Element Grouping for Side Walk or Fascia.

Sidewalk or Fascia [RC02, Sidewalk Type LEFT]	NYSDOT Design Type Coding
No Sidewalk	01
Concrete	02
Steel Plate	03
Steel Grating	04
Asphalt Concrete	05
Wood	06
Other	00

Structural Deck [RC15, Structural Deck Type]

Table 1-19: Element Grouping for Structural Deck.

Structural Deck [RC15, Structural Deck Type]	NYSDOT Design Type Coding
No Deck	01
C-I-P Concrete – Uncoated Rebars	02
Timber	03
Steel Grating	04, 05
Steel Plate	06, 07, 08, 09
Precast Concrete Plank	10
Open Deck	11
C-I-P Concrete – Epoxy Coated Rebar	12
C-I-P Concrete – Other Protections or Coatings	13, 14, 15, 16, 17, 18
Corrugated Steel	19
Other Deck Type	00

Present Wearing Surface [RC15, Present Wearing Surface]

Table 1-20: Element Grouping for Wearing Surface.

Wearing Surface [RC15, Present Wearing Surface]	NYSDOT Design Type Coding
None	01
Portland Cement Concrete Overlay	02
Precast Portland Cement Concrete Plank	03
Asphalt Concrete (includes block)	04, 05, 14, 24, 34, 44, 54, 64
Integral or Monolithic Portland Cement Concrete	06
Wood or Wood Block	07
Stone, Block, Brick	08
Steel Grate Open	09
Steel Grate, Concrete Filled	10
Epoxy or Similar Material	11
Bonded Concrete	12
Concrete with Membrane	22
High Density Concrete	32
Latex Modified Concrete	42
Micro-Silica Overlay	45
Other	00
Class H Concrete	52

Superstructure Design Type [ClassificationDesignType*, DesignType]

Table 1-21: Element Grouping for Superstructure Design Type.

Superstructure Design Type	NYSDOT Design Type Coding
Slab	1
Stringer/Multi-Beam or Girder	2
Girder and Floor beam System	3
Tee Beam	4
Box Beam or Box Girders (Multiple, Single or Spread)	5
Frame	6
Orthotropic	7
Truss (Deck and Thru)	8
Arch (Deck and Thru)	9
Suspension	10
Stayed Girder	11
Movable (Lift, Bascule, Swing)	12
Tunnel	13
Culvert	14
No Type is Dominant (Mixed Types)	15
Segmental Box Girder	16
Channel Beam	17
Other	18

* This table is created during the update process of the database.

Superstructure Material Type 1 [RC15, Material]

Table 1-22: Element Grouping for Material Type 1.

Superstructure Material Type 1	NYSDOT Design Type Coding
Steel	1, 3, 4
Weathering Steel	2
Corrugated Steel	5
Wrought or Cast Iron	6
Aluminium	7
Timber	8
Masonry	9
Concrete, Unreinforced or unknown	A, C
Concrete, Reinforced	B
Prestressed Concrete	D, E, F
Other	X

Superstructure Material Type 2 [RC02, GTMS – Material]*

Table 1-23: Element Grouping for Material Type 2.

Superstructure Material Type 2	NYSDOT Design Type Coding
Concrete	1
Concrete (Continuous)	2
Steel	3
Steel (Continuous)	4
Prestressed Concrete	5
Prestressed Concrete (Continuous)	6
Timber	7
Masonry	8
Aluminum, Wrought Iron or Cast Iron	9
Other	0
Unpainted Steel	A
Unpainted Steel (Continuous)	B
Not Applicable	N

* This material type is used only by "Superstructure Recommendation" element.

CHAPTER TWO: DATA FILTERING

2.1 Introduction

NYSDOT provided a database containing B-history (bridge history), S-history (span history) inspection data, and inventory data tables for the calculation of deterioration rates. Extensive data filtering has been done on the inspection data and bridge inventory information provided by NYSDOT for the classification and the calculation of deterioration rates. In addition to this, reconditioning of inspection data has been carried out based on certain rules developed by the NYSDOT engineers and observed material/construction practice in the state. Work carried out on data filtering and reconditioning is presented in the following.

2.2 Filtering of Inspection Data

In order to select reliable sets of data for the calculation of deterioration rates for bridge elements, several filters have been developed to perform following operations on the database:

- Filter Invalid Data Range
- Filter Rehabilitated / reconstructed Bridge Data
- Filter Effects of Rating Subjectivity
- Determine Element Built Year from Condition Rating or Work History Data
- Filter Bridges with Unusual Rating Drop
- Impose Maximum Expected Life Constraints at a Rating Based on Experience

Each of these filtering processes and results are described below.

2.2.1. Invalid Data Range

Errors may be introduced into the database because of issues such as missing/incomplete data. These errors may result in an invalid range of data. A filter was developed to identify such instances based on the study of the NYS Bridge Inspection Manual (1997).

Most bridges in New York State are only inspected every two years. Hence, inspection ratings for elements during intermediate years (between two consecutive inspection cycles) are set to values corresponding to those of the proceeding year.

If the bridge was built within a few years prior to when the NYSDOT bridge inspection program began in 1981 and the condition rating of the element during first few years after 1981 is zero (no inspection information available) and the first nonzero rating is 7, then all ratings from the year built to the year of nonzero rating is set to 7. For example, if the element was built in 1976, inspection started in 1981, ratings for 1981 and 1982 are zero and the condition rating in 1983 is 7, then the ratings from 1976 to 1983 are modified to 7. On the other hand, if the ratings are zero during first few years, and the rating in the following year (say in 1983) is less than 7 (say 5), then all ratings (maximum of 5 years) from the first inspection year to the year of nonzero rating are set to the nonzero rating, i.e., ratings for year 1981 to 1983 are modified to 5. The logic to address the Invalid Data Range is available in “Modules” in the database file “highway bridges.mdb”.

2.2.2. Rehabilitated / Reconstructed Bridge Data

Estimation of the correct age of bridge elements is necessary for the development of realistic

deterioration curves. In case of bridges with elements reconstructed after the original bridge built date, the year of bridge element reconstruction must be known to estimate the age of the element accurately. In the absence of bridge element work history data, approximate date of an element reconstruction may be derived from the bridge inspection condition rating data. If the built year of an element has been identified and if there are inspection data available before that year built, all data before element year built are discarded. For example, if a bridge deck is rebuilt in 1990, then inspection data for the older deck during 1981 to 1990 are discarded, since they correspond to the older deck.

Inspection data were analyzed to identify bridge elements with two point improvements in ratings over consecutive inspections. This would indicate significant rehabilitation work.

- (i) If the rating was a two point improvement to a 7, the element was likely replaced and therefore the element was assumed as new. All data before the improvement were discarded.
- (ii) If a two point improvement did not result in a new rating of 7, the element likely underwent significant rehabilitation, but not to the point of being a new element. These element data were not included as we were interested in the development of deterioration rates of non-rehabilitated elements.

The above filtering criteria cannot identify elements that were rehabilitated before the NYSDOT bridge inspection started in 1981. Additional rules have been implemented to identify possible rehabilitation in such cases. For example, if a steel bridge was built in 1950 and the primary member was replaced with weathering steel plate girders in 1975, additional algorithms were developed to indicate that the particular bridge element was likely rehabilitated, since weathering steel was not available in 1950. Detailed description of these rules for different elements is presented in section 2.3 (“Element Specific Data Reconditioning”).

2.2.3. Effects of Rating Subjectivity

Single point fluctuations may occur in element ratings because of subjectivity in ratings from different bridge inspectors. Extensive algorithms have been developed to identify such situations and to recondition identified data. For example, if inspection data for 14 years for an element are identified as 5, 5, 5, 5, 5, 5, 6, 6, 5, 5, 5, 5, 5, 5, then the two ratings of 6 are most probably because of inspector subjectivity. It is worth pointing out that the two ratings of 6 are likely due to only one inspection cycle, since most bridges are only inspected every two years. This data is modified to be condition rating 5 for 14 years, instead of rating 5 for 6 years, rating 6 for two years and then rating 5 for another 6 years. This modification is designed to minimize the effects of rater subjectivity. The logic to address the effects of inspector subjectivity is available in “Modules” in the database file “highway bridges.mdb”.

2.2.4. Element Built Year from Condition Rating or Work History Data

Since the New York State bridge inspection program is subject to a quality assurance program, condition ratings can be considered reliable for extracting information on element built year. For example, if the element rating jumped to 7 from a value lesser than 7 in successive inspection cycle, this can be considered as the effect of reconstruction. In such cases, year of Condition Rating 7 can be used to determine element built year.

NYSDOT also maintains an element work history in BHISTORY and SHISTORY databases. Information about element built year can also be derived from these databases. The work history database contains information about work done on specific elements, which may

not be related to rebuilding of the element. Hence, a filter was developed to identify if the condition rating was 7 at element rebuild year to identify element built year. The database was modified to include identified element built year.

2.2.5. Bridges with Unusual Rating Drop

Element ratings decrease gradually over years. However, a sudden drop of ratings over two consecutive inspections may be caused by unusual situations, for example, impact by ship/vessel/trucks, traffic accident, etc. Such rating decreases don't reflect normal operational deterioration. Filters have been implemented to identify such elements. Inspection data corresponding to these elements have been removed from the database.

2.2.6. Maximum Expected Life at a Rating Based on Experience

Inclusion of very old bridges in the deterioration rate calculations can introduce serious bias in the results. For example, several elements of bridges built in 1950s are likely to be replaced before the inspection started in 1981. In the absence of specific work history data, age of rebuilt elements in these bridges will have to be calculated based on original built year of the bridges, although condition ratings of these elements will be for rebuilt condition. For example, Figure 2-1 shows histogram for number of bridges with structural decks of different ratings for bridges with 70 year structural deck (based on original built year). It is observed that numerous bridge decks of 70 years age (based on original built year) have ratings of 5, 6 or 7. Ratings of 6 or 7 for decks of 70 year old bridges are likely because of reconstructed decks, and therefore, the in-place deck is not actually the original deck. In order to partially address this issue, a limit of maximum number of years in a rating was imposed on the inspection data. Calculations were carried out by both Markov Chain and Weibull based methods to study the effects of "maximum number of years at a condition rating" restrictions in the filtering logic on mean age at a condition rating, as shown in Figure 2-2. Based on these calculations, it was determined that bridge decks can stay up to 35 years in rating 7 and 50 years in rating 6. These restrictions were imposed on structural decks through a simple filtering logic.

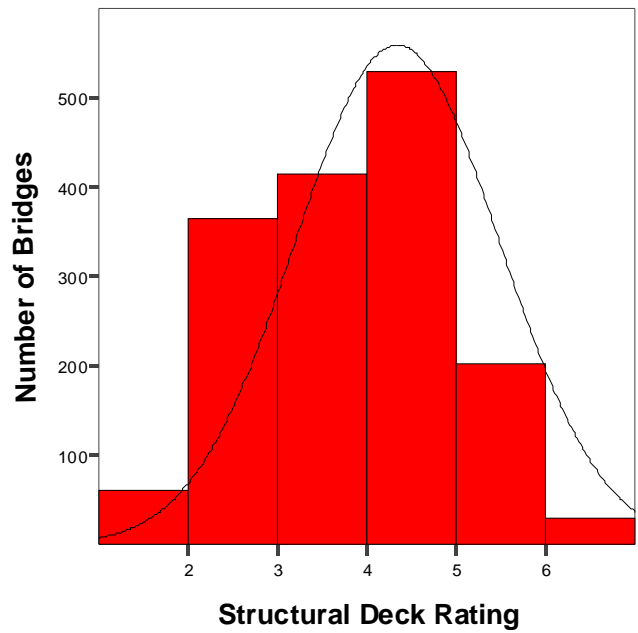


Figure 2-1: Histogram of Structural Deck Rating for Bridges of 70 years Age.

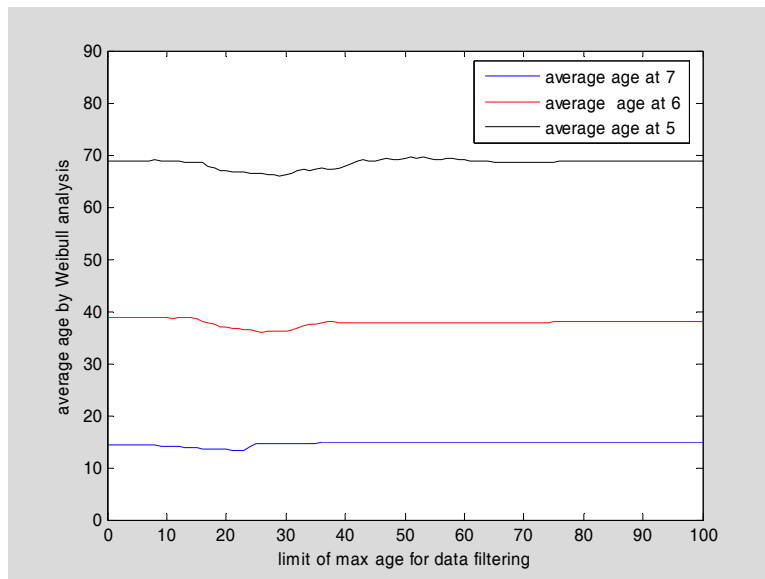


Figure 2-2: Average Duration at Rating 5, 6, and 7 Versus Maximum Number of Years in the filtering logic.

2.3 Element Specific Data Reconditioning

Although elements described above will minimize the presence of biased/erroneous data in the database to be used for deterioration rate calculation, the impact of some of the biases

introduced because of bridge element reconstruction before the start of bridge inspection in 1981 can be minimized by imposing further restrictions on some elements based on prevalent construction practices/materials. These restrictions are described for various elements in the following.

Structural Decks

- Eliminate or modify data based on stay-in-place forms not used prior to 1962 - only applies to deck types "02" (C-I-P Portland Cement Concrete - Uncoated Rebars) and "12" through "18" (C-I-P Portland Cement Concrete Decks with Epoxy Coated Rebars, w/Other Rebar Coating, Galvanized Rebars, Cathodic Protection, Polymer Impregnated, Internally Sealed, w/ Other Protection).
- Eliminate or modify data based on epoxy bars not used prior to 1973 - only applies to deck type "12" (C-I-P Portland Cement Concrete Decks with Epoxy Coated Rebars),
- Eliminate or modify data based on galvanized bars not used prior to 1993 - only applies to deck type "14" (C-I-P Portland Cement Concrete Decks with Galvanized Rebars),
- Eliminates or modify data based on composite decks not used prior to 1942 - only applies deck types "02" (C-I-P Portland Cement Concrete - Uncoated Rebars) and "12" through "18" (C-I-P Portland Cement Concrete Decks with Epoxy Coated Rebars, w/Other Rebar Coating, Galvanized Rebars, Cathodic Protection, Polymer Impregnated, Internally Sealed, w/ Other Protection).

Abutment Joints

- If built before 1920, eliminate data for abutment joint type "02" (Finger type).
- If built before 1890, eliminate data for abutment joint type "04" (Finger type) or joint type "07" (Preformed Elastomeric Seals).
- If built before 1960, eliminate data for abutment joint type "07" (expansion, Elastomeric) and joint type "08" (expansion, sealed-embedded membrane) or joint type "24" (fixed, sealed-embedded membrane) or joint type "27" (expansion, Elastomeric).
- If built before 1980, eliminate data for abutment joint types "15" to "18" or joint types "29" to joint type "34" (i.e., all strip seal joints).
- If built before 1980, eliminate data for abutment joint types "12" and "13" (expansion type compression seals).
- If built before 1970, eliminate data for abutment joint types \geq "11" or \leq "28" or \leq "14".

Primary Members

- If built before 1885, eliminate data for primary member design types "09", "10", "11" and "12" (all rolled beam primary members).
- If built before 1950, eliminate data for primary member design types "13", "14", "15" and "15" (all plate girder primary members with welded internal redundancy).
- If bridge built before 1968 and has weathering steel primary members, then primary member has been rebuilt after 1968.
- Use of pre-stressed concrete primary member started after 1955.
- Use of plate girder and rolled beam jack arches started between 1905 and 1950.

Superstructure Recommendation

- The same as that for Primary Members.

Wearing Surfaces

- If wearing surface was built before 1960, eliminate data for present wearing surface type “06” (Integral or Monolithic Portland Cement Concrete).
- If wearing surface was built before 1910, eliminate data for present wearing surface type “12” (bonded concrete).
- If the wearing surface was built before 1900, eliminate data for present wearing surface types “09” (Steel Grate Open) and “10” (Steel Grate, Concrete Filled).
- If the wearing surface was built before 1980, eliminate data for present wearing surface types “32” (High Density Concrete), “42” (Latex Modified Concrete) and “45” (Micro-Silica Overlay).
- If the wearing surface was built before 1990, eliminate data for present wearing surface types “11” (Epoxy or Similar Material), and “52” (Class HP Concrete).
- If the wearing surface was built before 1940, eliminate data for present wearing surface type “22” (Concrete with Membrane).

2.4 Impact of Data Reconditioning

Figure 2-3 shows the deterioration curve for structural deck using unfiltered data. It is observed that the structural deck condition ratings start increasing after the age of 50 years. This is because of bias introduced in condition ratings since age of elements reconstructed before the start of inspection in 1981 is calculated on the basis of bridge built year. Figure 2-4 shows deterioration curves generated by Markov and Weibull approaches after carrying out filtering and reconditioning described in previous subsection. It is observed that the filtering/reconditioning has effectively eliminated the effects of bias. As a result, condition ratings beyond the age of 60 years are seen to be decreasing with age.

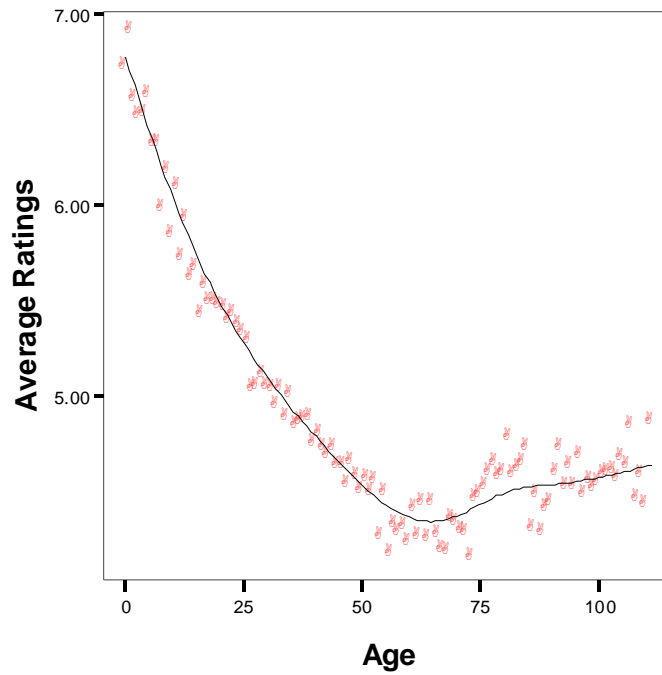


Figure 2-3: Deterioration Curve for Structural Deck using Raw Data (without significant filtering/reconditioning).

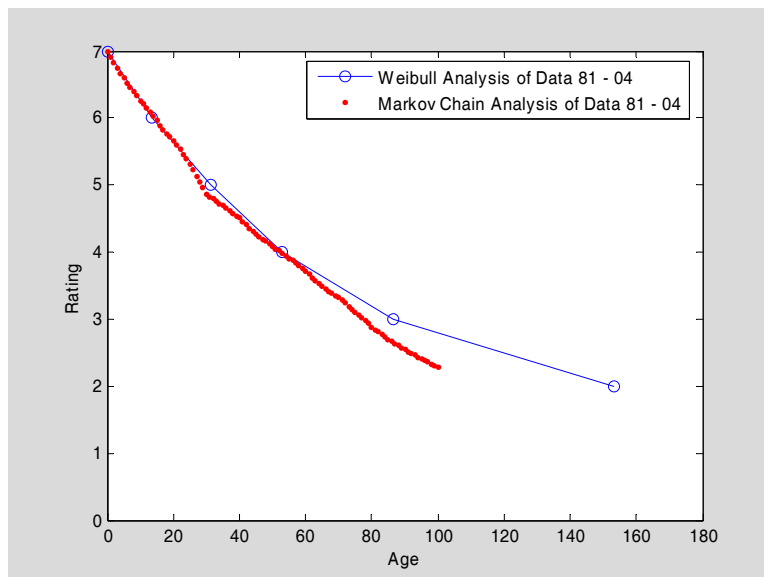


Figure 2-4: Deterioration Curves for Structural Decks Using Filtered/Reconditioned Data.

CHAPTER THREE: BRIDGE ELEMENT CLASSIFICATION

3.1 Introduction

The deterioration processes of bridge elements may depend on factors related to geographic locations, climatic conditions, traffic loads, material type of the bridge, etc. Hence, it is advantageous to classify all bridges based on available information so that we can apply the deterioration model on group of bridges with similar characteristic to achieve reasonable and accurate deterioration rates. To achieve this goal, filtered data for all bridges can be classified based on the following factors:

- Element Design Type
- NYSDOT Region
- Bridge Ownership
- Superstructure Design Type
- Superstructure Material Type
- Annual Average Daily Truck Traffic (AADTT)
- Salt Usage
- Snow Accumulation
- Climate Groups
- Functional Class
- Feature Under

A cascading algorithm has been developed so that bridges can be classified by considering a combination of any number of factors described above.

3.2 Classification Factors

A brief description of various factors for classification of bridges is presented in the following.

3.2.1. Element Design Type

A bridge element can be classified on the basis of its design types. Design types for all bridge elements considered for the calculation of deterioration rates are presented in Section 1.4 of Chapter 1. For some elements, such as “Abutment Backwall”, the design type is “Group all together”, implying that all abutment backwall element are grouped together for the calculation of deterioration rates. On the other hand, “Abutment Bearing” element can be classified into 6 design types listed in Table 1-4.

3.2.2. NYSDOT Region

NYSDOT is divided into 11 regions. In the database, field “REGION” in Table RC02 can be used to classify bridges in 11 classes corresponding to these 11 regions. Figure 3-1 shows a map of these 11 NYSDOT Regions along with their Regional designation.

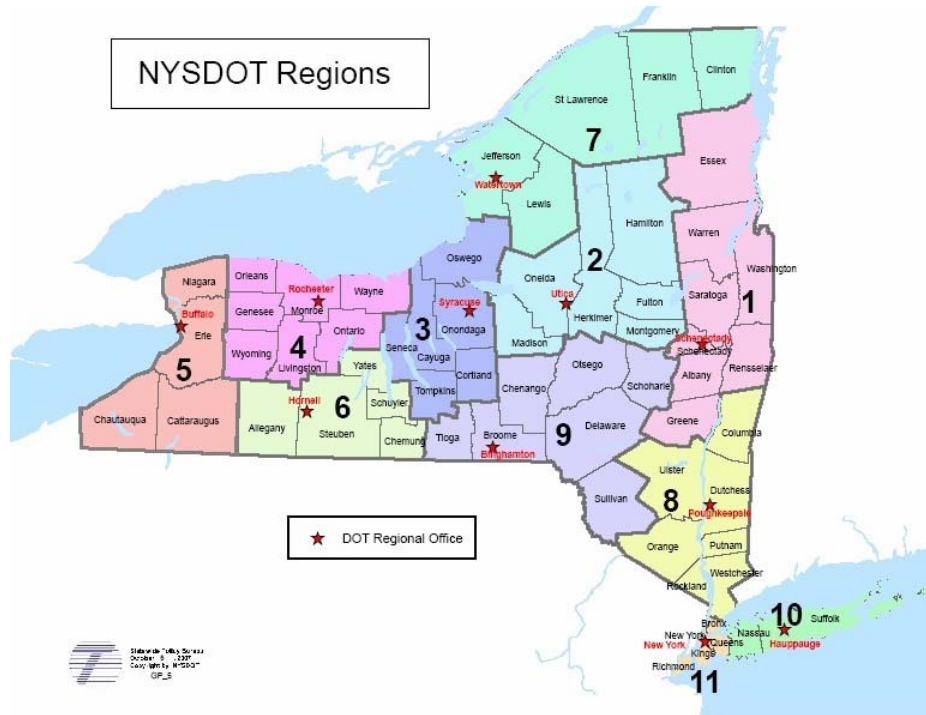


Figure 3-1: Map Showing NYSDOT Regions (Note that the responsibilities of Tioga County were moved from Region 6 to Region 9 in 2007).

3.2.3. Ownership

Field RC01.OWNER1 in Table RC01 records the primary owner for a bridge. Bridges can be classified by ownership type based on the primary ownership. Although there are 40 different types of ownerships, they can be combined into groups of 8 ownership as shown in Table 3-1. Bridges in the inventory database can be classified into these 8 ownership groups to investigate the effect of ownership on deterioration rates. Table 3-1 also shows number of bridges by ownership groups.

Table 3-1: Ownership Type Classification Based on Primary Ownership.

Ownership Group	Original Primary Owner Code	Number of Bridges by Ownership Grouping
NYSDOT	10	7659
Parks	2A, 2E, 2F, 2J, 2N, 2R, 22, 25, 26, 27, 28, 29, 53	150
Authority or Commission (non-parks)	2D, 2G, 2H, 2I, 2K, 2M, 2P, 2Q, 2R, 2S, 2T, 2U, 2V, 20, 21, 23, 24	479
NYS Thruway Authority	2L	749
Locally Owned	30, 40, 41, 42	9031
Railroads	60, 61, 62	1264
Privately Owned	70, 71	86
Others	20, 43, 50, 51, 52, 54, 55, 56, 72	245

3.2.4. Superstructure Design Type

All bridges can be classified by 18 superstructure design types as shown in Table 1-19. Classification on the basis of superstructure design type is done on the basis of field "DesignType" in the Table "ClassificationDesignType" in the database.

3.2.5. Superstructure Material Type

Superstructure Material Type 1 in Table 1-20 is used by all the elements except "Superstructure Recommendation" for classification of elements on the basis of material type. Superstructure Material Type 2 in Table 1-21 is only used by "Superstructure Recommendation".

3.2.6. Climate Classification

Climate data for New York State have been obtained from the National Oceanic and Atmospheric Administration (NOAA). Historic data are available from year 1895 to 2002. This data is being used to classify New York State in groups of similar climatic conditions. Three categories of climate data are used: Temperature, Precipitation, and Palmer Drought Severity Index. The data are presented as year-month time series for each of the ten climate divisions (shown in Figure 3-2) of the state, as defined by NOAA. A sample of temperature data is shown in Table 3-1 below. For the purpose of calculating bridge element deterioration rates, classifying bridge elements into 10 climate groups will result in large number of combinations and small number of bridges in any particular bridge group. Hence, these 10 NOAA climate regions are clustered into smaller number of groups of identical climatic conditions.

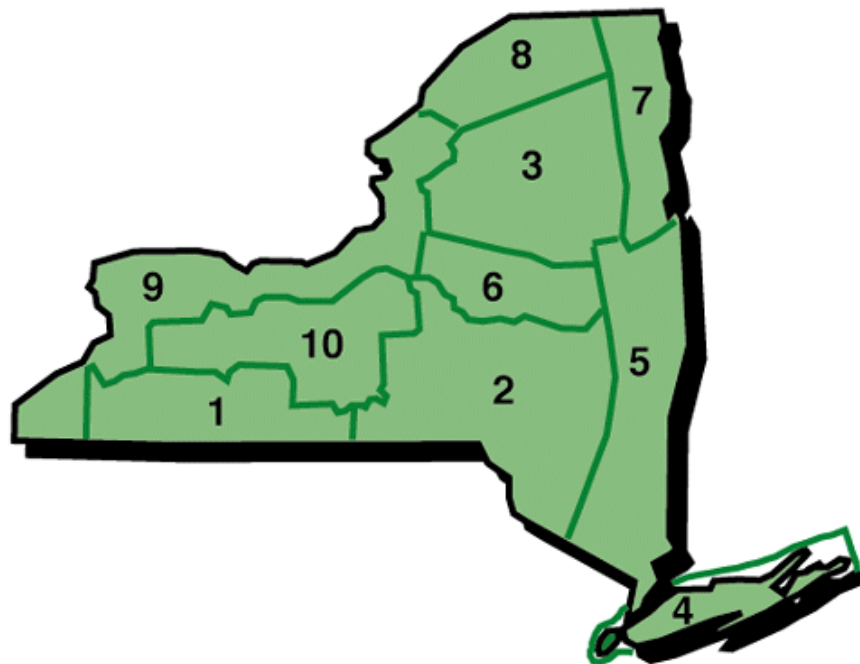


Figure 3-2. New York State Climate Divisions defined by NOAA. 1 Western Plateau, 2 Eastern Plateau, 3 Northern Plateau, 4 Coastal, 5 Hudson Valley, 6 Mohawk Valley, 7 Champlain Valley, 8 St. Lawrence Valley, 9 Great Lakes, 10 Central Lakes. Note that NOAA boundaries in Figure 3-2 are different than DOT region boundaries.

Rigorous statistical classification procedures are employed for the classification of climate according to conditions expressible in numerical measurements. To obtain such classifications, K-Mean Clustering and Hierarchical Classification algorithms have been considered. We choose the former algorithm for its overall simplicity and performance. Brief description of K-Mean Clustering algorithm is presented in Appendix A.

Table 3-2: Sample Climate Data.

	Reg. ²	Ele. ³	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
30	1	2	1895	18.9	13.3	23.9	43.1	55.6	67.3	63.9	65.9	61.2	41.7	37.6	29.5
30	1	2	1896	20.3	22	22.1	47.4	59.3	63.1	68.1	66.7	58.1	44.1	40.9	25.4
30	1	2	1897	20.8	22.1	31.4	42.1	50.1	59.7	69	63.1	58.3	49	36.4	27.8
30	1	2	1898	24.5	24.8	39.6	40.2	54.8	65.5	70.1	67.6	61.6	49.7	35.5	26.2
30	1	2	1899	21.4	18.9	30.5	45.5	55.7	65.4	67.9	67.4	57.3	50.6	37.6	27.2
30	1	2	1900	25.1	21.8	23.6	42.9	53.9	64.8	68.9	70.6	62.8	54.5	37.9	25.4

K-Mean Clustering

All three categories of available data are joined together for each region and each year. K-Mean clustering algorithm is applied on available data over all years. The running average of each cluster is used during the iteration for formation of clusters. The algorithm is configured to form 5 clusters.

Figure 3-3 shows the climate data membership of each region in 5 clusters (the membership count for 5 clusters is shown in Table 3-3). The size of the bubble in the figure reflects the contribution of data points from a region to a cluster. Hence, the membership of a NOAA Region to one of 5 clusters is determined by the size of the bubble. For example, region 4 belongs to Cluster 1 since region 4 has largest bubble corresponding to cluster 1. It is observed from Figure 3-3 that region 3, 4, and 5 should be classified into clusters 3, 1, and 5, respectively, without any ambiguity. Majority data points for region 9 and 10 are classified into cluster 5. Thus, these two NOAA regions should be classified into this cluster. Region 1, 2, and 6 have more data classified into cluster 2 than those classified into either cluster 4 or cluster 5. Hence, we put region 1, 2, and 6 into cluster 2. For a similar reason, region 8 has been classified into cluster 3. Region 7 has slightly more data classified in cluster 4 than those in either cluster 2 or 3. Hence, we classify region 7 into cluster 4. Thus, we have the following cluster classification for climate in the New York State:

- Cluster 1: NOAA Region 4 (Long Island)
- Cluster 2: NOAA Region 1, 2, 6 (Western Plateau, Eastern Plateau, Mohawk Valley)
- Cluster 3: NOAA Region 3, 8 (Northern Plateau, St. Lawrence Valley)
- Cluster 4: NOAA Region 7 (Champion Valley)
- Cluster 5: NOAA Region 5, 9, 10 (Hudson Valley, Great Lakes, Central Lakes)

² Region Code

³ Element Measurement Code. 1, precipitation; 2, temperature; 3, Palmer Drought Severity Index.

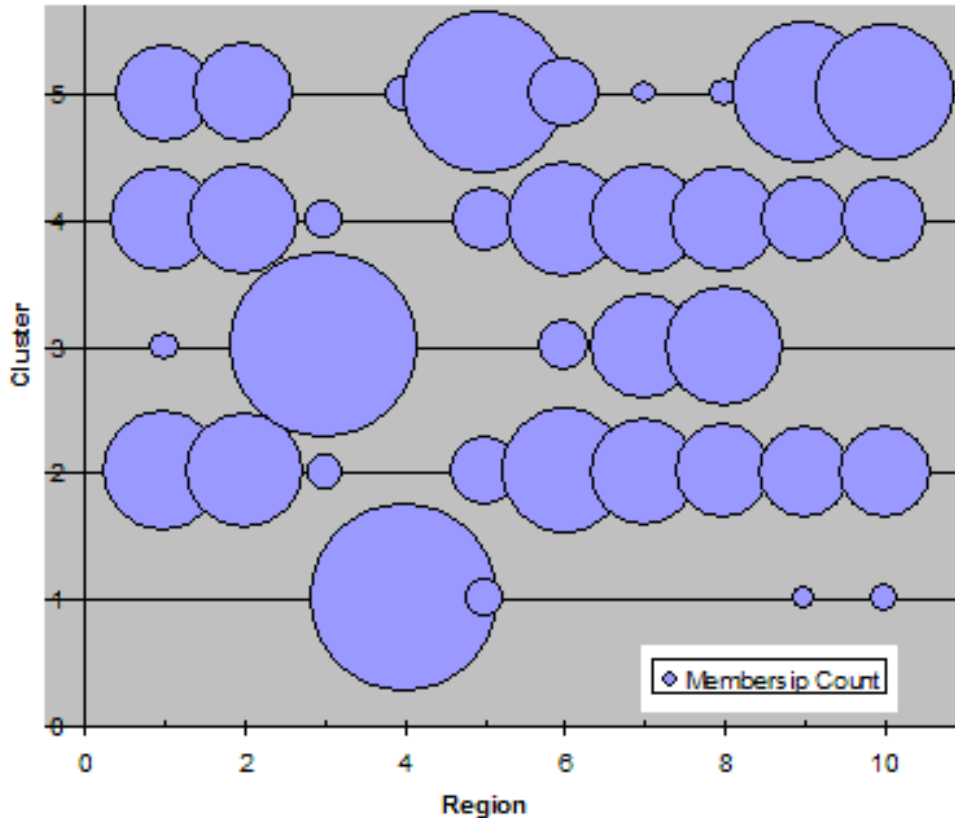


Figure 3-3: Climate NOAA Region membership classified into 5 clusters.

Assigning Bridges to NOAA Climate Regions

In order to determine which division a particular bridge is located in, climate division boundary files are obtained from NOAA. The boundary files are in the format of GIS software “ArcView”. The data were visualized in ArcView and boundary points are recorded in the format of (Longitude, Latitude) pairs for the polygon that surrounds each division. Some boundary points are modified to make the polygon convex and make it enclose as many bridges as possible, since some inconsistency has been observed for a small number of bridges between the bridge location maintained by NYSDOT and the New York State boundaries reported by NOAA. High precision bridge GIS data are obtained from NYSDOT in ArcGIS format. Cartesian coordinates are extracted from GIS objects for each bridge. After conversion of bridge locations from the Cartesian coordinate system into geographical coordinate system (longitude, latitude) using PROJ. 4⁴, each bridge was associated with the NOAA region that contains the bridge. A Matlab program was written to determine the membership of each bridge (point in plane) in ten NOAA regions (polygon). Using this program, 20375 bridges were identified with the NOAA regions that contained them, as shown in Figure 3-4.

⁴ <http://kai.er.usgs.gov/intro/MAPGENdetails.html>

Table 3-3: Climate Data Membership Count in 5 Clusters.

NOAA Region	Cluster	Bridge Membership Count	NOAA Region	Cluster	Bridge Membership Count
1	2	43	6	3	8
1	3	3	6	4	38
1	4	33	6	5	15
1	5	29	7	2	35
2	2	41	7	3	34
2	3	1	7	4	37
2	4	36	7	5	2
2	5	30	8	2	28
3	2	4	8	3	42
3	3	99	8	4	35
3	4	5	8	5	3
4	1	104	9	1	2
4	5	4	9	2	26
5	1	5	9	4	22
5	2	15	9	5	58
5	4	13	10	1	3
5	5	75	10	2	26
6	2	47			

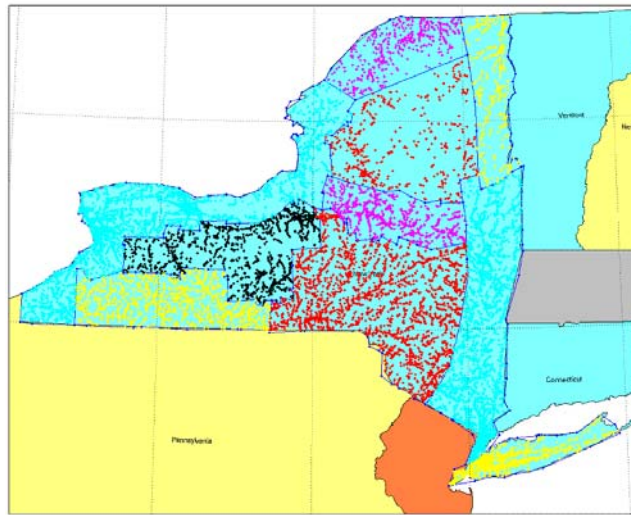


Figure 3-4: Bridge distribution in the 10 NOAA regions. NOAA region boundaries are shown as connected blue lines while bridges are dots of different colors.

These bridges can be further classified into five clusters (or weather classes) since these clusters consist of specific NOAA regions. If a new bridge is included in the database, it can be classified in one of the five clusters by determining the membership to one of the NOAA regions. This can be done either by downloading GIS Shape files for NOAA Region from NOAA website⁵ or by using the shape files included on the CD-ROM enclosed with this report.

⁵ FTP directory /pub/data/divboundaries/gis/ at ftp.ncdc.noaa.gov

3.2.7. Annual Average Daily Truck Traffic (AADTT)

The Average Annual Daily Truck Traffic (AADTT) information is calculated by multiplying the field “Average Annual Daily Traffic” (AADT) to the field “Daily Truck Traffic (%)” in Table RC12. AADTT for each bridge may change over time. Based on the suggestions from NYSDOT engineers, five groups were found appropriate for the classification of bridge elements based on AADTT.

Since parkways are not allowed to have any truck traffic, irrespective of how their AADTT are recorded, parkway bridges have been classified into the class with AADTT = 0. These AADTT groups and distribution of bridge elements among these groups is shown in Table 3-4 below.

Table 3-4: Classification and number of Bridges based on AADTT.

Class	AADTT Min	AADTT Max	Number of Bridges
1	0	0	2712
2	1	1000	13727
3	1001	2000	1430
4	2001	5000	1127
5	5001		724

3.2.8. Functional Class Carried by the Bridge

All bridges in New York State can be classified by five functional classes carried by the bridges. Information for the functional class carried is derived from the “Functional Classification” field of RC12. Table 3-5 shows functional classification of the bridges based on NYSDOT coding and number of bridges in each of the classes.

Table 3-5: Classification and number of Bridges based on Functional Class Carried.

Class	Functional Classification	NYSDOT Coding (Functional Classification in RC12)	Number of Bridges
1	Interstate	01, 11	2093
2	Principal and Minor Arterial	02, 06, 12, 14	3949
3	Collector	07, 08, 17	4095
4	Local	09, 19	6306
5	None	00	2103

3.2.9. Feature Under

All bridges in New York State can be classified into “Interstate Under”, “Highway Under” and “Water Under” categories using the information in Subsets Table.

3.2.10. Snow Classification

Snow accumulation data were obtained from NYSDOT for each county for a relatively short period spanning 1995 to 2003. Some counties have snow accumulation recorded for different regions of the counties. For example, snow accumulation for Suffolk County was recorded separately for east, central, and west Suffolk. Such snow accumulation data were summed first as the location of each bridge is recorded at the level of county, not county regions. After this necessary preprocessing, K-Mean cluster algorithm was applied to classify all NYS counties into 3 classes based on snow accumulation. These three clusters, along with number of bridges in

each cluster, are shown in Table 3-6. The bridges located in each county are assigned to the same class as the county. No snow accumulation data was documented for NYSDOT region N (NYC). Consequently, bridges in this region don't get assigned to any of the classes. Table 3-7 shows membership of individual counties to snow clusters.

Table 3-6: Three Cluster Centers for Snow Accumulation in inches during 1995 to 2003.

Snow Cluster	Snow Accumulation Level (Inches)	Snow Classification	Number of Bridges
1	Less than 171	Low	9370
2	Greater than 171, Less Than 278	Medium	5913
3	Greater than 278, less than 458	High	2331

3.2.11. Salt Usage

Yearly salt usage data were provided by NYSDOT for each county for the period from 1992 to 2003. After necessary preprocessing (similar to snow accumulation), all the counties except Erie were classified into clusters (classes) 1 to 3 by K-Mean cluster algorithm. As salt usage for Erie County is substantially greater than any other counties, it is assigned to a cluster (cluster 4) by itself. Table 3-8 shows these three clusters, salt usage levels in these clusters, number of bridges in each of these clusters and number of counties in each cluster. Each bridge was assigned to the same salt usage class as the county it belongs to. Since no salt usage data were available for the 5 counties of NYC (NYSDOT region N), the bridges of these counties were not assigned to any of the 4 clusters. Individual membership of a county to a particular cluster is shown in Table 3-9.

Table 3-7: Membership of Counties in Snow Clusters.

County	Region	Cluster	County	Region	Cluster	County	Region	Cluster
Albany	1	1	Genesee	4	1	St. Lawrence	7	2
Essex	1	2	Livingston	4	1	Columbia	8	1
Greene	1	1	Monroe	4	2	Dutchess	8	1
Rensselaer	1	1	Wayne	4	2	Orange	8	1
Saratoga	1	1	Orleans	4	1	Putnam	8	1
Schenectady	1	1	Wyoming	4	2	Rockland	8	1
Warren	1	1	Ontario	4	2	Ulster	8	1
Washington	1	1	Cattaraugus	5	2	Westchester	8	1
Fulton	2	1	Chautauqua	5	2	Broome	9	1
Hamilton	2	2	Erie	5	3	Chenango	9	1
Herkimer	2	1	Niagara	5	1	Delaware	9	2
Oneida	2	2	Allegany	6	3	Otsego	9	1
Montgomery	2	1	Chemung	6	2	Schoharie	9	1
Madison	2	2	Yates	6	1	Sullivan	9	1
Cayuga	3	2	Steuben	6	1	Tioga	9	1
Cortland	3	2	Schuyler	6	1	Nassau	10	1
Onondaga	3	3	Clinton	7	2	Suffolk	10	1
Oswego	3	3	Franklin	7	2	Jones Beach	10	1
Seneca	3	2	Jefferson	7	2			
Tompkins	3	2	Lewis	7	2			

Table 3-8: Bridge Distribution Across Salt Usage Classes.

Salt Cluster	Salt Usage Level (tons)	Snow Classification	Number of Bridges	Number of Counties
1	6893 to 13492	Low	5743	7
2	10,175 to 25,457	Medium	7766	26
3	16,969 to 40,195	High	2986	23
4	46,375 to 94,739	Very High	1119	1

Table 3-9: Membership of Counties in Salt Clusters.

County	Region	Cluster	County	Region	Cluster	County	Region	Cluster
Albany	1	1	Genesee	4	1	St. Lawrence	7	2
Essex	1	2	Livingston	4	1	Columbia	8	1
Greene	1	1	Monroe	4	2	Dutchess	8	1
Rensselaer	1	1	Wayne	4	2	Orange	8	1
Saratoga	1	1	Orleans	4	1	Putnam	8	1
Schenectady	1	1	Wyoming	4	2	Rockland	8	1
Warren	1	1	Ontario	4	2	Ulster	8	1
Washington	1	1	Cattaraugus	5	2	Westchester	8	1
Fulton	2	1	Chautauqua	5	2	Broome	9	1
Hamilton	2	2	Erie	5	3	Chenango	9	1
Herkimer	2	1	Niagara	5	1	Delaware	9	2
Oneida	2	2	Allegany	6	3	Otsego	9	1
Montgomery	2	1	Chemung	6	2	Schoharie	9	1
Madison	2	2	Yates	6	1	Sullivan	9	1
Cayuga	3	2	Steuben	6	1	Tioga	9	1
Cortland	3	2	Schuyler	6	1	Nassau	0	1
Onondaga	3	3	Clinton	6	1	Suffolk	0	1
Oswego	3	3	Franklin	7	2	Jones Beach	0	1
Seneca	3	2	Jefferson	7	2			
Tompkins	3	2	Lewis	7	2			

Note: Second Column Under County Indicates The County Code.

3.2.12. Classification by Wearing Surface

For “Structural Deck” element only, classification can be done by “Present Wearing Surface” on the basis of 17 wearing surface types in Table 1-18. Structural decks can also be classified on the basis of “Original Wearing Surface” into classes shown in Table 3-10 below.

Table 3-10: Classification based on Original Wearing Surface.

Original Wearing Surface Classes, OWS Still in Place, RC15	NYSDOT Coding
Still in Use	01
Still in place (overlaid)	02
Removed	03
Unknown	*

3.2.13. Cascading Classification

In order to carry out cascading classification to include effects of many factors, a classification form has been developed. Figure 3-5 shows the classification form. This form contains all the classification items described above. Cascading classification can be done by selecting an element and various factors to be considered for classification. For example, “Abutment Bearing” element has 6 design types. By selecting “All Design Types” for “Abutment Bearings”, inventory data for abutment bearings will be divided into 6 classes, one for each design type. Figure 3-5 shows classification screen with 6 classes and number of bridges in each class. If we want to study the combined effect of “Design Type” and “DOT Region” for “Abutment Bearing”, there will be $6 \times 11 = 66$ classes. Out of these 66 classes, users can select classes with sufficient number of bridges by checking the box under “Selected” in Figure 3-6 for further deterioration rates.

Since the cascading is dynamic, any number of factors can be selected for cascading. However, the number of cascaded groups may become too high with only a few bridges in each group if too many factors are included in the cascading analysis. This may lead to results that are statistically insignificant.

Figure 3-5: Screening for Element Selection and Cascading Classification.

Classification Workspace					
Classification		Result			
	Id	Selected	Class Detail	Progress	Number of Bridges
1	1	<input type="checkbox"/>	Element : Abutment Bearing		8356
2	2	<input type="checkbox"/>	Element : Abutment Bearing		7025
3	3	<input type="checkbox"/>	Element : Abutment Bearing		169
4	4	<input type="checkbox"/>	Element : Abutment Bearing		611
5	5	<input type="checkbox"/>	Element : Abutment Bearing		4290
6	6	<input type="checkbox"/>	Element : Abutment Bearing		397

Figure 3-6: Cascading Classification Showing Number of Bridges Under Each Classification.

CHAPTER FOUR: METHODS FOR DETERIORATION RATES CALCULATIONS

4.1. Introduction

Approaches for the calculation of deterioration rates for bridge elements can be classified into two broad categories: (i) Deterministic Approaches, and (ii) Stochastic Approaches. Deterministic approaches are based on statistical and non-linear regression analysis of data to determine deterioration rates. Some of the common deterministic methods to calculate deterioration rates are (i) Average ΔT for Transition of States Curves, (ii) Average of Ratings Curves, (iii) Minimum of Ratings Curves and (iv) Ordinary Least Square Approach. In Average ΔT for Transition of States, average duration, ΔT , at each of the condition states is determined statistically. In Average of ratings curves method, average of ratings at different element age is determined to obtain average ratings versus age curve. In minimum of ratings curves, minimum of ratings of a particular element is plotted as a function of element age. The ordinary least square approach can be used to obtain condition rating as a function of different factors affecting bridge element deterioration using least square minimization. Deterministic approaches have been used extensively by Yanev (1996, 1997, 1998) and Yanev and Chen (1993).

In stochastic approaches, bridge element ratings or duration at a particular rating are assumed to be random variables and are modeled by an underlying probability distribution. In order to calculate deterioration rates using these models, parameters of these distributions are calculated through nonlinear regression of available regression data. Then, deterioration rates can be calculated from the underlying distribution using calculated distribution parameters.

Bridge deterioration process depends on many factors, such as Average Annual Daily Truck Traffic (AADTT), climate, maintenance level, etc. Although deterministic models have been used to calculate deterioration rates because of widespread availability of statistical tools, stochastic models are inherently capable of accounting for the uncertainty and randomness factors affecting the bridge deterioration process. These models can be classified either as discrete-time, state-based or discrete-time, time-based models [Mauch and Madanat (2001)]. In discrete-time, state-based models, such as Markov chains, the deterioration process is modeled through a probability of transition from one condition state to another in a discrete time, given that the deterioration process is dependent on a set of explanatory variables such as AADT, climate, age, etc. In discrete-time, time-based models, the duration that a bridge element remains at a particular state is modeled as a random variable using Weibull-based probability density functions to characterize the deterioration process, given its dependence on the same set of explanatory variables described above. In this project, we have selected both Markov chains and Weibull-based approach to calculate deterioration rates using NYSDOT bridge inspection data. Hence, these two methods have been programmed into a computer program developed for the calculation of deterioration rates for NYSDOT.

4.2. Markov Chains Approach

Markovian models are the most common stochastic techniques and have been used extensively in modeling deterioration rates of infrastructure facilities, e.g., pavement prediction model [Butt et al. (1987)], storm water pipe deterioration [Micevski et al. (2002)], bridge types and components [Jiang et al. (1988), Cesare et al. (1992)]. These models use the Markov decision process based on the concept of defining states of facility condition transitioning from

one state to another during one transition period [Jiang et al. (1988), Jiang and Sinha (1989)]. Statistical appropriateness of the Markovian process for bridge deterioration modeling has been shown by Madanat and Ibrahim (1995).

Although Markovian models address the uncertainty of the deterioration process and account for the current facility condition in predicting the future one, they still suffer from several limitations such as: (i) they assume discrete transition time intervals, constant bridge population, and stationary transition probabilities (i.e., transition probabilities don't change with bridge age), which are sometimes impractical [Collins (1972)], (ii) Markovian models currently implemented in advanced bridge management systems such as Pontis and BRIDGIT use the first-order Markovian decision process that assumes duration independence for simplicity (i.e., probability of transition doesn't depend on the duration for which an element stays at a particular rating) [DeStefano (1998)], i.e., the future facility condition depends only on the current facility condition and not on the facility condition history, which is unrealistic [Madanat et al. (1997)]; (iii) transition probabilities assume that the condition of a facility can either stay the same or decline (11); (iv) Markovian models cannot efficiently consider the interactive effects between deterioration mechanisms of different bridge components [Sianipar and Adams (1997)] and (v) transition probabilities require updates when new data are obtained. Among the limitations described above, stationarity of transition probabilities and duration independence assumptions have been observed to have most significant effects on the reliability of using the Markov chains approach for developing deterioration rates. These assumptions may lead to under-estimation in deterioration rates that may not be reasonable for an effective bridge management system. Despite the limitations of the Markov chains process, it is the most widely used approach for deterioration modeling.

For the NYSDOT bridge inspection system, seven bridge condition ratings (from 7 to 1) can be defined as seven Markovian states with each condition rating corresponding to one of the seven states. For example, condition rating 7 is defined as State 1; rating 6 as State 2, and so on. Without repair or rehabilitation, the bridge condition rating should decrease with increase in bridge age. Therefore, there is a probability, p_{ij} , of a bridge element transiting from one condition state, say i , to another state, j , between inspections. The probability of state i not transitioning to state j is then $1 - p_{ij}$. By knowing this probability for each of the states transitioning, e.g., 1 to 2, 2 to 3, 3 to 4, etc., we can obtain the transition matrix P , which is defined as

$$P = \begin{bmatrix} p(1) & q(1) & 0 & 0 & 0 & 0 & 0 \\ 0 & p(2) & q(2) & 0 & 0 & 0 & 0 \\ 0 & 0 & p(3) & q(3) & 0 & 0 & 0 \\ 0 & 0 & 0 & p(4) & q(4) & 0 & 0 \\ 0 & 0 & 0 & 0 & p(5) & q(5) & 0 \\ 0 & 0 & 0 & 0 & 0 & p(6) & q(6) \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (4-1)$$

In Eq.(4-1), $q(i) = 1 - p(i)$, $p(i)$ corresponds to $P_{i,i}$ and $q(i)$ corresponds to $P_{i,i+1}$. Hence, $p(1)$ is the probability of transition from condition rating 7 (State 1) to rating 7 (state 1), i.e., staying at rating 7, and $q(1) = 1 - p(1)$ is the probability of transitioning from rating 7 (State 1) to rating 6

(State 2). The lowest rating possible is 1. Hence, the corresponding probability $p(7)$ is 1. Then, by the Markov chains approach, the state vector (i.e., a vector of element rating) for any time t , $Q_{(t)}$, can be obtained by the multiplication of the initial state vector Q_0 and the transition probability matrix P raised to the power t , i.e.,

$$Q_{(t)} = Q_{(0)} * P^t \quad (4-2)$$

where $Q_{(t)}$ is the state vector at any time t and $Q_{(0)}$ is the state vector at time $t = 0$. For example, a newly constructed bridge element at the time of first inspection will have an initial state vector as $Q_{(0)} = [1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]$. Similarly, a bridge element with rating 5 at time $t = 0$ will have an initial state vector as $Q_{(0)} = [0 \ 0 \ 1 \ 0 \ 0 \ 0 \ 0]$. Let R be a vector of condition ratings, i.e., $R = [7 \ 6 \ 5 \ 4 \ 3 \ 2 \ 1]$, and R' be the transform of R , then the estimated condition rating $R_{P,t}$ as a function of time by Markov Chains is obtained as,

$$R_{P,t} = Q_{(t)} * R' \quad (4-3)$$

The deterioration rate at any age can be defined as the slope of the condition rating curve in Eq.(4-3). The transition matrix P in Eq.(4-1) can be calculated by formulating the nonlinear programming objective function as

$$\min \sum_{J=1}^N |Y(t) - R_{P,t}| \quad \text{subject to } 0 \leq p(i) \leq 1 \text{ for } i = 1, 2, \dots, I \quad (4-4)$$

where N is the number of inspection data for a particular element used in the minimization problem and I is the number of unknown probabilities, i.e., $I = 6$, $p =$ a vector of length $I = [p(1), p(2), \dots, p(i)]$, and $Y(t)$ is the average of condition ratings at time t . The objective function in Eq.(4-4) can be minimized by a constrained nonlinear programming approach to obtain values of transition probabilities $p(i)$, $i = 1, 2, \dots, 6$.

In the Markov Chains approach, non-homogeneity of the continuous deterioration process (i.e., time-dependence of deterioration process) is captured indirectly through segmentation of bridge elements into age groups, i.e., 0-10 yrs, 10-20 yrs, etc. Within each group, Markov Chains are assumed to be homogeneous. A new bridge element is almost always given a condition rating of 7. In other words, a bridge element at age 0 has a condition rating 7. Thus, the initial state vector $Q_{(0)}$ for a new element is $[1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]$, where the numbers are the probabilities of having a condition rating of 7, 6, 5, 4, 3, 2 and 1 at age 0, respectively. The transition matrix P in Eq.(4-1) is determined using nonlinear programming in Eq.(4-4) for each age group. Then, equations (4-2) and (4-3) are used to determine the rating vector $R_{P,t}$ in Eq.(4-3) at different ages. For example, $Q_{(0)} = [1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]$ can be used for the age group 1 (i.e., 0-10 yrs) to iteratively determine $Q_{(t)}$ and $R_{P,t}$ for the 0 to 10 years interval. For the age group 2 (10 to 20 years), $Q_{(10)}$ is used as the starting state vector to determine $R_{P,t}$ for 10 to 20 years interval using P matrix for this age group. This process is followed until $R_{P,t}$ is generated for the entire age range of interest.

One major drawback of this approach is that the nonlinear optimization in Eq.(4-4) will not converge and will essentially give the transition matrix P as a unity matrix or close to it, if condition ratings in a particular age group don't decrease or tend to increase. This issue has been resolved by carrying out a second level Markov Process. In this process, data generated by Markov Chains processes using 10-year age groups are used as original data $Y(t)$ in Eq.(4-4) to derive one transition matrix for the age group from 0 to 40 years. Markov chains data generated by this transition matrix will follow the dominant deteriorating behavior during the first 40 years.

For example, Figure 4-1 shows the comparison between first and second level Markov Chains plots for structural decks. It is observed from Figure 4-1 that, while the deterioration curve using first level Markov Chains stops decreasing beyond 30 years, the curve by the second level Markov chains follows the original data during first 40 years and continues a decreasing trend beyond that age.

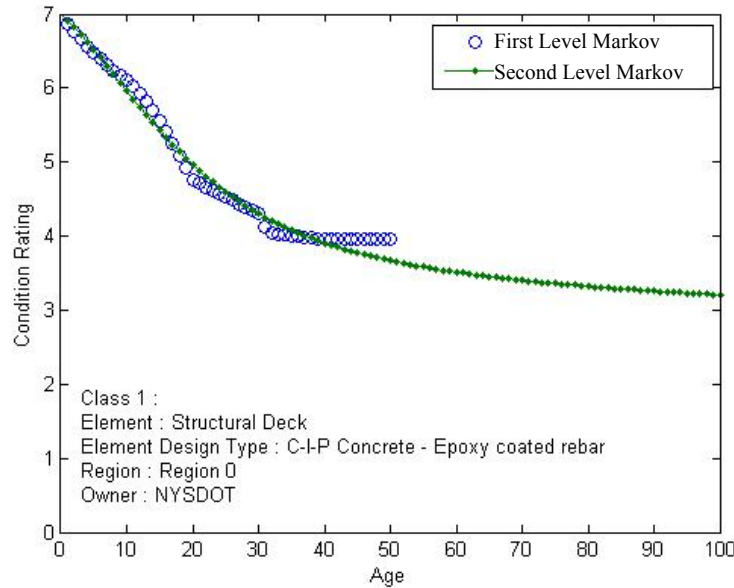


Figure 4- 1: Comparison between deterioration rate curves using first and second level Markov Chains processes.

4.3. Weibull-Distribution Based Approach

Assuming that the variable $T_i, i = 7, 6, \dots, 1$, which represents the duration in number of years that an element stays in a particular condition rating, is a random variable modeled by a Weibull distribution, the probability $P(T_i > t)$ that T_i exceeds t years is called survival function of T_i and is denoted by,

$$S_i(t) = e^{-(t/\eta_i)^{\beta_i}}, t > 0, \beta_i > 0, \eta_i > 0, i = 7, 6, 5, \dots, 1 \quad (4-5)$$

For each condition rating, T_i (durations) is assumed to comprise a random sample from the Weibull distribution described by Eq. 4-5. Each such sample is then analyzed with the objective of estimating (β_i, η_i) pair. The parameters β_i and η_i in Eq. 4-5 are called *shape* and *scale* parameters, respectively. The shape parameter determines whether the so-called *failure* or *hazard rate* is decreasing ($\beta_i < 1$), constant ($\beta_i = 1$), or increasing ($\beta_i > 1$). An increasing failure rate means that at any particular time, the longer an element has been at a particular condition rating (CR), the more likely it will transition to a lower CR in the next instant. For example, suppose that $n(t)$ samples of an element have been at k^{th} CR for t years and that $h(t)$ is the failure rate at any time t . Then, $n(t)h(t)$ is approximately the expected number of samples of an element that will transition to $(k-1)^{\text{th}}$ CR within the following year. More rigorous description of failure rate and other probabilistic properties used to describe durational phenomena is provided by Mishalini and Madanat (2002) and DeLisle et al (2004).

Distributions of durational phenomena at a particular rating are typically skewed and

consequently are rarely normally distributed. For example, Figure 4-2 shows the frequency distribution of durations at different condition ratings for structural decks. It is observed that distributions of durations for condition ratings are skewed towards the left (lower age). The most frequently used distributions for such data are the Weibull and lognormal. It has been shown by DeLisle et al (2004) that the Weibull distribution generally provides the best overall fit for infrastructure deterioration data. This fact has been verified by analysis of reconditioned inspection data of most of the bridge elements in New York State during preliminary analysis of the work presented in this report.

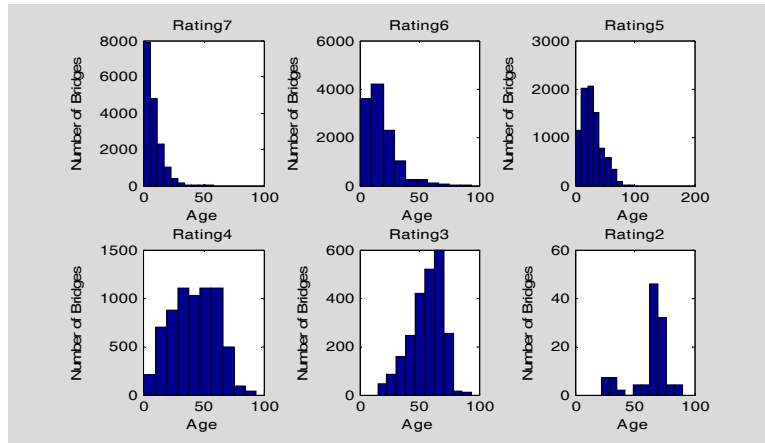


Figure 4-2: Frequency Distribution of Durations for Different Condition Ratings.

Weibull distribution parameters β_i and η_i , $i = 1, 2, \dots, 6$, obtained by fitting duration data for different condition ratings can then be used to estimate *any* other distributional characteristic such as percentiles and probabilities of exceeding any specified duration t . For example, DeLisle et al (2004) have obtained β_6 and η_6 for CR6 for structural deck elements as 27.3 and 1.2 respectively. Then, the probability that a bridge deck entering into CR6 at some particular time remaining at CR6 for more than 10 years is obtained from Eq.(4-5) as $P(T_6 > 10) = S_6(10) = e^{-(10/27.3)^{1.2}} = 0.74$. Hence, the probability that the deck will transition to CR5 in 10 or less years is $1 - 0.74 = 0.26$. Similarly, the probability that a deck element that has been at CR6 will remain at CR6 for an additional 10 years can be estimated as $S_6(20)/S_6(10) = 0.68$. Alternatively, the probability that a structural deck that has been at CR6 for 10 years will move to CR5 within the next 10 years is $1 - 0.68 = 0.32$. This type of information is extremely important for effective bridge management and cannot be obtained by other approaches, including the Markov chains approach.

For the Weibull distribution, mean T_i for a condition rating i is calculated by

$$E(T_i) = \eta_i \Gamma\left(1 + \frac{1}{\beta_i}\right) \quad (4-6)$$

where Γ is the Gamma function. Using Eq.(4-6), mean durations for different CRs are obtained cumulatively, i.e., CR7 to CR6 = $E(T_7)$, CR7 to CR5 = $E(T_7) + E(T_6)$, etc. Although mean T_i represents average duration that a bridge element will stay at i^{th} CR, some of the elements will transition to $(i-1)^{\text{th}}$ CR during this period. This information can be calculated by percentile of CR, given by

$$t_p = \eta[-\ln(1-p)]^{1/\beta} \quad (4-7)$$

where t_p is the duration after which p% of the samples of an element will move to lower CR. For example, T_5 for CR5 to CR4 is 23 years and $t_{25\%} = 11$ years. This means that 25% of the samples of an element will transition to CR4 within 11 years, although mean T_5 is 23 years.

4.4. Computer Program for Deterioration Rates Calculations

A computer program, Bridge Element Deterioration Rates (BEDR), has been developed in C++ using filtered and reconditioned data, as described in Chapter 2. The computer program has the capability to carry out cascading classification so that a particular bridge element can be classified on the basis of numerous factors, e.g., design type, material type, AADTT, etc. Some of the unique features of the computer program are:

- (i) The element grouping is done by using the file MetaDataElementGrouping.ini, which is located in “Main Program” folder of the computer program. The grouping can be changed by simply changing the entries for a particular grouping in this file, provided titles of the groupings aren’t changed.
- (ii) The program uses the filtered database. “Update Database” macro that is integrated with the database accompanied with this program should be used when updating the database using new inspection data. Instructions on updating the database are provided in Appendix B and also as a part of the computer program package on the CD-ROM.
- (iii) Database filtering and reconditioning logic are implemented through various modules written in Visual Basic. These modules are integrated with the database accompanied with this program. These modules should be used when updating the database using new inspection data.
- (iv) The computer program calculates deterioration curves using both Markov and Weibull approaches. These curves can be represented by simplified equations obtained by curve fitting of deterioration curves. Curve fitting equations for both Markov chains and Weibull-based approaches can be expressed as

$$CR = d + cT + bT^2 + aT^3 \quad (4-8)$$

in case of a cubic equation. Coefficients d, c, b and a in Eq.(4-8) are generated by the program. Users can choose any degree of quadratic equation. For higher order quadratic equations, order of the use of coefficients generated by the program will be the same. After finishing curve fitting, deterioration curve data can be exported to a file by using “Export” button on “Polynomial Fit” window (obtained by clicking “Regression”).

For Weibull-based approach, the computer program also gives an options to obtain curve fitting by using Bleasdale form of curve fit equation which is of the form

$$CR = (a + bT)^{1/c} \quad (4-9)$$

This equation is displayed on the top portion of the graph window that appears after the “Bleasdale” option under “Weibull” option is clicked. It should be noted from the Eq.

(4-9) above that $a^{(1/c)} = 7$ when $T = 0$.

- (v) The computer program can compare deterioration curves between two classes in case of both Markov Chain and Weibull-Based approach.

(vi) Special Notes for Markov Chains Approach

- a. The Markov chains approach utilizes second level approach as described in Section 4.2.
- b. Level 2 Markov Chain is generated by using only first 40 years of data generated during the Level 1 Markov Chain.
- c. Transition matrix generated for the Level 2 Markov Chain can be output into a file by clicking the “Transition Matrix” button under the “Markov” menu. Markov chain plot window shows the coefficient of determination for the results. The coefficient of determination has been calculated by using the first 40 years of first level Markov data, since older data may be affected by bias errors. The coefficient of determination r^2 gives an indication of the “fit” strength of the Markov Chain equation and is expressed as,

$$r^2 = 1 - \frac{S_r}{S_t} \quad (4-10)$$

In Eq.(4-10), S_r is the sum of squares of the residuals with respect to the regression line (Second Level Markov) for scattered points (x_i, y_i) given by

$S_r = \sum_{i=1}^n (y_i - \lambda_i)^2$ where S_t is the sum of the squares of the residuals with respect

to the average. For scattered points (x_i, y_i) , $S_t = \sum_{i=1}^n (y_i - \bar{y})^2$ and $\bar{y} = \frac{1}{n} \sum_{i=1}^n y_i$.

Here scattered points (x_i, y_i) are average inspection ratings at different ages.

(vii) Special Notes for Weibull-Based Approach

- a. In Weibull-based approach, the mean duration may not exist at an intermediate rating because of insufficient data. For example, mean duration may exist for ratings 7, 6, 5, 4, and 2 and not for 3. In this case, age at rating 2 cannot be estimated since the mean duration for rating 3 (i.e., from 3 to 2) is not available. In this situation, mean durations for only ratings 7, 6, 5 and 4 are used to develop the deterioration curve.

4.5. Computer Program Interface

Figure 4-3 shows the main interface of the computer program. The program has the following four interfaces:

Element View: In element view, users can see the “HANDLED” table (Table generated by the filtering/reconditioning module). This table contains filtered data for all BINs, work history information, year built information and span information. Element View can be opened by either of the following two options:

- a. From the menu bar, View -> Element View
- b. From the toolbar, click "Element"

Class View: Once cascaded classes have been selected from the classification form, class view can be used to see detailed information on properties of classes, e.g., element and other classification factors, number of bridge elements, etc. Class view can be opened by either of the following two options:

a. From the menu bar, View-> Class View

b. From the toolbar, click "Class"

Help View: In help view, users can see the help menu to use the computer program. Help view can be opened by either of the following two options:

a. From the menu bar, View-> Help View

b. From the toolbar, click "Help"

Markov Chain View: Markov chain view opens up the Markov Chain window where the users can perform Markov Chain analysis. Markov view can be opened by either of the following two options:

a. From the menu bar, View-> Markov Chain View

b. From the toolbar, click "Markov"

Weibull View: Weibull view opens up the Weibull window where the users can perform Weibull analysis. Weibull view can be opened by either of the following two options:

a. From the menu bar, View-> Weibull View

b. From the toolbar, click "Weibull"

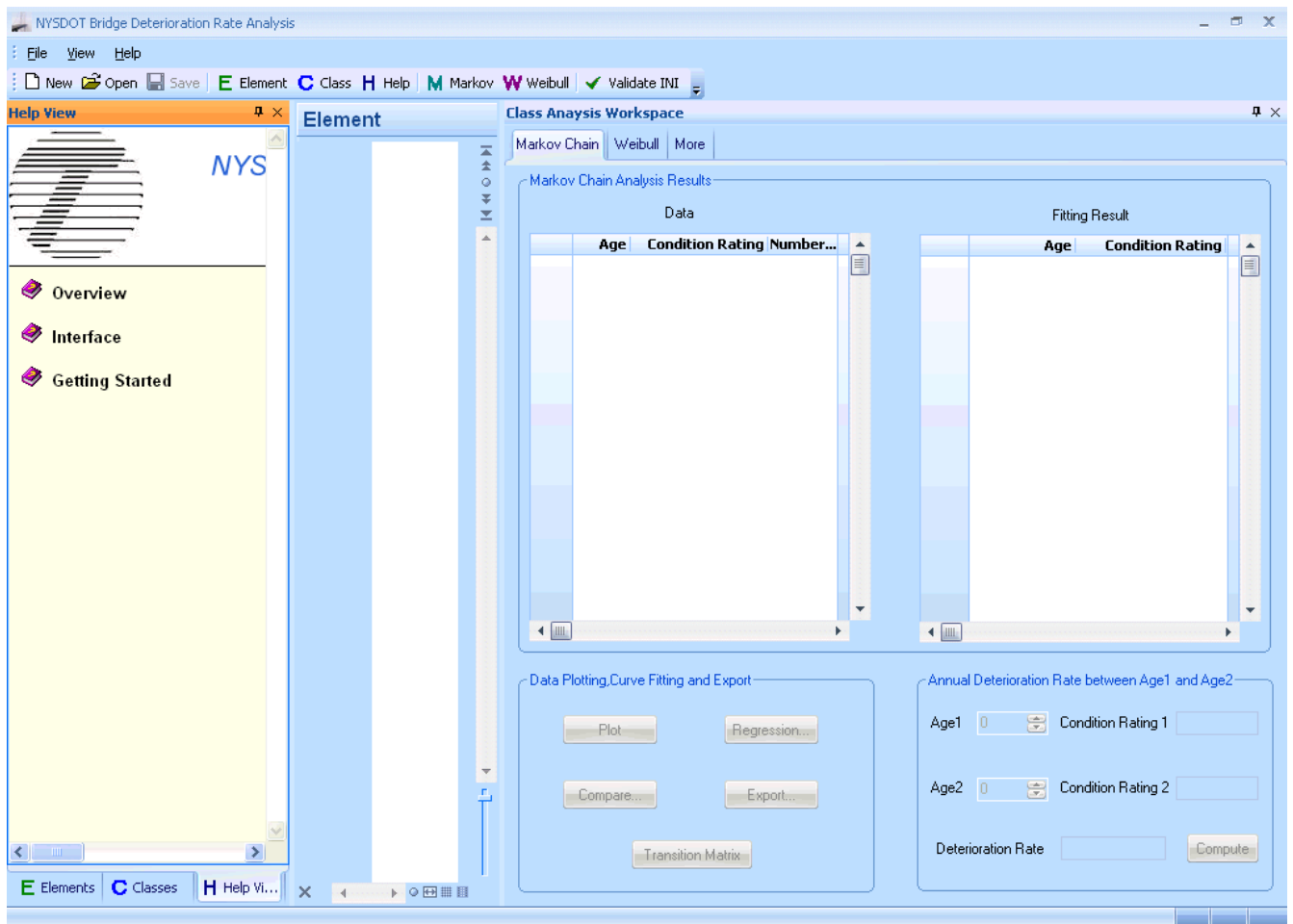


Figure 4-3: Screenshot of the Computer Program Showing Interfaces.

4.6. Computer Program Manual

4.6.1. Creating a new project

Before starting a new project, click "Validate INI" button from toolbar which will check the validity of file "MetaDataElementGrouping.ini". It is important to check whether tables and fields do exist in the database. However the validity of field values has to be checked manually.

To create a new project, from the menu bar, click File -> New or from the toolbar, click "New" button.

A "Classification Workspace" dialog, as shown in Figure 4-4 below, will pop up which includes two sub dialogs, one is "Classification" dialog in which one can select the classification items, and the other is "Result" dialog which shows classification results. A user can also switch the views of these two sub dialogs by clicking the tabs at the top of "Classification Workspace" dialog.

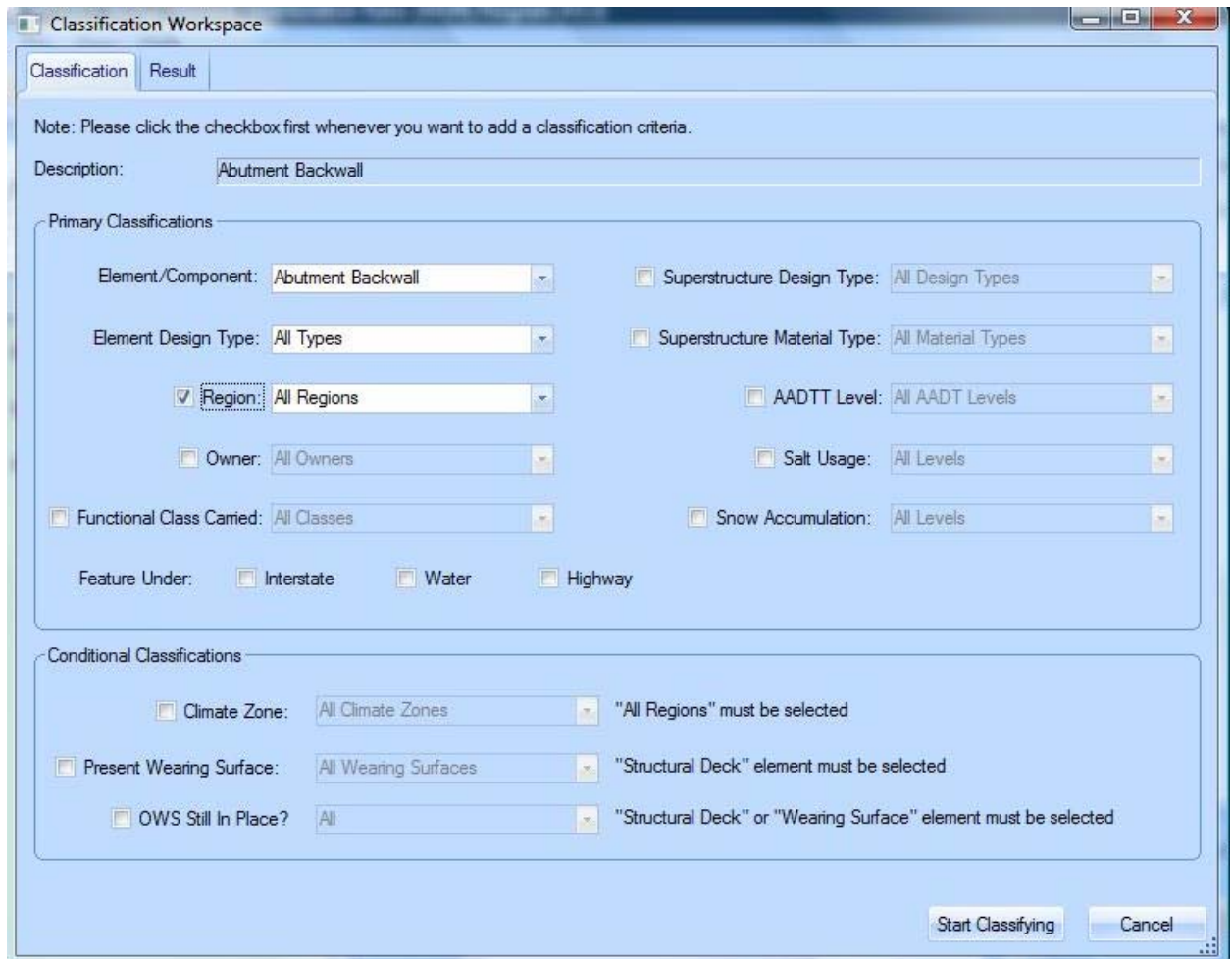


Figure 4-4: Classification Workspace Interface (Selecting too many classification items may lead to smaller number of bridges in analyzed classes, leading to statistically insignificant results)

In "Classification" sub dialog, user can select an element from the Element/Component drop-down menu. For the selected element, a combination of classification items can be selected as desired. Before choosing an item, first click the checkbox on the left side of the item. For example, in order to select "Region" as a classification criterion, click the checkbox on the left side of "Region" dropdown menu. For each item, the default value is "all", which means the bridge element will be classified into all classes in the dropdown item. For example, selecting "Primary Member" under "Element/Component", selecting "Plate Girder" under "Design Type" and checking "Region" box and selecting "all" will result in 11 classes, each class consisting of plate girder type primary members in one of the DOT regions. Instead of selecting "all" regions, one can select a specific item, e.g., "Region 1". This will create a single class of plate girder type primary members in Region 1. If "Region" item is left unchecked, there will be a single class not separated by "Region".

When classification items have been selected, click "start classifying" button. The program will start classifying bridge elements according to classification items selected. This process may take few minutes, depending on the complexity of the selection and speed of the computer being used. During the classification, all bridges in the database are classified into the different classes based on classification items selected. The progress of classification step can be monitored through green progress bars for each class, as shown in Figure 4-5 below. The classification can be interrupted by the "stop" button. However, this action will only return partial results. When the classification is finished, the window shows class details and number of bridges in each class.

Id	Selected	Class Detail	Progress	Number of Bridges
1	<input checked="" type="checkbox"/>	Element : Abutment Backwall Element Design Type : All Region : Region 0	100%	895
2	<input checked="" type="checkbox"/>	Element : Abutment Backwall Element Design Type : All Region : Region 1	100%	1913
3	<input checked="" type="checkbox"/>	Element : Abutment Backwall Element Design Type : All Region : Region 2	100%	1361
4	<input checked="" type="checkbox"/>	Element : Abutment Backwall Element Design Type : All Region : Region 3	100%	1410
5	<input checked="" type="checkbox"/>	Element : Abutment Backwall Element Design Type : All Region : Region 4	100%	1680
6	<input checked="" type="checkbox"/>	Element : Abutment Backwall Element Design Type : All Region : Region 5	100%	2555
7	<input checked="" type="checkbox"/>	Element : Abutment Backwall Element Design Type : All Region : Region 6	100%	1745
8	<input checked="" type="checkbox"/>	Element : Abutment Backwall Element Design Type : All Region : Region 7	100%	1275
9	<input checked="" type="checkbox"/>	Element : Abutment Backwall Element Design Type : All Region : Region 8	100%	2766
10	<input checked="" type="checkbox"/>	Element : Abutment Backwall Element Design Type : All Region : Region 9	100%	2014
11	<input type="checkbox"/>	Element : Abutment Backwall	100%	

Figure 4-5: Classification Workspace Showing Results of Classification.

Results in Figure 4-5 can be arranged in increasing or decreasing order of total bridges in each class by clicking the header of the column "Number of Bridges". One can select classes for which deterioration rates are desired to be calculated by checking the corresponding box under "Selected" column and then clicking "OK" button. All selected classes now will be listed in the "Class" View, as shown in Figure 4-6 below.

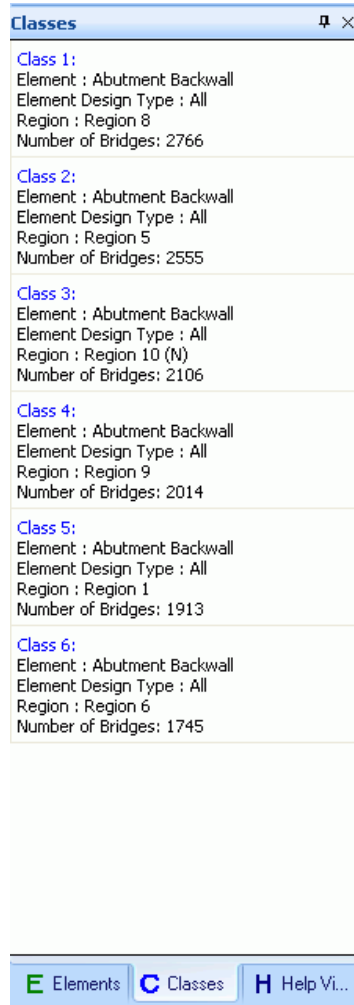


Figure 4-6: Class View Showing Selected Classes.

At this point, one can choose to save the project by selecting "Save As" from the "File" menu or by clicking "save" button on the toolbar. The save action only saves the results of classification. In the popup window "Save DOT project file", give the name to the file and save it somewhere in your computer. The filename postfix is ".dotprj".

The save project file can be opened by selecting "Open" under the "File" menu or by clicking "Open" on the toolbar.

4.6.2. Analyzing Classes

Inspection data for a class can be loaded in the "Class Analysis Workspace" by double clicking a particular class in the class view. Note: in some cases, when you double click a class in "Class View", no data is loaded into the datagrids in "Markov Chain View" or "Weibull View". The reason is that although the selected class may contain certain number of bridges after classification, those bridges may not have condition rating data in relevant combined table because of filtering or reconditioning.

Figure 4-7 shows "Class Analysis Workspace" Window. This window has "Markov chains", "Weibull" and "More" buttons. One can select Markov Chain or Weibull approaches by clicking the appropriate tab. Figure 4-7 shows the Markov Chains view of the class analysis workspace window.

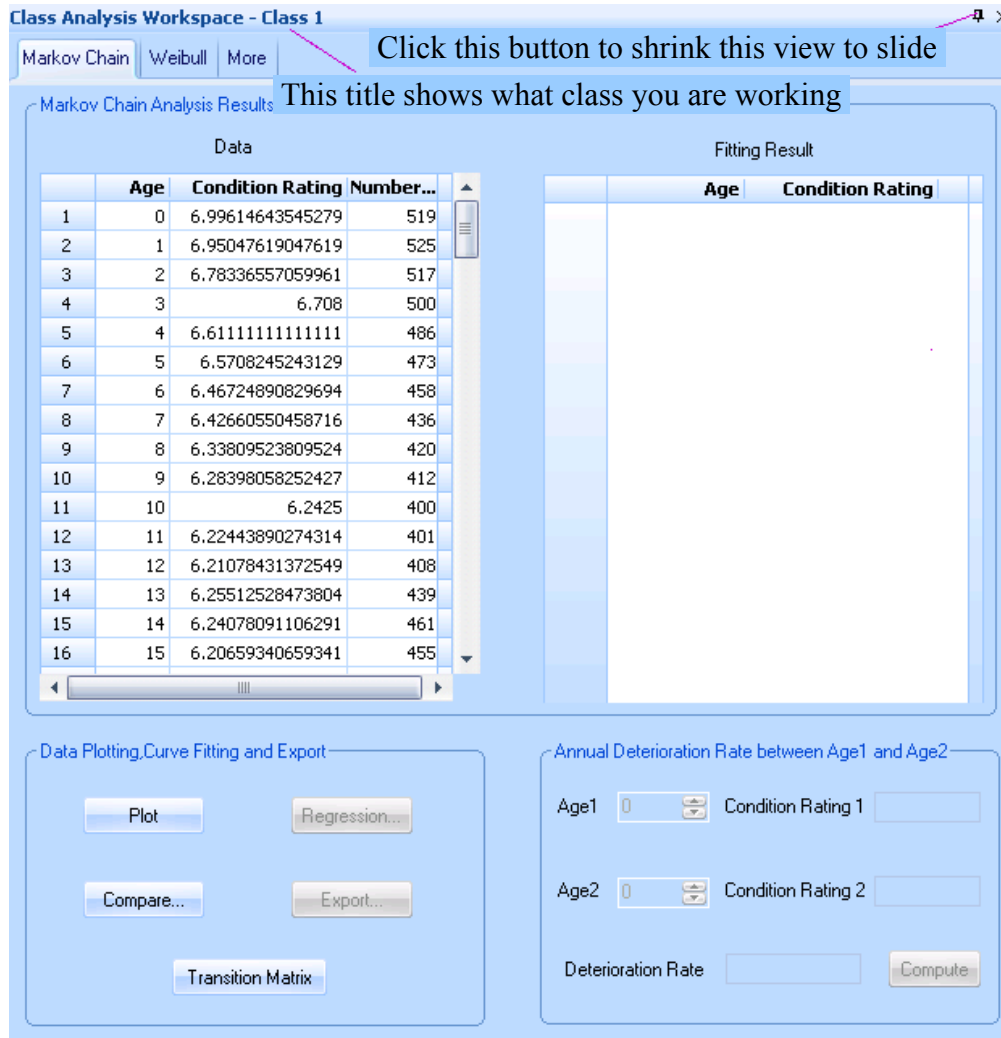


Figure 4-7: Class Analysis Workspace Window.

Functionalities of Markov Chain View:

Plot: Clicking the “plot” button fits the average condition data in the left window to the Markov Chain model. Fitted data is populated in the right hand “Fitting Result” window. A plot in Matlab showing comparisons between original data (left window) and fitted data (right window) appears in a popup window, as shown in Figure 4-8.

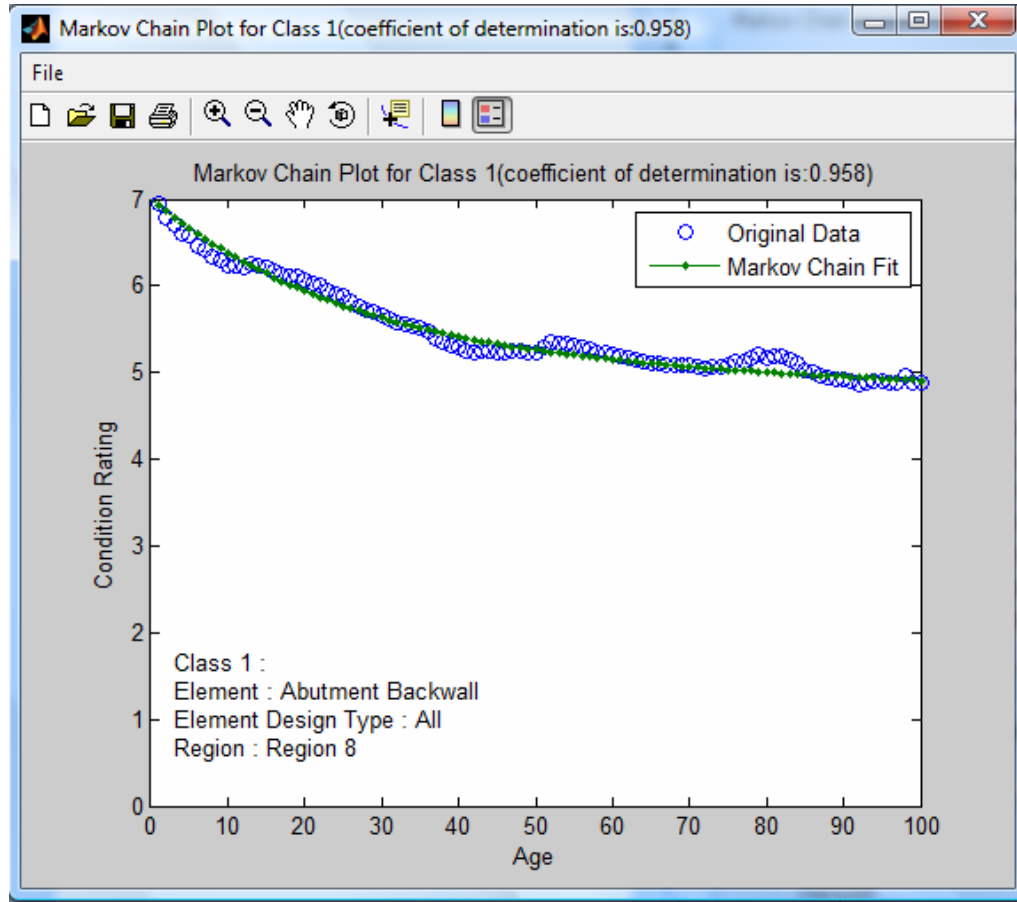


Figure 4-8: Markov Chain Plot Showing Comparisons Between Original and Fitted Data.

Compare: This functionality allows comparisons between two different classes. When the "Compare" button is clicked, a "Compare Classes" window, as shown in Figure 4-9, pops up. In this window, one can select the class to be compared with the current class and then press “OK”. A plot in Matlab showing comparison between two classes, as shown in Figure 4-10, shows up.

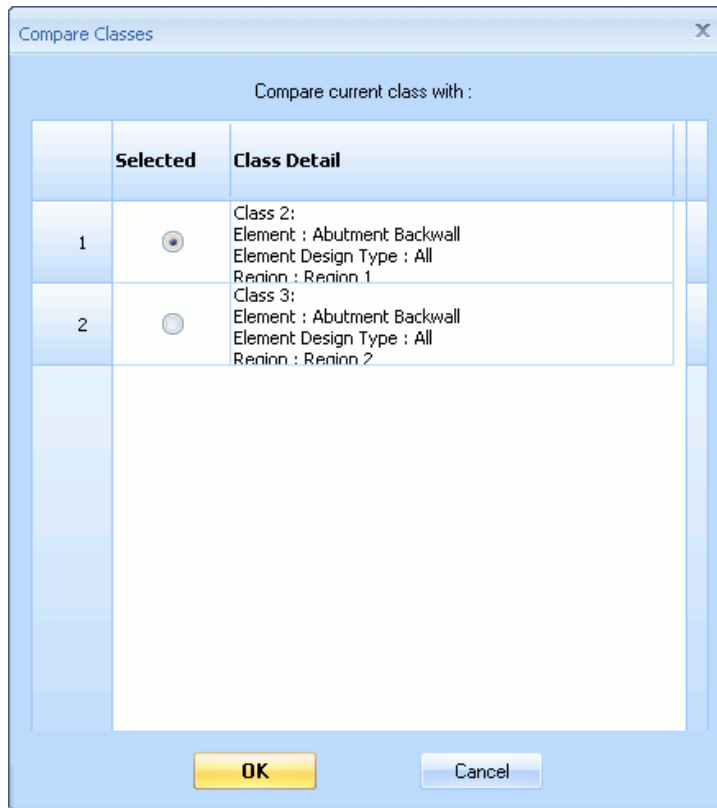


Figure 4-9: Compare Class Window.

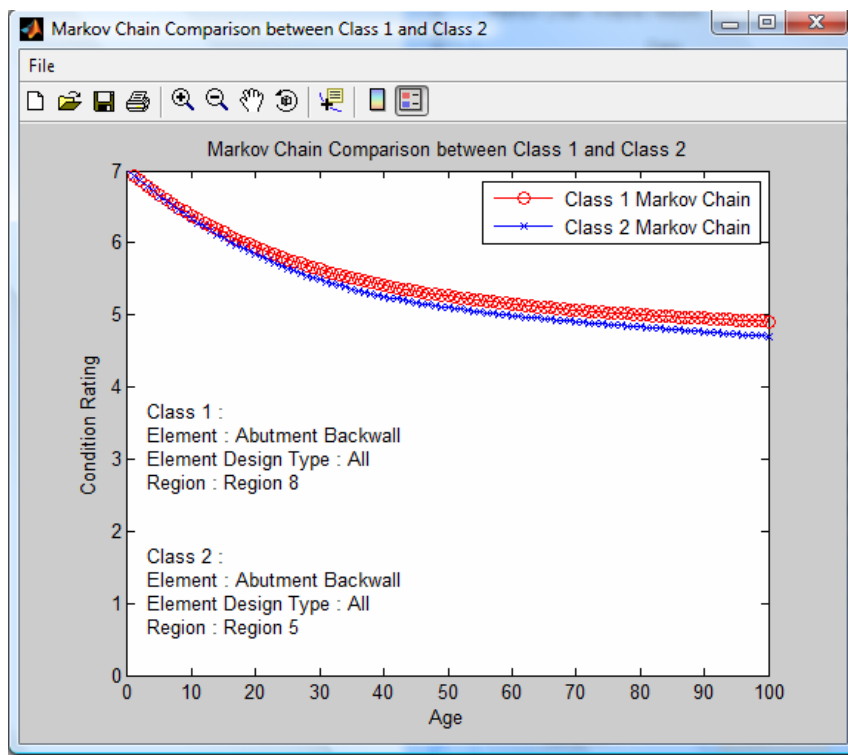


Figure 4-10: Matlab Plot Showing Comparisons Between Two Classes.

Regression: This functionality is enabled after the "Plot" has been generated. A polynomial fitting window appears after the "Regression" window is clicked, as shown in Figure 4-11. In this window, one can choose the degree of regression in the top portion of the window and then click "Plot". This will generate polynomial fit data to the regression curve. Parameters of polynomial regression are displayed in the lower left window. Data generated by the fitted curve are displayed in the upper right window. By clicking "Export", results of regression can be saved in a text file. Deterioration rates of the element between two ages can be calculated by selecting two ages in the lower right window and clicking "Compute". Figure 4-12 shows the Matlab plot generated by clicking the plot button on "Polynomial Fitting" window.

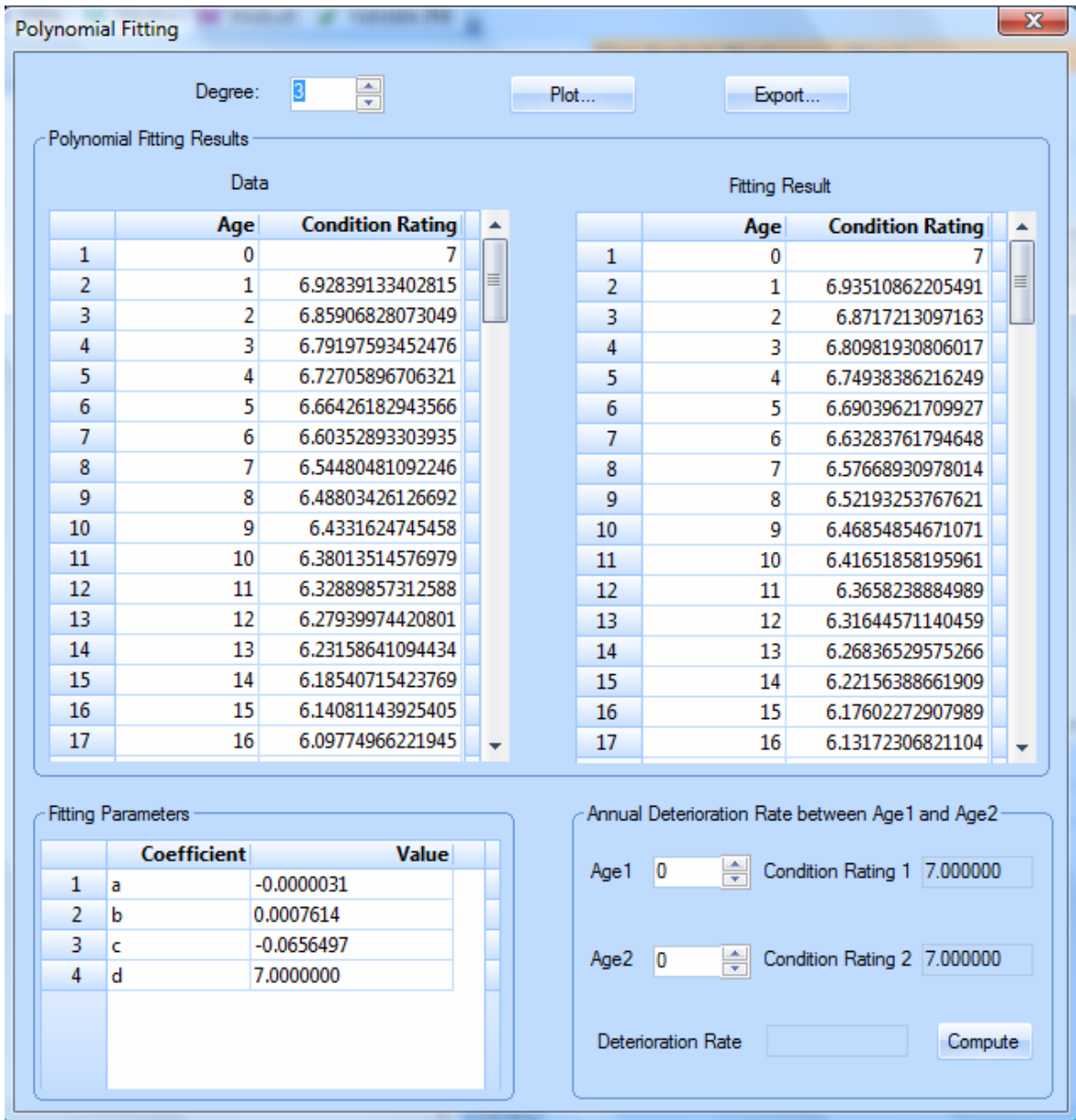


Figure 4-11: Polynomial Fitting Window.

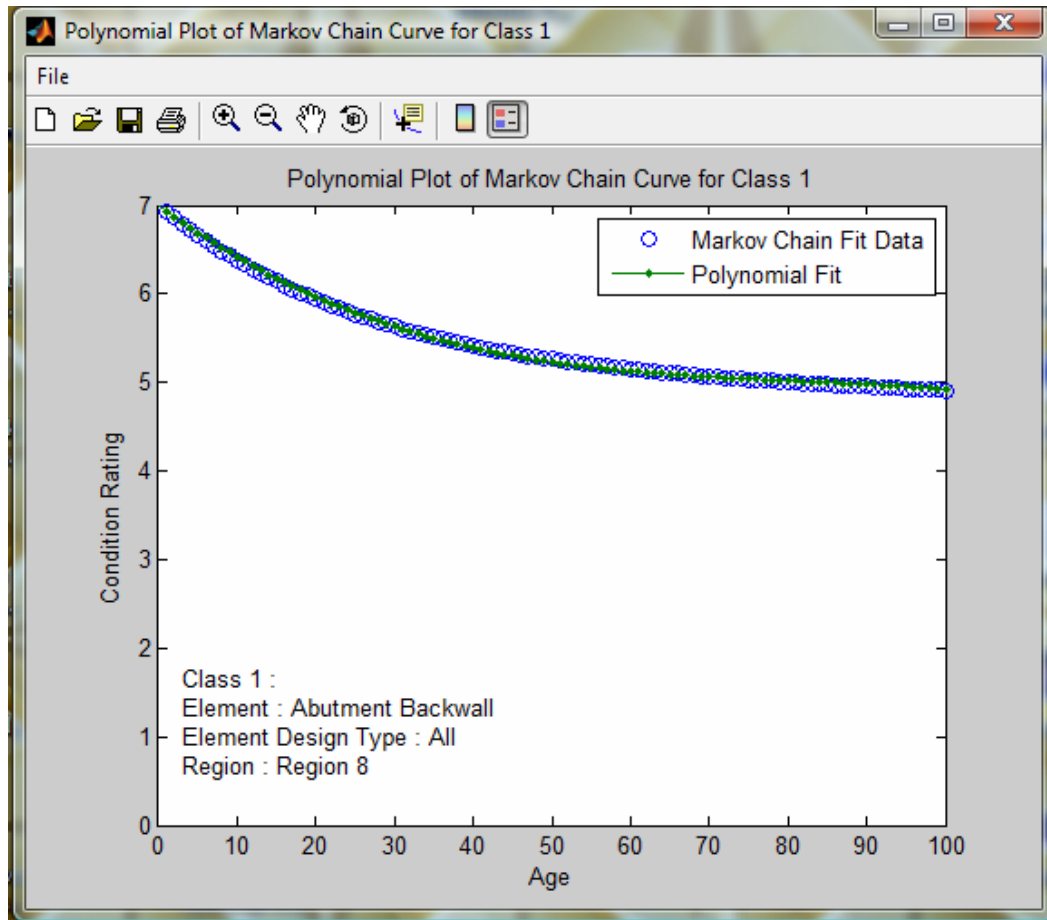


Figure 4-12: Plot Showing Polynomial Fit to Markov Chains Curve.

Export: This button is enabled after the "Plot" is clicked. By clicking the Export" button, one can save the fitted data a to txt or csv file.

Transition Matrix: By clicking this button, the transition matrix for the second level Markov Chains approach is save in a file. A pop up window appears to allow users to enter the file name and directory where it should be saved.

Annual Deterioration Rate between Age1 and Age2: This functionality is enabled after the "Plot" button is clicked. Deterioration rates of the element between two ages can be calculated by selecting two ages in the lower right window and clicking "Compute".

Functionalities of Weibull-based Analysis: Weibull analysis view shows, as in Figure 4-13, once Weibull tab on the class analysis view is clicked.

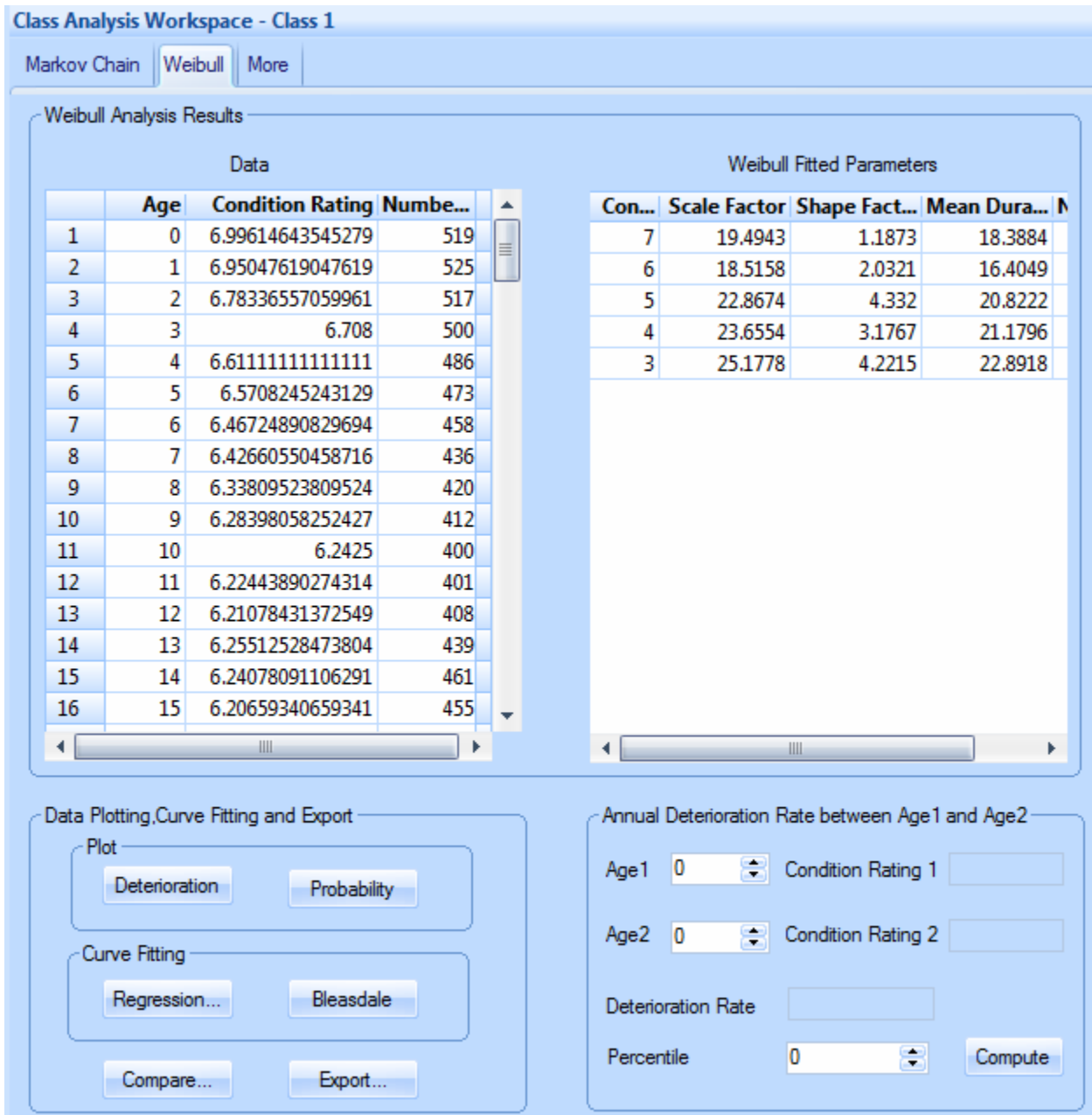


Figure 4-13: Weibull Analysis View.

Plot: The Plot box has “Deterioration” and “Probability” buttons. Clicking the “Deterioration” button fits the average condition data in the left window to the Weibull-based model. Parameters of Weibull-fitting for different condition ratings are displayed in the right window. A plot in Matlab showing comparisons between original data and fitted data appears in a popup window. Another popup window shows the fitted curve along with 95% confidence interval plots. Figure 4-14 shows screenshots of these two plot windows. Clicking the “Probability” button plots the Weibull probability distribution for ratings 7 to 1 in a popup window. Figure 4-15 shows screenshot of the probability distribution plot.

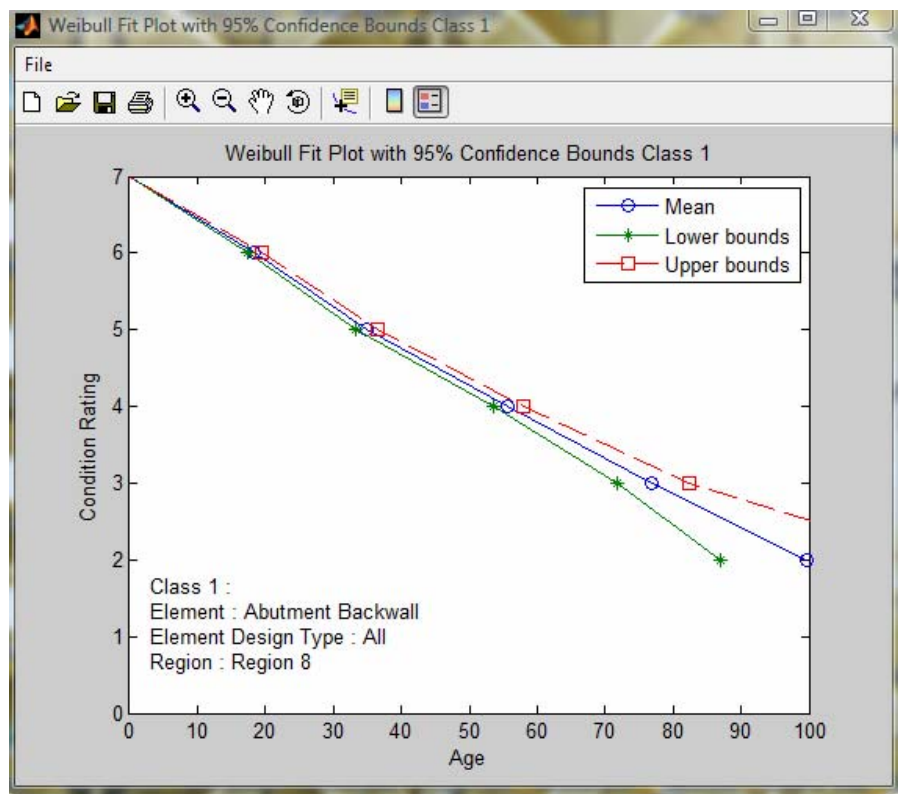
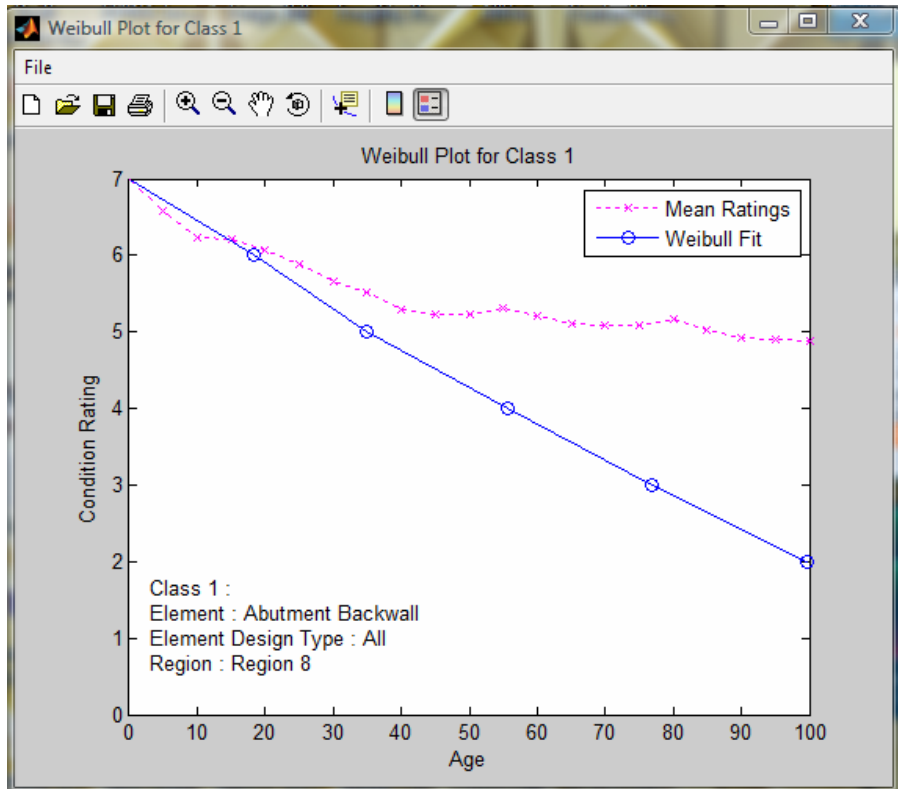


Figure 4-14: Matlab Plots Weibull Based Deterioration Curves; (a) Original Data versus Fitted Data; (b) Fitted Data with 95% Confidence Level Bounds.

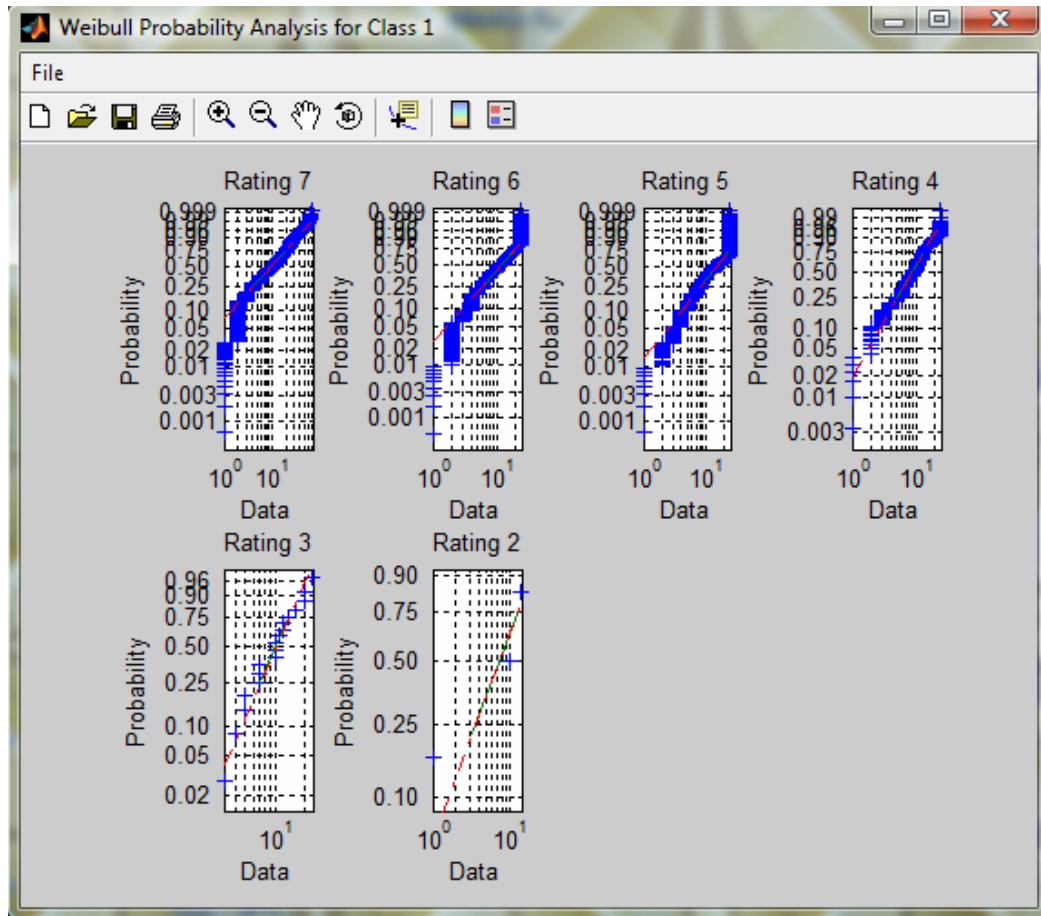


Figure 4-15: Plot Showing Weibull Probability Distributions.

Curve Fitting: The curve fitting box offers the option of deriving equations by either Polynomial Curve fitting or Bleasdale equation. A polynomial fitting window appears after the “Regression” window is clicked, as shown in Figure 4-11. In this window, one can choose the degree of regression in the top portion of the window and then click “Plot”. This will generate polynomial fit data to the regression curve displayed in the lower left window, as shown in Figure 4-11. The plot generated by clicking the “Plot” button is similar to that in Figure 4-12. Data generated by the fitted curve is displayed in the upper right window. By clicking “Export”, results of regression can be saved in a text file. Deterioration rates of the element between two ages can be calculated by selecting two ages in the lower right window and clicking “Compute”.

The main Weibull analysis view (see Figure 4-13) also allows the ability to do curve fitting using the Bleasdale equation. Detailed information on Bleasdale equation is provided in Section 4-4. Clicking “Bleasdale” button generates a plot with Bleasdale equation parameters, as shown in Figure 4-16.

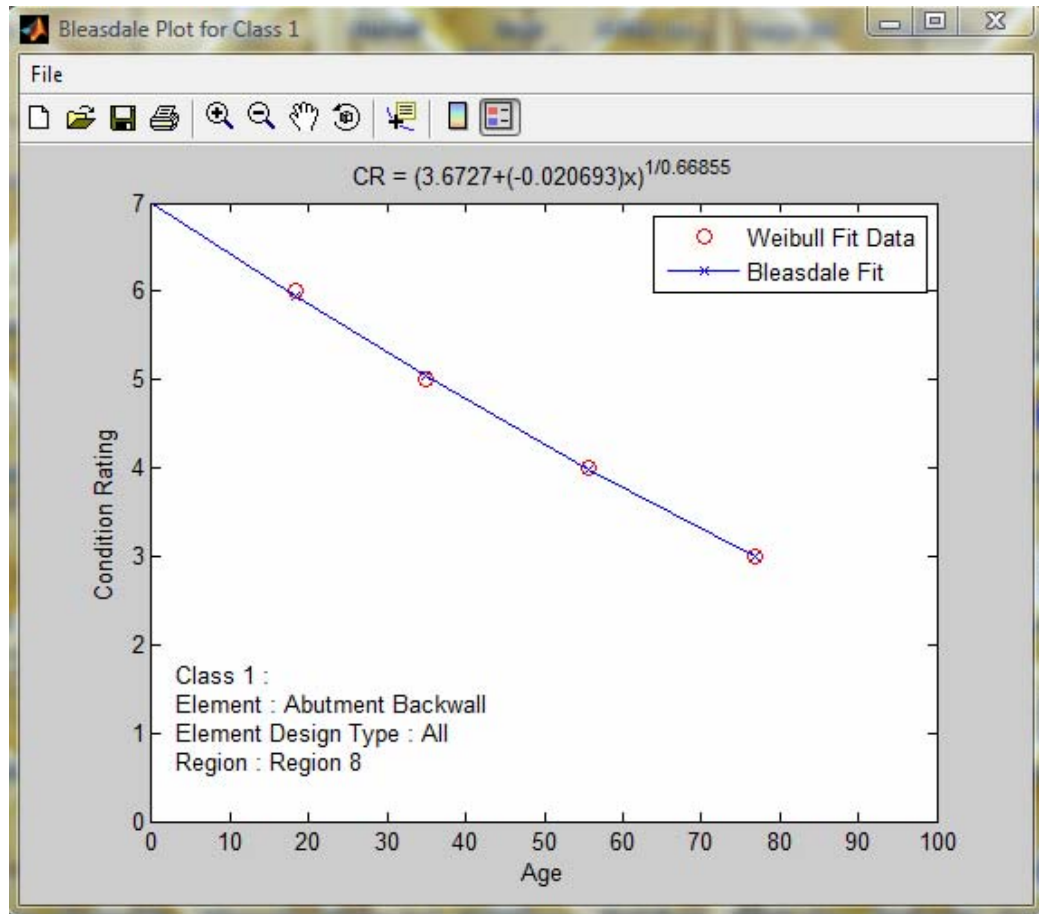


Figure 4-16: Curve Fitting of Weibull-Based Deterioration Curve Using Bleasdale Equation.

Compare: As shown in Figure 4-9, after clicking the “Compare” button, the “Compare Classes” dialog pops up. One can choose the class that needs to be compared with the current class from this window and then click “OK”. A plot in Matlab will appear in a popup window showing the comparison of the two classes. Note that the Group1 in the comparison is the current class, and Group2 is the class you chose in the “Compare Classes” window. Figure 4-17 shows the comparison between deterioration curves for two classes.

Export: This button is enabled after the “Plot” is clicked. By clicking the “Export” button, one can save the fitted data to a txt or csv file.

Annual Deterioration Rate between Age1 and Age2: This functionality is enabled after the “Plot” button is clicked. Deterioration rates of an element between two ages can be calculated by selecting two ages in the lower right window and clicking “Compute”. In the “Percentile” box, one can enter the percentile of bridges (e.g., 25%) for which the annual deterioration rate is to be calculated. It should be noted that the mean age calculated by Weibull-based approach may be for approximately 50 percentile of the bridges (this may vary for different condition ratings). Hence, annual deterioration rate calculated by this functionality may be different than that calculated by considering mean deterioration curve obtained by the Weibull-based approach.

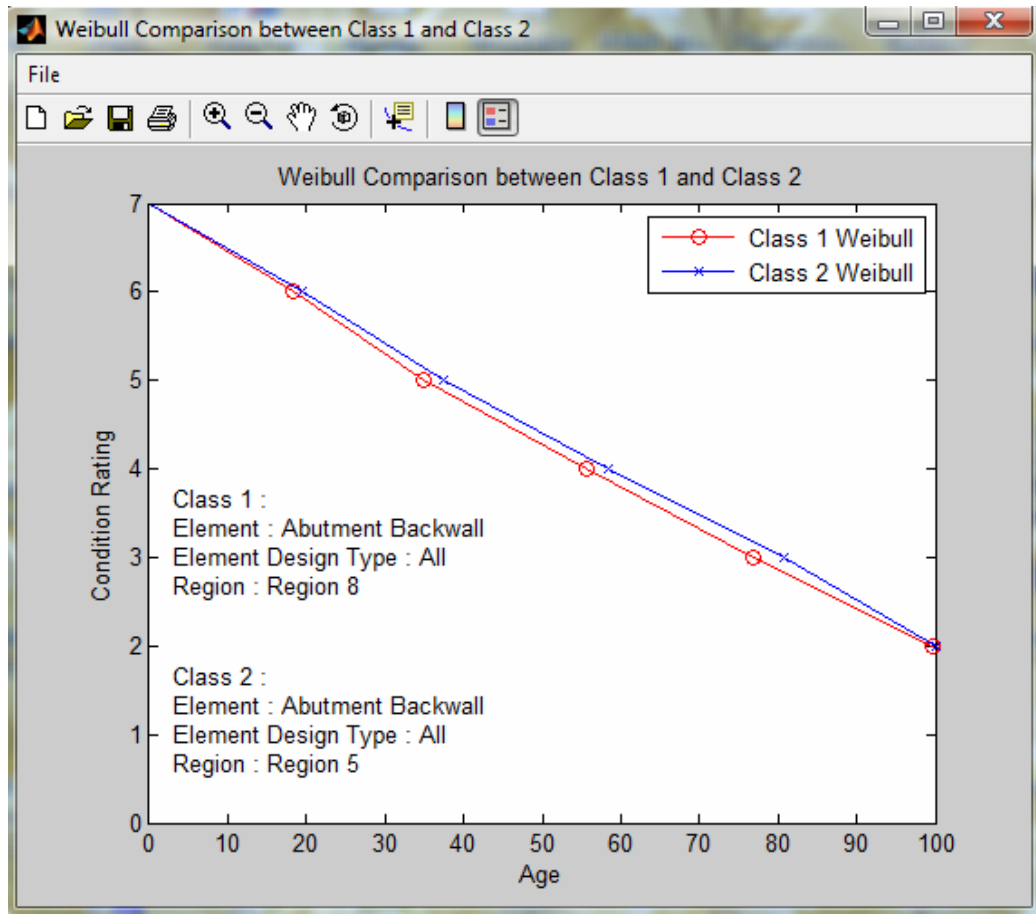


Figure 4-17: Comparison Between Weibull-Based Deterioration Curves for Two Classes.

Functionalities of “More” View: This view provides details on bridges used in deterioration rate calculations. Figure 4.18 shows the “More” view. After clicking on “More” button on “Class Analysis Workspace”, click on “Run”. This view shows three tables.

- Table1 shows all the bridges that belong to the selected class.
- Table2 shows the bridges that belong to the class and have conditional rating data.
- Table3 shows the bridges that belong to the class but do not have conditional rating data.

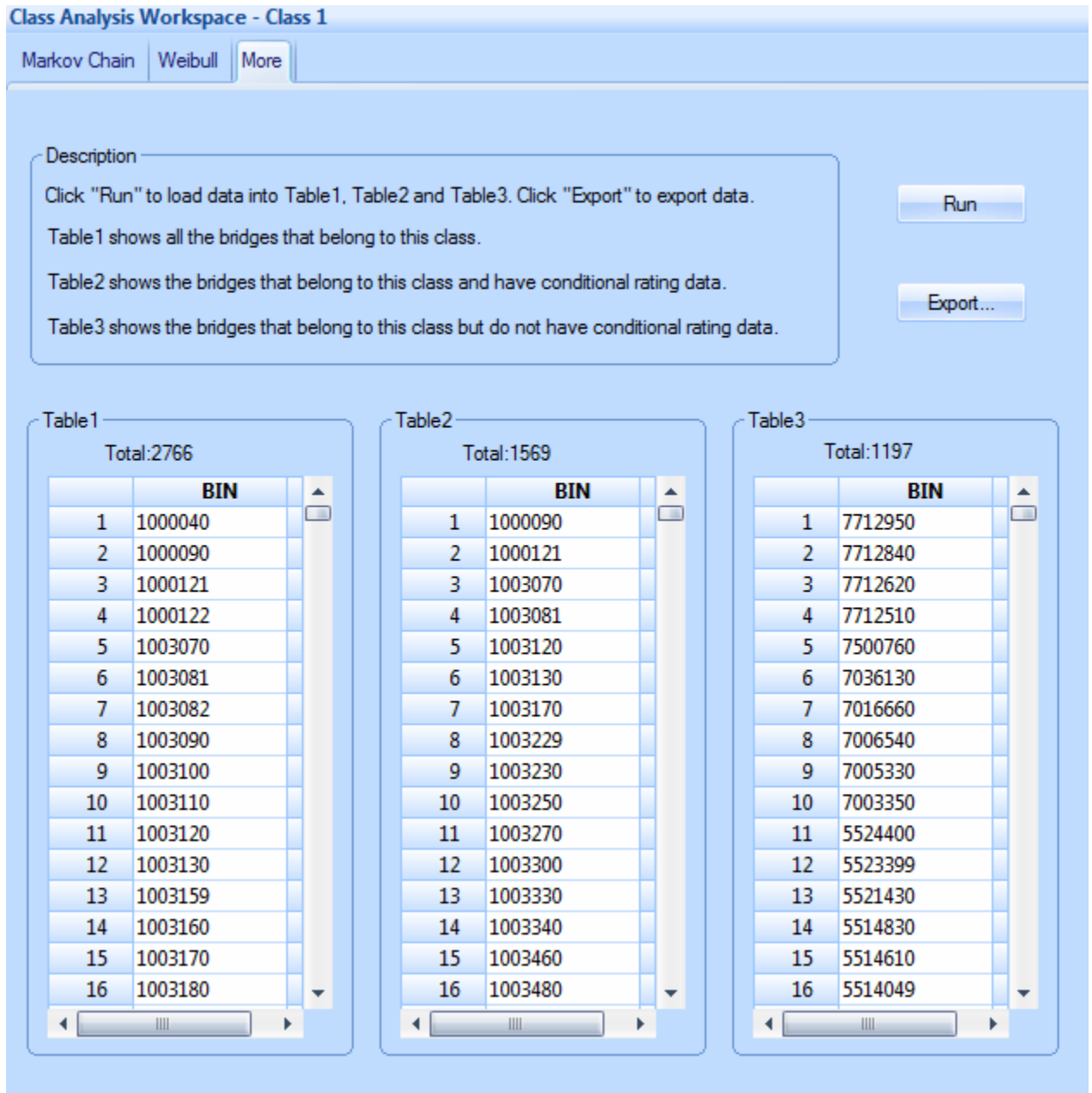


Figure 4-18: "More" View Window.

4.6.3. Viewing Element Rating Data

Element rating data can be viewed by clicking on "Element" tab on the toolbar. "Element" View lists all bridge elements. A specific element can be selected by double clicking by the mouse. All element rating data in the handled table will be displaced in the right side window. Figure 4-19 shows the element view for "Pier Joint" element.

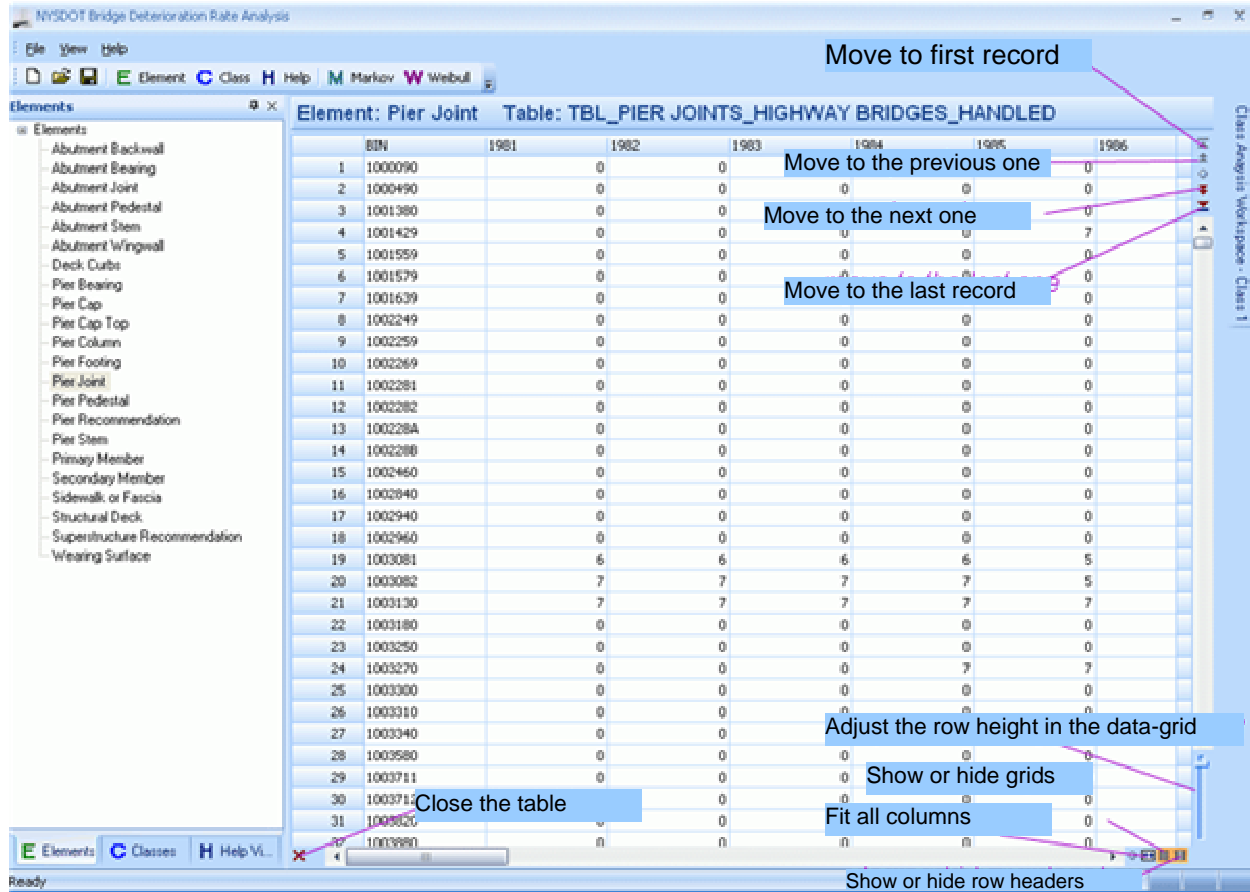


Figure 4-19: Element View Window Showing Element Ratings.

4.7. Comparisons between Markov Chain and Weibull-Based Approaches

Applications of Markov chains and Weibull distribution based approaches in calculating deterioration rates are illustrated through several case studies as described next. For Weibull based approach, figures for case studies also show plots of condition ratings versus age using 3rd order polynomial curves regressed with very good fit coefficients to deterioration curve obtained by Weibull-based approach.

Case 1: Primary Member - Plate Girder - Steel versus Primary Member - Plate Girder - Weathering Steel

Figures 4-20(a) and 4-20(b) show deterioration plots for plate girder type primary members made of steel and weathering steel using Markov Chains and Weibull-based approaches, respectively. It has been observed that Markov chains follow the original data more closely and Weibull-based approach generally gives higher deterioration rate than that by Markov Chains. It is observed from Fig. 4-20(a) using Markov chains that plate girders made of weathering steel deteriorate slower than those made of steel from the beginning. On the other hand, it is observed from Fig. 4-20(b) using Weibull-based approach that plate girders made of steel and weathering steel deteriorate at the same rate during first 20 years. Beyond 20 years of age, weathering steel plate girders deteriorate slower than steel plate girders. In fact, the condition rating of 60 years old steel plate girders drops to 4 whereas it is close to 4.64 for weathering steel girders of the

same age. This makes sense as weathering steel bridges form the protective rust patina that forms during the early years, resulting in a decrease in deterioration of weathering steel bridges. Hence, results using Weibull-based approach confirm the fact that weathering steel plate girders perform significantly better than steel plate girders.

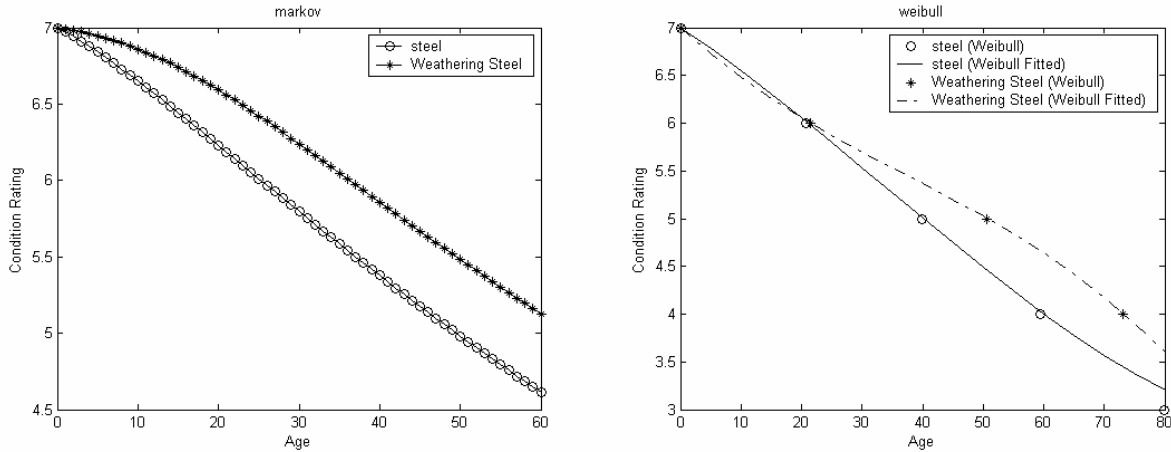


Figure 4-20: Deterioration plots for plate girders made of steel and weathering steel in bridges owned by NYSDOT; (a) Using Markov chains, (b) Using Weibull-based approach.

It is observed from Figure 4-20 that the deterioration behavior using the Markov chains approach are quite different for bridges with steel and weathering steel primary members. On the other hand, deterioration behavior of these two types of primary members using Weibull-based approach is almost identical during the first 20 years. These differences between Markov and Weibull distribution-based approaches in Figure 4-20 can be explained on the basis of their inherent assumptions. One of the main assumptions of Markovian process is of independence from history or duration independence or lack of memory. The Markov chains approach also cannot take into consideration censored condition data. Censoring takes place when the duration at a specific condition level is not completely observed. This happens for the latest condition rating on file or when the condition rating of a bridge element is improved. For the latest condition rating, it is unknown how long the element will remain at its present condition, but the duration is *at least* the number of years already recorded. When an improvement occurs, it is unknown how long the element would have remained at its prior condition level if the improvement had not occurred. As before, the duration is *at least* the number of years recorded at the prior condition rating before the improvement occurred. In both instances, the durations are referred to as *right-censored* and must be handled appropriately.

In Markov Chains, there are only two choices regarding censored observation: disregard them or treat them as actual durations. Either of these choices may lead to seriously biased estimates. Weibull distribution-based approach can handle censored data by explicitly considering duration dependency in the analysis. For example, Weibull-distribution parameters, i.e., (β_7, η_7) pairs in Eq.(4-5) for plate girders of steel and weathering steel in Figure 4-20 are $(3.2473, 23.155)$ and $(2.722, 24.059)$, respectively. Values of $\beta_7 > 1$ clearly show that the deterioration hazard rate is increasing and that it is durationally dependent. Since Markov Chain approach assumes duration independency, Weibull-based approach seems to be more appropriate to calculate deterioration rates.

Case 2: Structural Deck - C.I.P Uncoated Rebar - NYSDOT versus Structural Deck - C.I.P Epoxy Coated Rebar - NYSDOT

Figures 4-21(a) and 4-21(b) show deterioration plots for structural decks with coated and uncoated rebars in bridges owned by NYSDOT using Markov chains and Weibull-based approaches, respectively. It is observed from plots in Fig. 4-21(a) using Markov chains approach that the condition ratings of structural decks with uncoated rebars drops from 7 to 5 in 32 years. For structural decks with epoxy-coated rebars, this happens in 38 years. Using Weibull-based approach, condition ratings drop from 7 to 5 in 31.5 and 37.6 years for structural decks with uncoated and epoxy-coated rebars, respectively. Hence, deterioration rates using both Markov chains and Weibull-based approaches are similar for structural decks with coated and uncoated rebars during first 30-40 years. Durations for condition ratings to drop from 7 to 4 are 49 and 62 years by Markov chains approach for structural decks with uncoated and coated rebars, respectively. These durations are 43 and 60 years, respectively, by the Weibull-based approach. It is obvious from plots in Fig. 4-21 that structural decks with epoxy-coated rebars perform significantly better than those with uncoated rebars, especially in the later years. This is because of higher corrosion in decks with uncoated rebars.

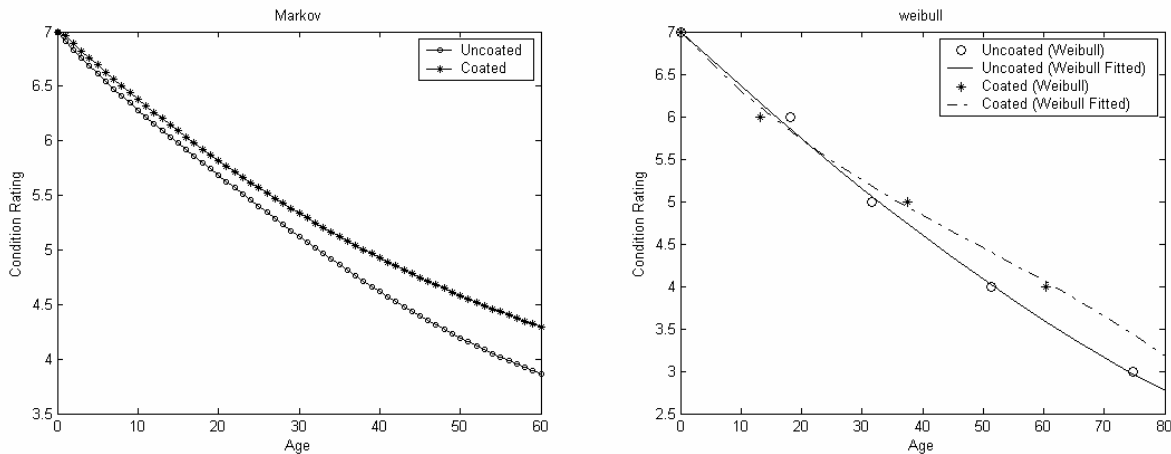


Figure 4-21: Deterioration plots for structural decks with coated and uncoated rebars in bridges owned by NYSDOT; (a) Using Markov-chains approach, (b) Using Weibull-based approach.

Case 3: Structural Deck - C.I.P Uncoated Rebar - NYSDOT vs Structural Deck - C.I.P Uncoated Rebar - Locally Owned

Figure 4-22(a) and 4-22(b) shows plots of structural decks with uncoated rebars and owned by NYSDOT and by locally agencies (denoted as “Locally Owned”) using Markov chains and Weibull-based approaches, respectively. It is observed that decks of locally owned bridges deteriorate slightly faster than those owned by NYSDOT. Higher rate of deterioration in locally owned bridge decks may be because of several factors such as different construction practices, details, and quality assurances, different levels of maintenance as well as other external factors.

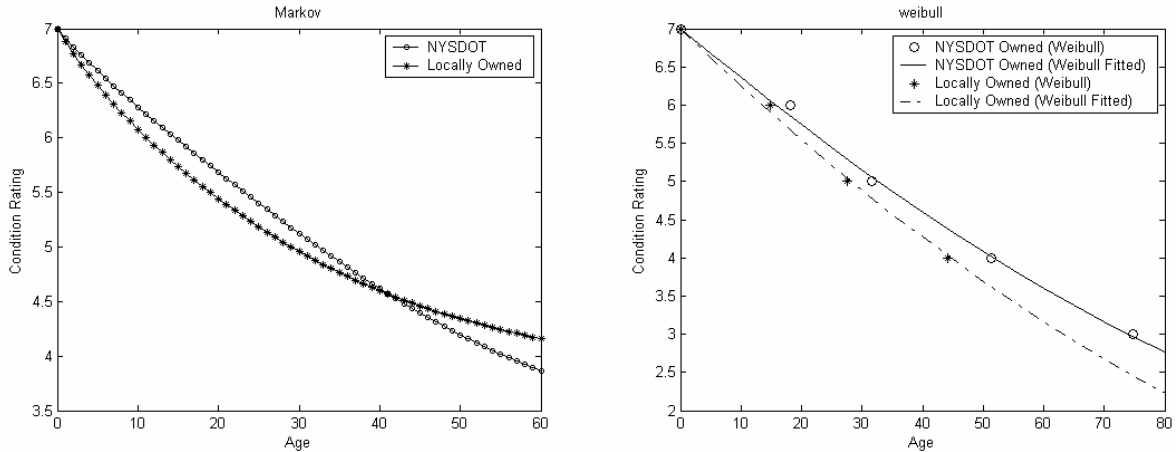


Figure 4-22: Deterioration plots for structural decks with uncoated rebars; (a) Using Markov chains approach, (b) Weibull-based approach.

Case 4: Pier Cap - Concrete - NYSDOT

Figure 4-23 shows deterioration plots for concrete caps in bridges owned by NYSDOT. It is observed from Fig. 4-23 that concrete piers cap deterioration predicted by both Markov and Weibull is almost similar for first 30 years. Behavior of Markov chains plot for pier caps older than 30 years is because of large scatter in inspection data. It is observed from Fig. 4-23 that pier caps deteriorate to condition ratings 6, 5 and 4 in 18, 34 and 54 years. This information can be used for bridge management decisions, such as estimating and scheduling needed maintenance and rehabilitation work. It can also be useful in estimating remaining life of a pier cap when deciding between a superstructure replacement and complete bridge replacement.

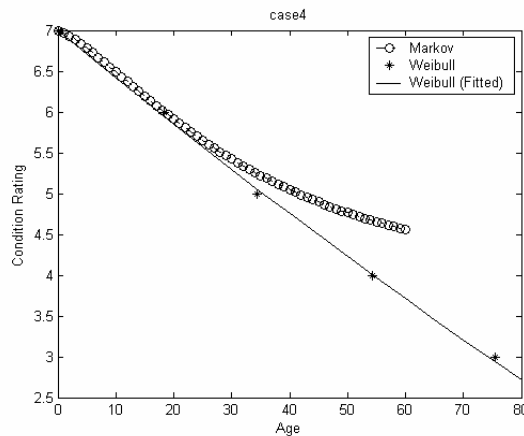


Figure 4-23: Deterioration plots for concrete pier caps in bridges owned by NYSDOT.

Case 5: Abutment Bearing (or Pier Bearing) – Elastomeric

Figure 4-24 shows deterioration plots for Elastomeric Abutment bearings. It is observed from Fig. 4-24 that abutment bearing deterioration predicted by both Markov and Weibull is the same for the first 30 years. Different behavior of Markov chains plot for abutment bearings older than 30 years is because of large scatter in inspection data of abutments bearings older than 30 years. It is observed from Figure 4-24 that abutment bearings deteriorate from condition rating 7 to condition ratings 6, 5 and 4 in 17, 36 and 58 years, respectively.

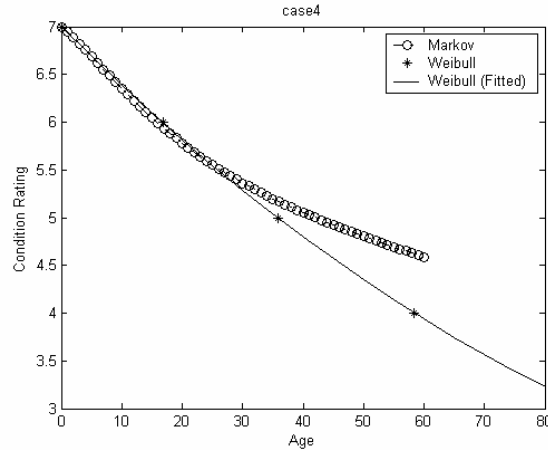


Figure 4-24: Deterioration plots of Elastomeric Abutment Bearings in Bridges Owned by NYSDOT.

Case 6: Abutment Joints with elastic (filled) and compression (including armored) materials

Figure 4-25(a) and 4-25(b) show deterioration plot for abutment joints with elastic (filled) and compression materials for Markov chains and Weibull-based approaches, respectively. It is observed that deterioration rates for both types of materials are almost the same during the first 9 years using Markov chains and during the first 30 years using the Weibull-based approach. Different behavior of plots by Markov chains than those of Weibull-based approach is because of segmentation of data in 10 years groups to derive the first level Markov chains and larger scatter in inspection data of abutment joints with elastic material. From plots of Weibull-based approach, it is observed that condition ratings of abutment joints with elastic materials drop from condition rating 7 to ratings 6, 5 and 4 in 8, 15 and 31 years, respectively. For abutment bearings with compression materials, the ratings drop to 6, 5 and 4 in 6, 16 and 28 years, respectively.

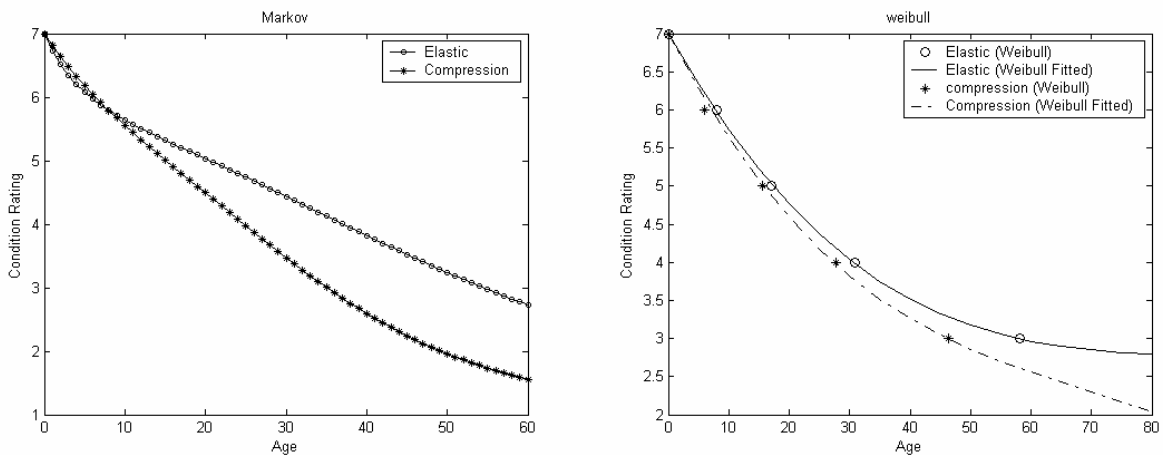


Figure 4-25: Deterioration plots for Abutment Joints with Elastic (Filled) and compression materials; (a) Using Markov chains and (b) Using Weibull-based approaches.

4.8. Deterioration Curves and Rates for Typical Bridge Elements Using Weibull-Based Approach

It is observed from various case studies in previous section that bridge element deterioration rates calculated by the Weibull-based approach are more reliable than those by Markov chains approach. While Markov chain method simply carries out curve fitting to average condition rating data and doesn't explicitly take into account scatter in the data at a particular age, Weibull-based approach takes the scatter into account by calculating Weibull distribution parameters. Hence, a further study of deterioration rates for various bridge elements has been carried out using the Weibull-based approach, as shown in Figures 4-26 to 4-47. Tables 4-1 to 4-22 present polynomial equations for deterioration curves in Figures 4-26 to 4-47, respectively.

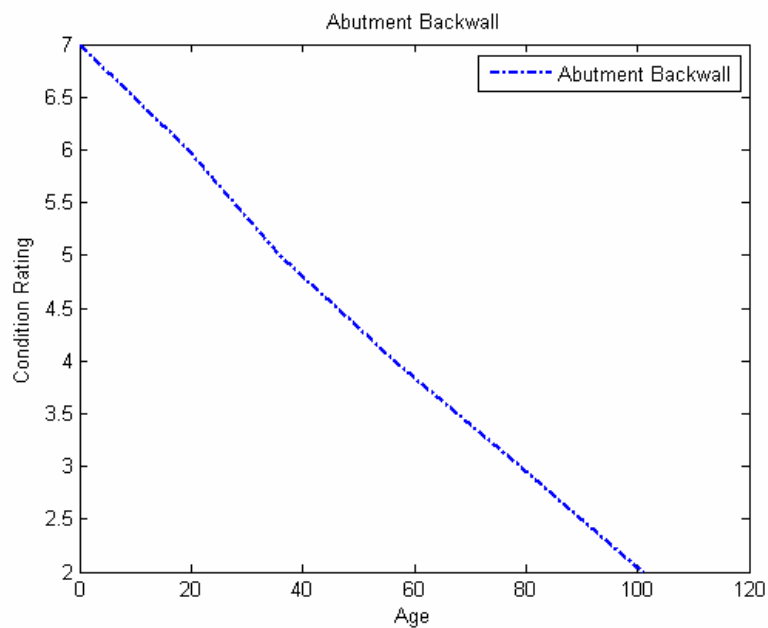


Figure 4-26: Deterioration curve for Abutment Backwall.

Table 4-1: Deterioration Equation for Abutment Backwall.

Abutment Backwall	$CR = 7 - 0.0564703 T + 0.0000667 T^2$
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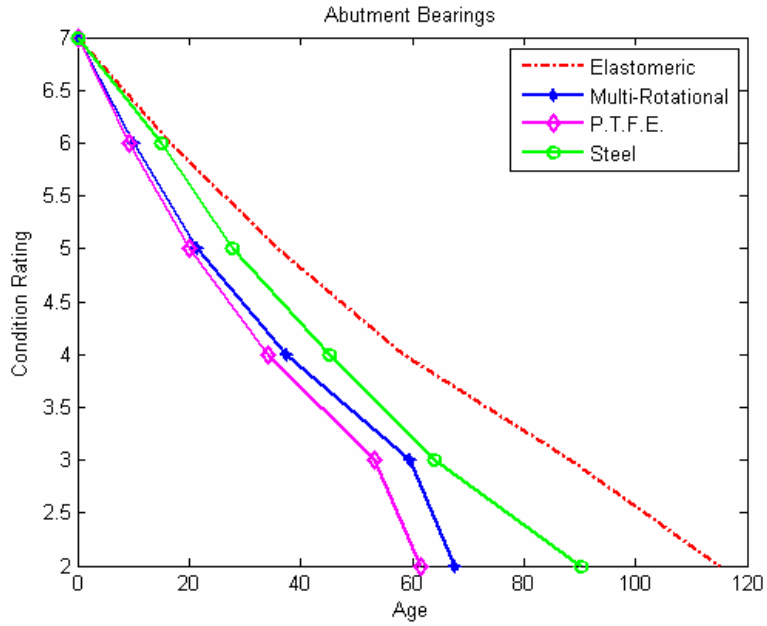


Figure 4-27: Deterioration curve for Abutment Bearing Design Types.

Table 4-2: Deterioration Equations for Abutment Bearing Design Types.

Abutment Bearings	Steel	$CR = 7 - 0.0773187 T + 0.0002408 T^2$
	PTFE	$CR = 7 - 0.1369652 T + 0.0023073 T^2 - 0.0000225 T^3$
	Multi Rotational	$CR = 7 - 0.1276043 T + 0.0020318 T^2 - 0.0000180 T^3$
	Elastomeric	$CR = 7 - 0.0633160 T + 0.0002109 T^2 - 0.0000001 T^3$

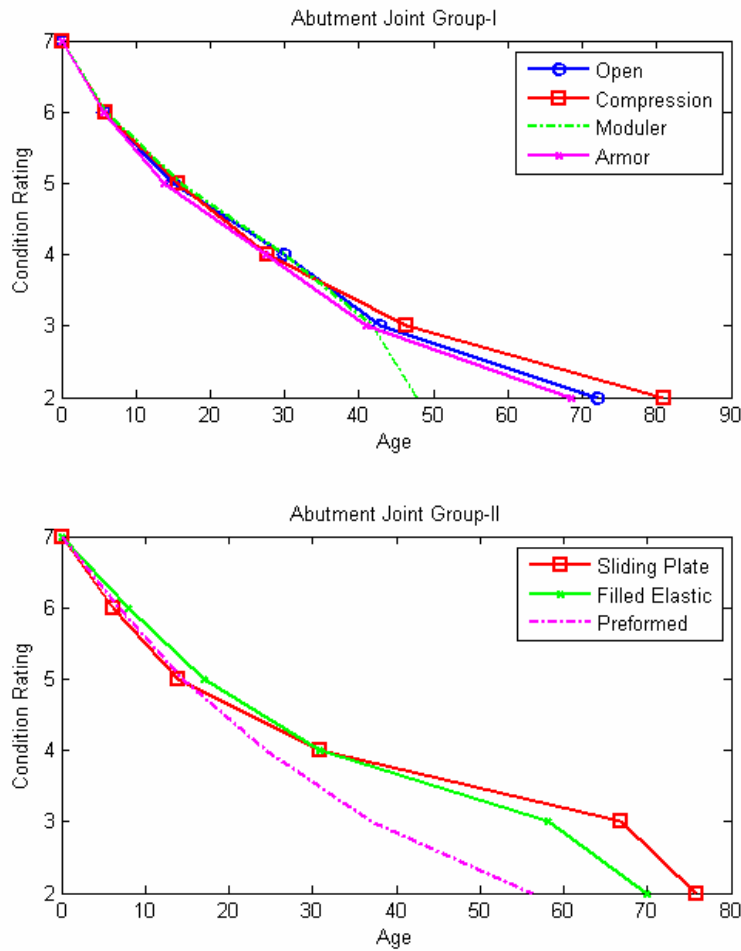


Figure 4-28: Deterioration curve for Abutment Joint Design Types.

Table 4-3: Deterioration Equations for Abutment Joint Design Types.

Abutment Joint	Group-I	
	Open	$CR = 7 - 0.1544542 T + 0.0019093 T^2 - 0.0000101 T^3$
	Compression	$CR = 7 - 0.1546255 T + 0.0019008 T^2 - 0.0000093 T^3$
	Modular	$CR = 7 - 0.1944402 T + 0.0054188 T^2 - 0.0000740 T^3$
	Armor	$CR = 7 - 0.1667466 T + 0.0022536 T^2 - 0.0000129 T^3$
	Group-II	
	Sliding Plate	$CR = 7 - 0.1955859 T + 0.0043095 T^2 - 0.0000342 T^3$
	Filled Elastic	$CR = 7 - 0.1416458 T + 0.0016176 T^2 - 0.0000063 T^3$
	Preformed	$CR = 7 - 0.1563427 T + 0.0014834 T^2 - 0.0000050 T^3$

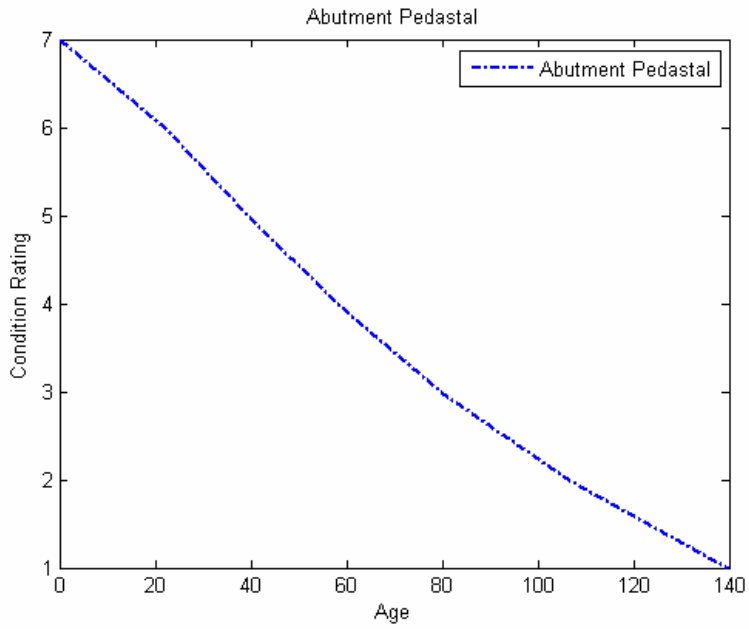


Figure 4-29: Deterioration curve for Abutment Pedestal.

Table 4-4: Deterioration Equations for Abutment Pedestal.

Abutment Pedestal	$CR = 7 - 0.0484691 T - 0.0000925 T^2$
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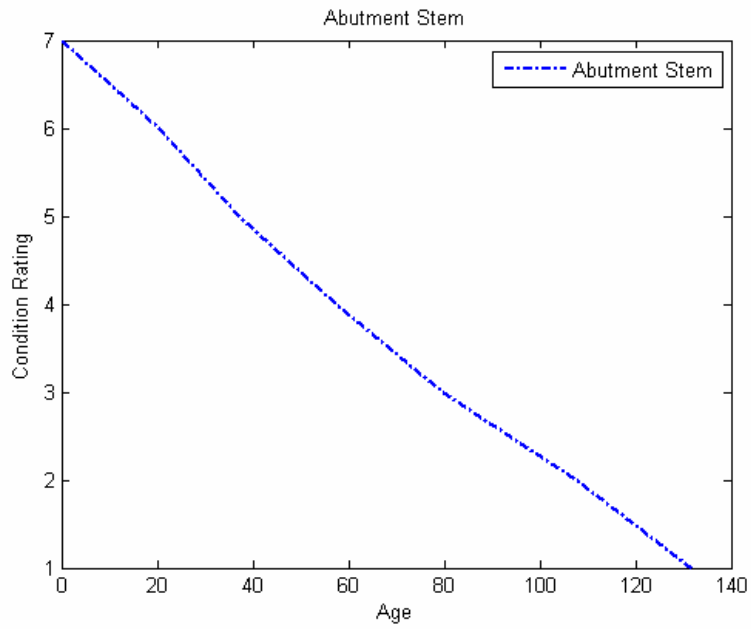


Figure 4-30: Deterioration curve for Abutment Stem.

Table 4-5: Deterioration Equations for Abutment Stem.

Abutment Stem	$CR = 7 - 0.0562065 T + 0.0000832 T^2$
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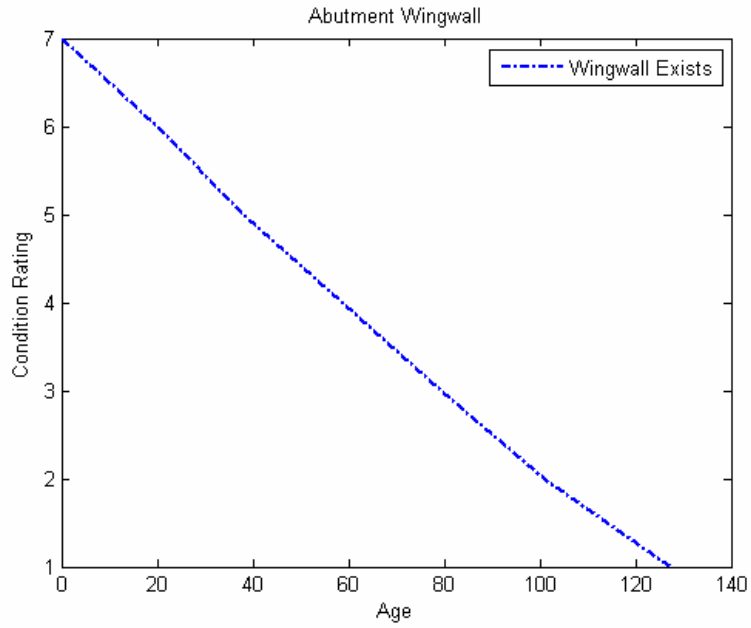


Figure 4-31: Deterioration curve for Abutment Wingwall.

Table 4-6: Deterioration Equations for Abutment Wingwall.

Abutment Wingwall	Wingwall Exists	$CR = 7 - 0.0500728 T - 0.0000546 T^2 + 0.0000006 T^3$
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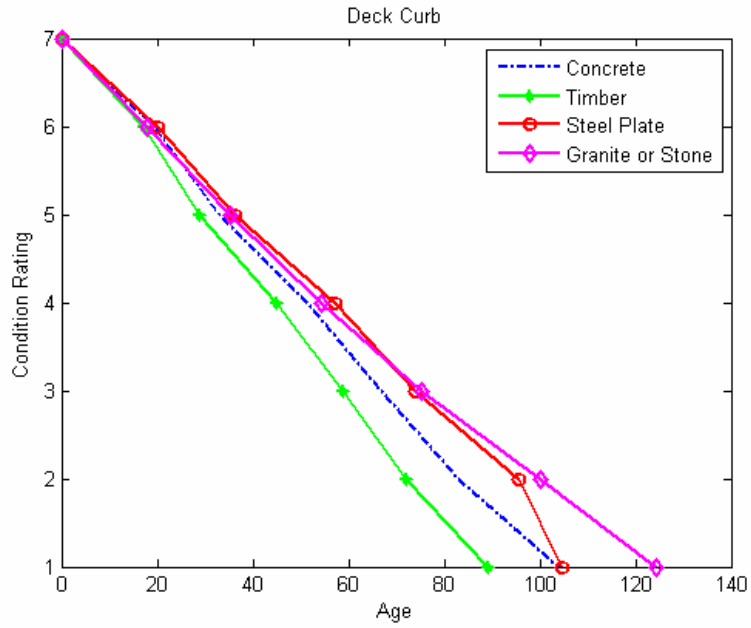


Figure 4-32: Deterioration curve for Deck Curb Design Types.

Table 4-7: Deterioration Equations for Deck Curb Design Types.

Deck Curb	Granite or Stone	$CR = 7 - 0.0605424 T + 0.0001089 T^2 - 0.0000001 T^3$
	Steel Plate	$CR = 7 - 0.0577393 T + 0.0001956 T^2 - 0.0000017 T^3$
	Timber	$CR = 7 - 0.0584921 T - 0.0003144 T^2 + 0.0000024 T^3$
	Concrete	$CR = 7 - 0.0507576 T - 0.0002625 T^2 + 0.0000019 T^3$

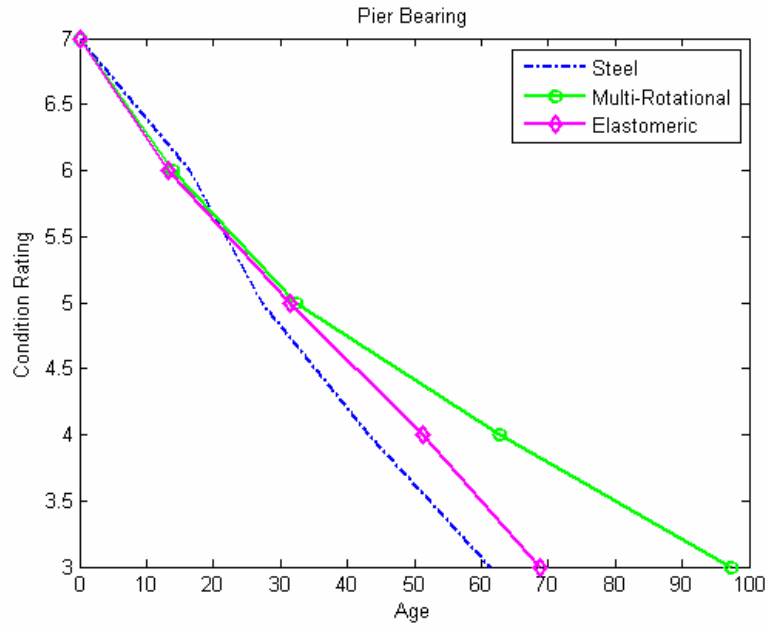


Figure 4-33: Deterioration curve for Pier Bearing Design Types.

Table 4-8: Deterioration Equations for Pier Bearing Design Types.

Pier Bearing	Steel	$CR = 7 - 0.0681319 T - 0.0001597 T^2 + 0.0000034 T^3$
	Multi-Rotational	$CR = 7 - 0.0833154 T + 0.0008055 T^2 - 0.0000038 T^3$
	Elastomeric	$CR = 7 - 0.0845871 T + 0.0008876 T^2 - 0.0000073 T^3$

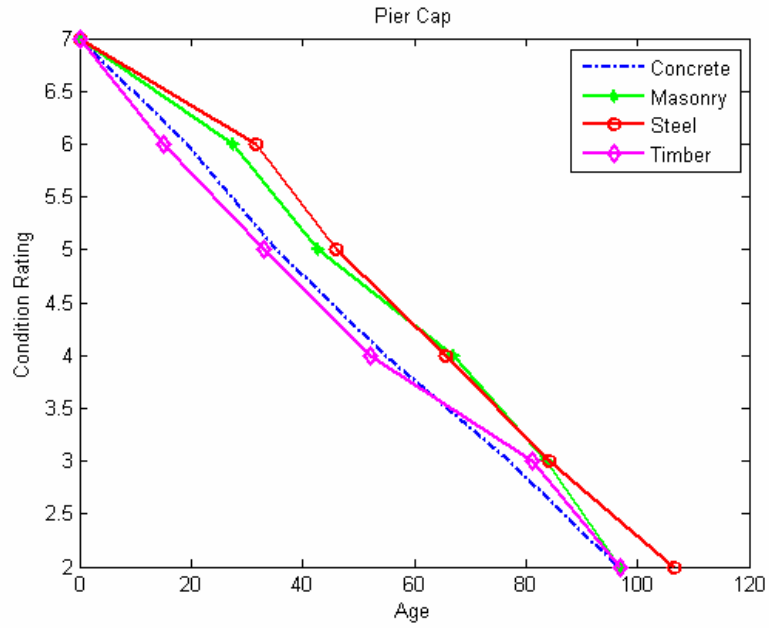


Figure 4-34: Deterioration curve for Pier Cap Design Types.

Table 4-9: Deterioration Equations for Pier Cap Design Types.

Pier Cap	Concrete	$CR = 7 - 0.0575767 T + 0.0000583 T^2 + 0.0000001 T^3$
	Masonry	$CR = 7 - 0.0347071 T - 0.0002426 T^2 + 0.0000011 T^3$
	Steel	$CR = 7 - 0.0172139 T - 0.0006854 T^2 + 0.0000038 T^3$
	Timber	$CR = 7 - 0.0674187 T + 0.0001438 T^2 + 0.0000010 T^3$

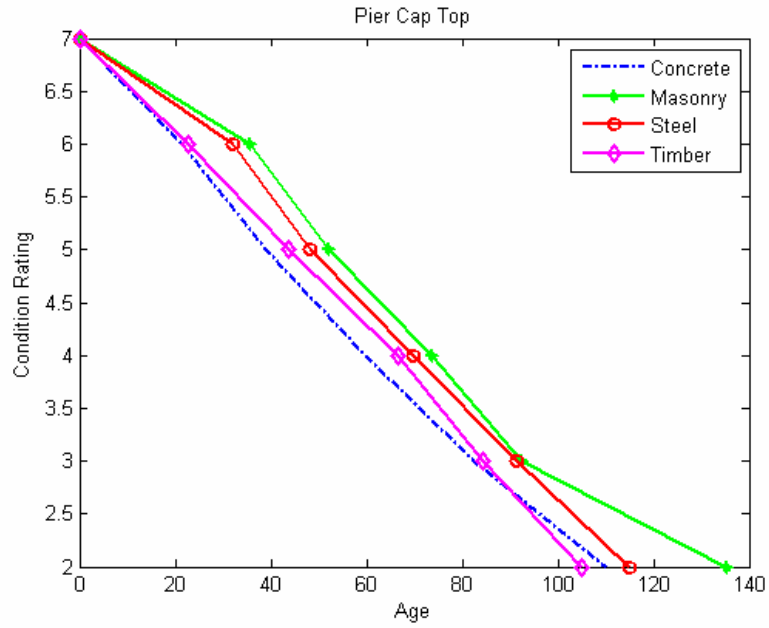


Figure 4-35: Deterioration curve for Pier Cap Top Design Types.

Table 4-10: Deterioration Equations for Pier Cap Top Design Types.

Pier Cap Top	Concrete	$CR = 7 - 0.0475800 T - 0.0001091 T^2 + 0.0000012 T^3$
	Masonry	$CR = 7 - 0.0094394 T - 0.0007153 T^2 + 0.0000038 T^3$
	Steel	$CR = 7 - 0.0131302 T - 0.0007820 T^2 + 0.0000049 T^3$
	Timber	$CR = 7 - 0.0467232 T + 0.0001051 T^2 - 0.0000013 T^3$

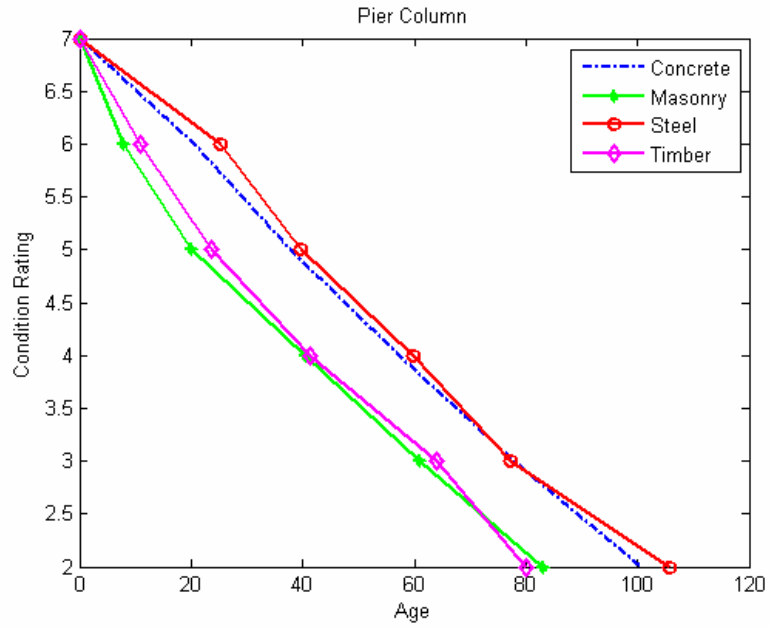


Figure 4-36: Deterioration curve for Pier Column Design Types.

Table 4-11: Deterioration Equations for Pier Column Design Types.

Pier Column	Concrete	$CR = 7 - 0.0486218 T - 0.0001326 T^2 + 0.0000012 T^3$
	Masonry	$CR = 7 - 0.1461181 T + 0.0028522 T^2 - 0.0000266 T^3$
	Steel	$CR = 7 - 0.0594952 T + 0.0002300 T^2 - 0.0000004 T^3$
	Timber	$CR = 7 - 0.1077933 T + 0.0012051 T^2 - 0.0000079 T^3$

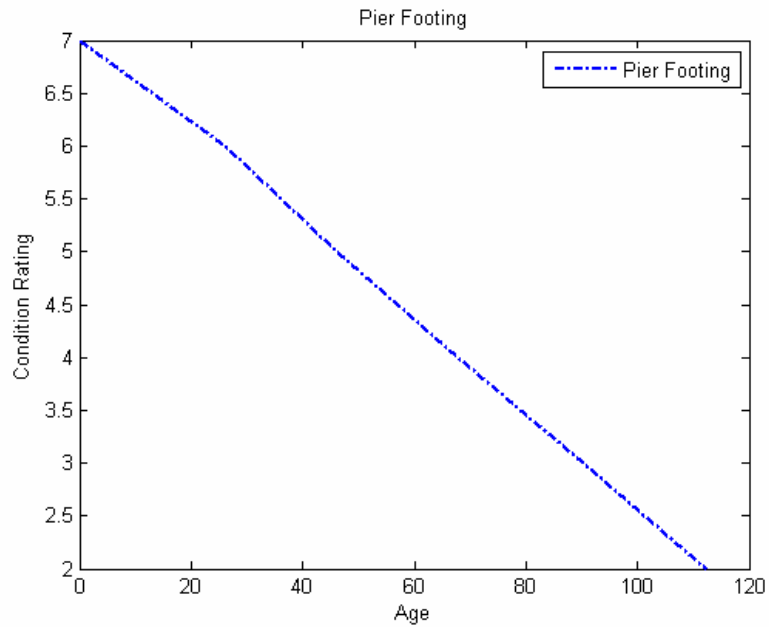


Figure 4-37: Deterioration curve for Pier Footing.

Table 4-12: Deterioration Equation for Pier Footing.

Pier Footing	$CR = 7 - 0.0361181 T - 0.0001836 T^2$
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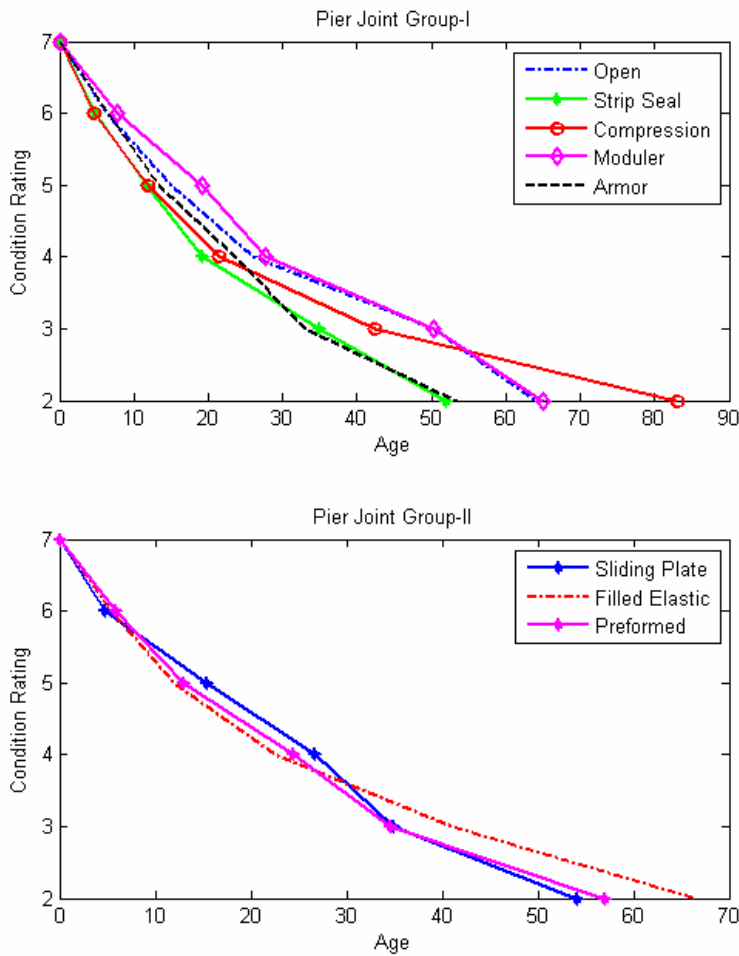


Figure 4-38: Deterioration curve for Pier Joint Design Types.

Table 4-13: Deterioration Equations for Pier Joint Design Types.

Pier Joint	Group-I	
	Open	$CR = 7 - 0.1746867 T + 0.0029733 T^2 - 0.0000224 T^3$
	Strip Seal	$CR = 7 - 0.2222855 T + 0.0043429 T^2 - 0.0000368 T^3$
	Compression	$CR = 7 - 0.2047452 T + 0.0034777 T^2 - 0.0000209 T^3$
	Modular	$CR = 7 - 0.1178004 T + 0.0000691 T^2 + 0.0000137 T^3$
	Armor	$CR = 7 - 0.1623125 T + 0.0012891 T^2 - 0.0000001 T^3$
	Group-II	
	Sliding Plate	$CR = 7 - 0.1581306 T + 0.0016926 T^2 - 0.0000089 T^3$
	Filled Elastic	$CR = 7 - 0.1937046 T + 0.0028916 T^2 - 0.0000130 T^3$
	Preformed	$CR = 7 - 0.1725949 T + 0.0020362 T^2 - 0.0000096 T^3$

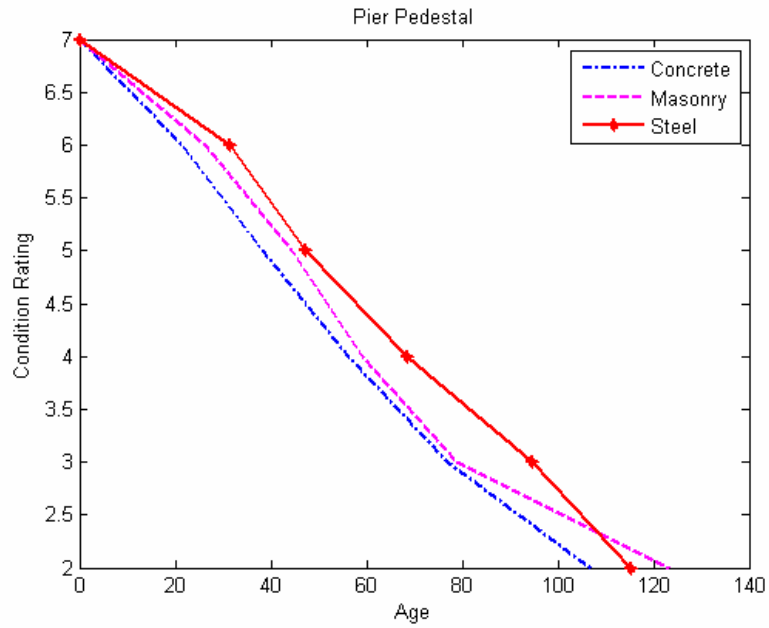


Figure 4-39: Deterioration curve for Pier Pedestal Design Types.

Table 4-14: Deterioration Equations for Pier Pedestal Design Types.

Pier Pedestal	Concrete	$CR = 7 - 0.0427029 T - 0.0003432 T^2 + 0.0000028 T^3$
	Masonry	$CR = 7 - 0.0214166 T - 0.0007708 T^2 + 0.0000050 T^3$
	Steel	$CR = 7 - 0.0294246 T - 0.0002940 T^2 + 0.0000015 T^3$

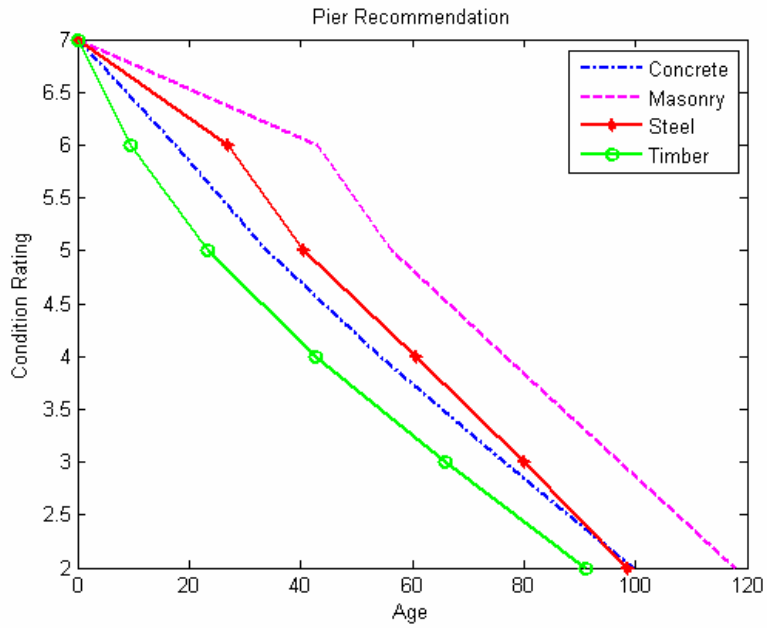


Figure 4-40: Deterioration curve for Pier Recommendation Design Types.

Table 4-15: Deterioration Equations for Pier Recommendation Design Types.

Pier Recommendation	Concrete	$CR = 7 - 0.0616063 T + 0.0001235 T^2 - 0.0000001 T^3$
	Masonry	$CR = 7 + 0.0189981 T - 0.0013498 T^2 + 0.0000075 T^3$
	Steel	$CR = 7 - 0.0335030 T - 0.0004089 T^2 + 0.0000024 T^3$
	Timber	$CR = 7 - 0.1156794 T + 0.0014818 T^2 - 0.0000098 T^3$

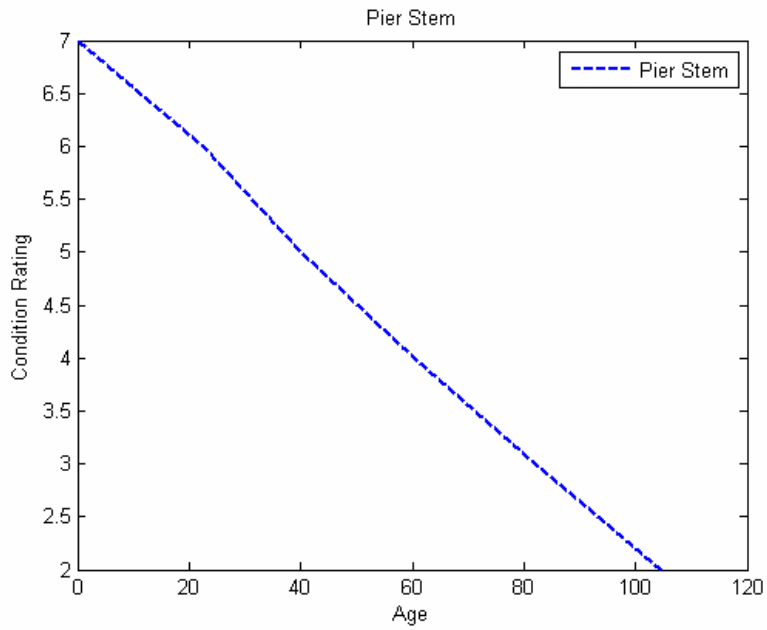


Figure 4-41: Deterioration curve for Pier Stem.

Table 4-16: Deterioration Equation for Pier Stem.

Pier Stem	$CR = 7 - 0.0445180 T - 0.0001482 T^2 + 0.0000011 T^3$
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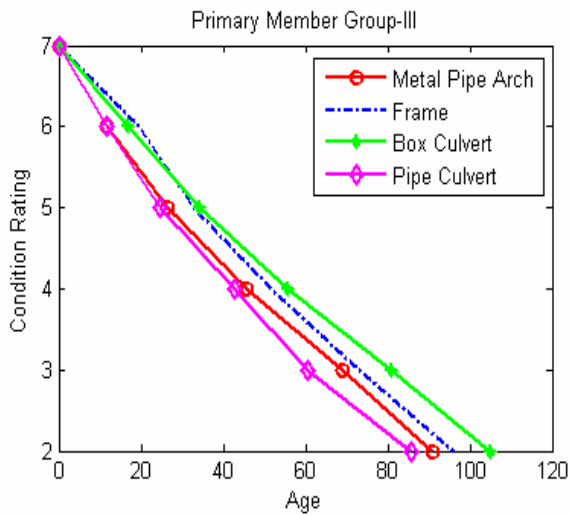
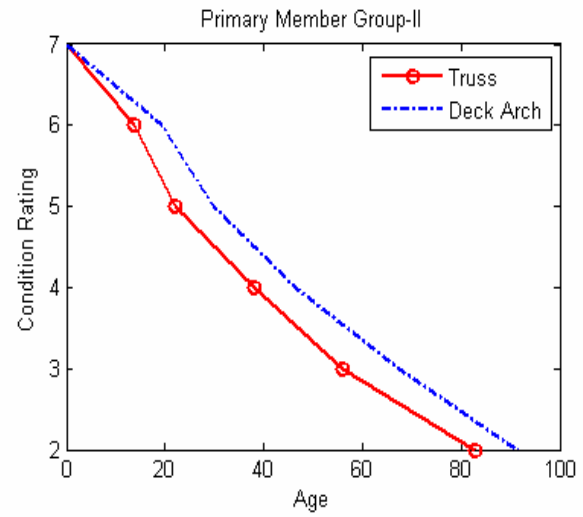
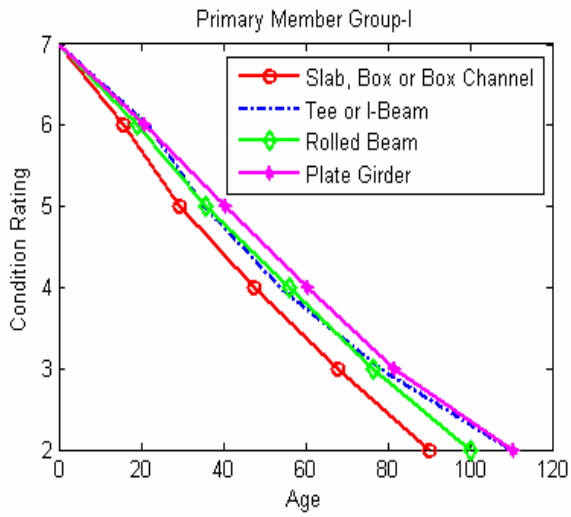


Figure 4-42: Deterioration curves for Primary Member Design Types.

Table 4-17: Deterioration Equations for Primary Member Design Types.

Primary Member	Group-I	
	Slab, Box or Box Channel	$CR = 7 - 0.0724412 T + 0.0002255 T^2 - 0.0000004 T^3$
	Tee or I-Beam	$CR = 7 - 0.0509168 T - 0.0001729 T^2 + 0.0000021 T^3$
	Rolled Beam	$CR = 7 - 0.0573849 T + 0.0000603 T^2 + 0.0000001 T^3$
	Plate Girder	$CR = 7 - 0.0533815 T + 0.0000618 T^2$
	Group-II	
	Truss	$CR = 7 - 0.0962120 T + 0.0005460 T^2 - 0.0000016 T^3$
	Deck Arch	$CR = 7 - 0.0608540 T - 0.0001644 T^2 + 0.0000025 T^3$
	Group-III	
	Metal Pipe Arch	$CR = 7 - 0.0917752 T + 0.0006315 T^2 - 0.0000012 T^3$
	Frame	$CR = 7 - 0.0586090 T - 0.0000153 T^2 + 0.0000009 T^3$
	Box Culvert	$CR = 7 - 0.0662312 T + 0.0002877 T^2 - 0.0000011 T^3$
	Pipe Culvert	$CR = 7 - 0.0918358 T + 0.0005486 T^2 - 0.0000019 T^3$

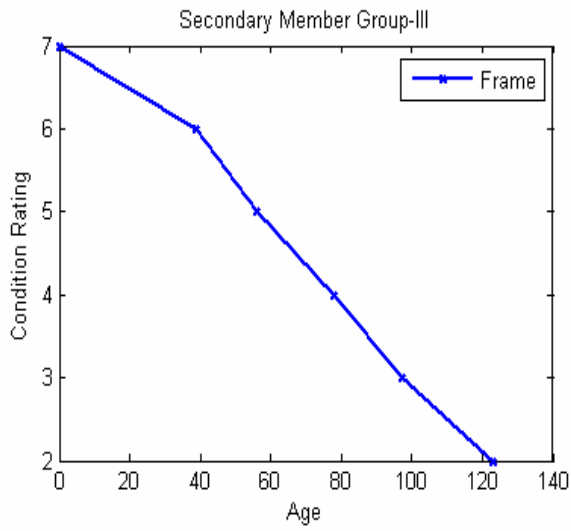
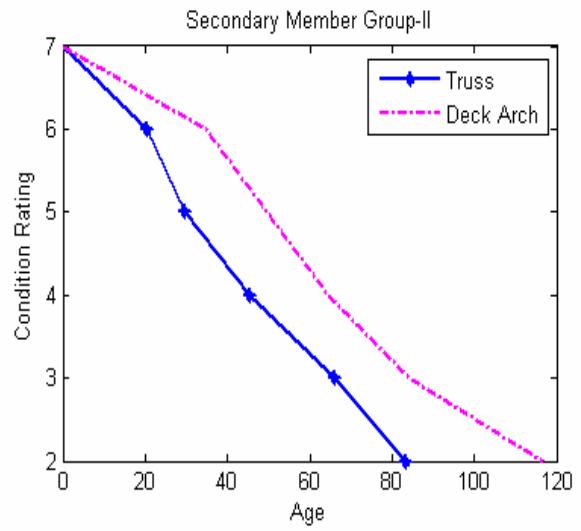
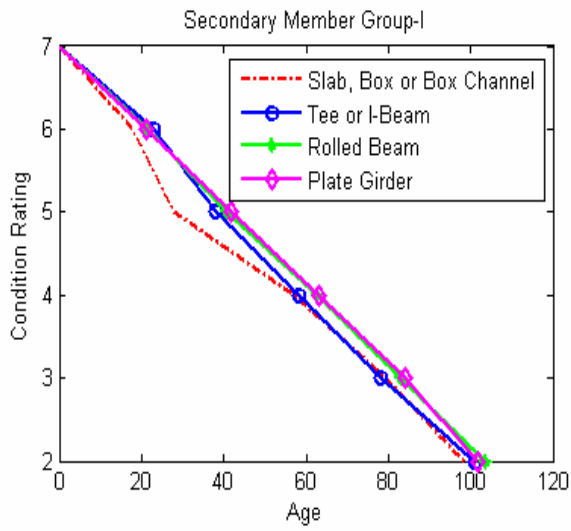


Figure 4-43: Deterioration curves for Secondary Member Design Types.

Table 4-18: Deterioration Equations for Secondary Member Design Types.

Secondary Member	Group-I	
	Slab, Box or Box Channel	$CR = 7 - 0.0705115 T + 0.0002846 T^2 - 0.0000002 T^3$
	Tee or I-Beam	$CR = 7 - 0.0371296 T - 0.0004970 T^2 - 0.0000041 T^3$
	Rolled Beam	$CR = 7 - 0.0536963 T + 0.0002090 T^2 - 0.0000016 T^3$
	Plate Girder	$CR = 7 - 0.0403950 T - 0.0002383 T^2 + 0.0000016 T^3$
	Group-II	
	Truss	$CR = 7 - 0.0600905 T - 0.0001653 T^2 + 0.0000021 T^3$
	Deck Arch	$CR = 7 + 0.0225284 T - 0.0019546 T^2 + 0.0000138 T^3$
	Group-III	
	Frame	$CR = 7 - 0.0031620 T - 0.0007666 T^2 + 0.0000039 T^3$

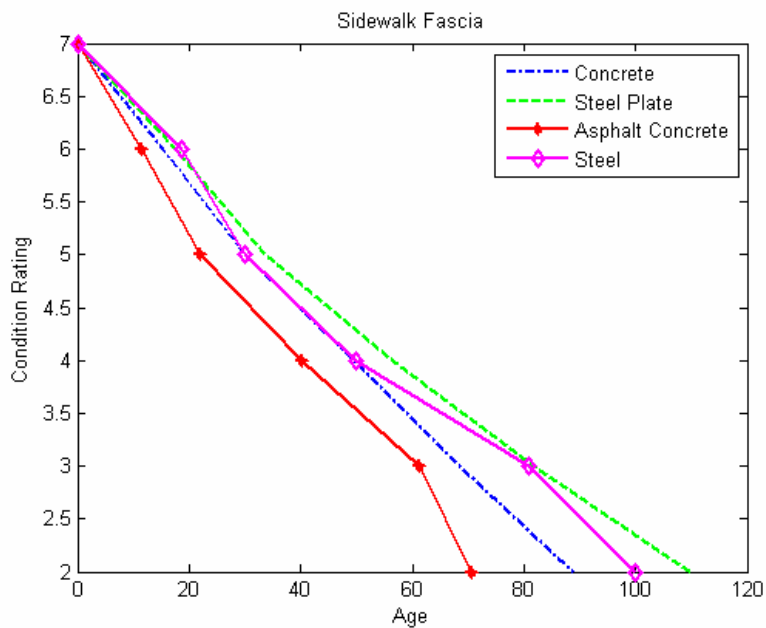


Figure 4-44: Deterioration curves for Sidewalk Fascia Design Types.

Table 4-19: Deterioration Equations for Sidewalk Fascia Design Types.

Sidewalk/Fascia	Concrete	$CR = 7 - 0.0697598 T + 0.0001899 T^2 - 0.0000004 T^3$
	Steel Plate	$CR = 7 - 0.0636279 T + 0.0001742 T^2 + 0.0000001 T^3$
	Asphalt Concrete	$CR = 7 - 0.1145251 T + 0.0015822 T^2 - 0.0000134 T^3$
	Steel	$CR = 7 - 0.0055077 T - 0.0034812 T^2 + 0.0000478 T^3$

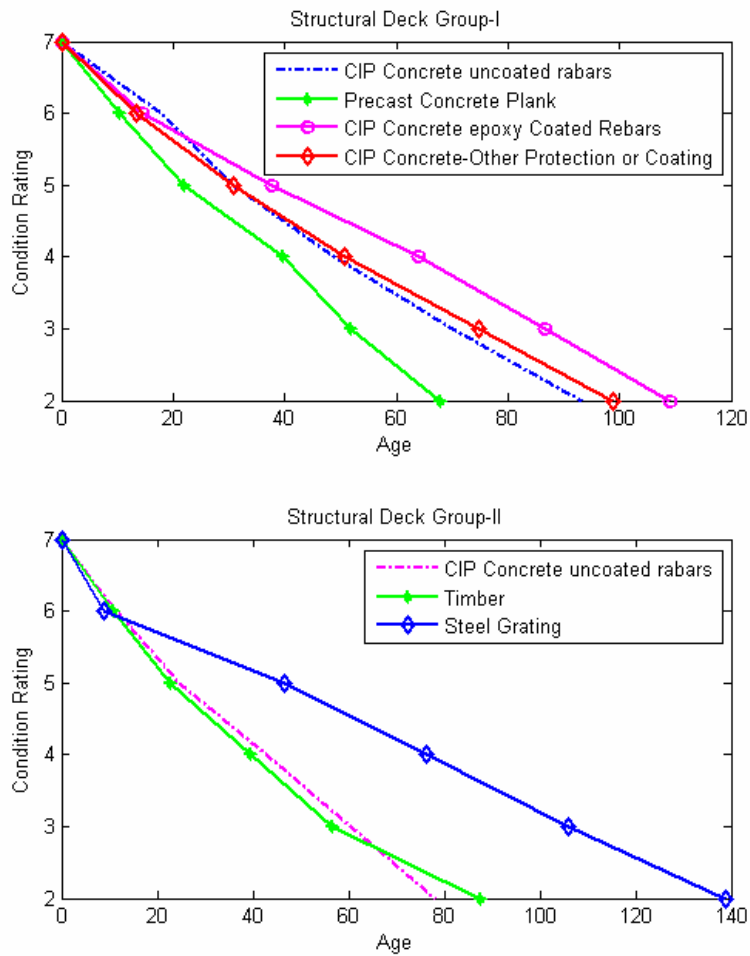


Figure 4-45: Deterioration curves for Structural Deck Design Types.

Table 4-20: Deterioration Equations for Structural Deck Design Types.

Structural Deck	Group-I	
	CIP Concrete uncoated Rebars	$CR = 7 - 0.0675608 T + 0.0001411 T^2 + 0.0000001 T^3$
	Precast Concrete Plank	$CR = 7 - 0.1188157 T + 0.0018646 T^2 - 0.0000204 T^3$
	CIP Concrete epoxy Coated Rebars	$CR = 7 - 0.0767927 T + 0.0007988 T^2 - 0.0000051 T^3$
	CIP Concrete-Other Protection or Coating	$CR = 7 - 0.0793700T + 0.0005157 T^2 - 0.0000023 T^3$
	Group-II	
	Timber	$CR = 7 - 0.1015141 T + 0.0010366 T^2 - 0.0000073 T^3$
	Steel Grating	$CR = 7 - 0.0971087 T + 0.0005147 T^2 - 0.0000007 T^3$
	Steel Plate	$CR = 7 - 0.1387853 T + 0.0032377 T^2 - 0.0000253 T^3$

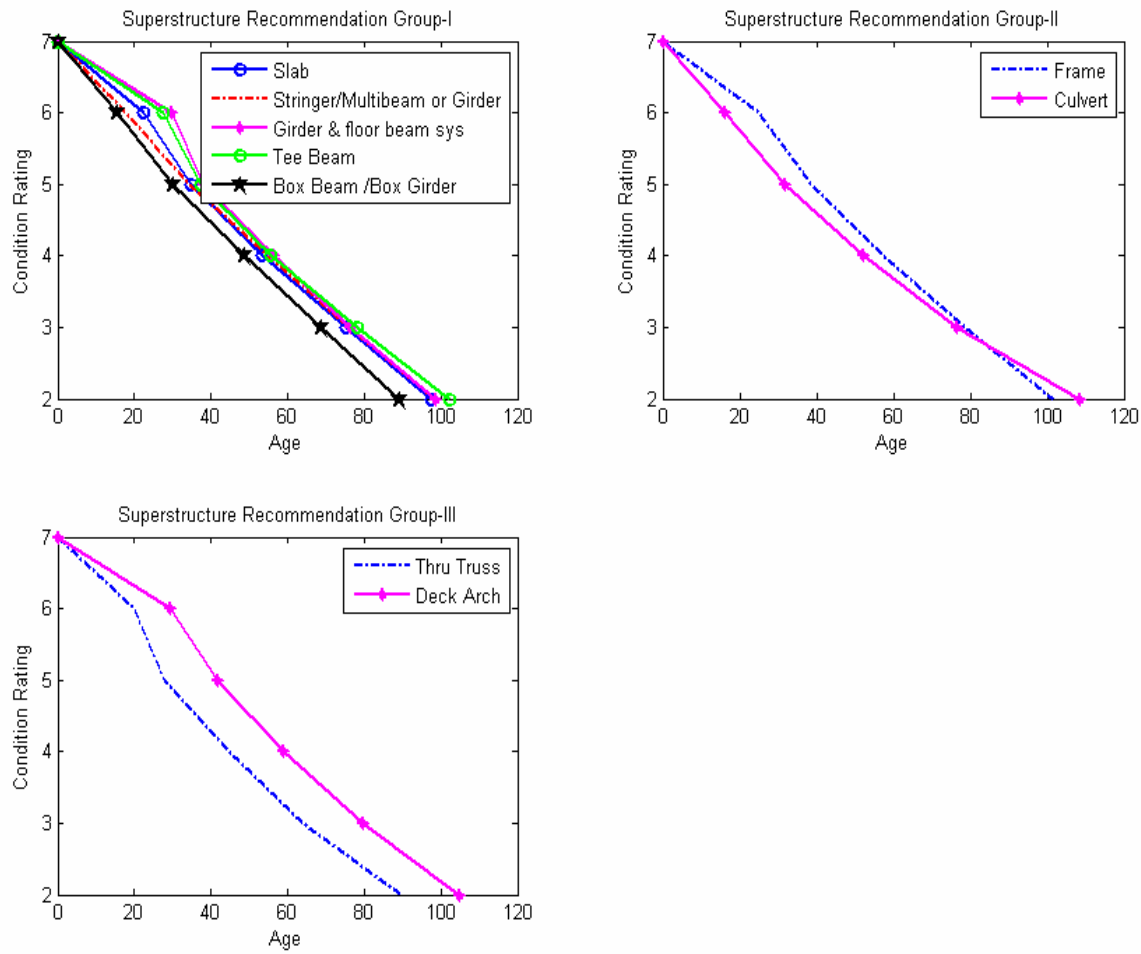


Figure 4-46: Deterioration curves for Superstructure Recommendation Design Types.

Table 4-21: Deterioration Equations for Superstructure Recommendation Design Types.

Superstructure Recommendation	Group-I	
	Slab	$CR = 7 - 0.0550966 T - 0.0000107 T^2 + 0.0000005 T^3$
	Stringer/Multi-beam or Girder	$CR = 7 - 0.0608104 T + 0.0001228 T^2 - 0.0000002 T^3$
	Girder and Floor beam System	$CR = 7 - 0.0375553 T - 0.0003374 T^2 + 0.0000019 T^3$
	Tee Beam	$CR = 7 - 0.0334694 T - 0.0005675 T^2 + 0.0000041 T^3$
	Box Beam or Box Girder	$CR = 7 - 0.0671339 T + 0.0000287 T^2 + 0.0000015 T^3$
	Group-II	
	Frame	$CR = 7 - 0.0374148 T - 0.0004245 T^2 + 0.0000031 T^3$
	Culvert	$CR = 7 - 0.0683836 T + 0.0002159 T^2 - 0.0000001 T^3$
	Group-III	
Thru Truss	$CR = 7 - 0.0719036 T + 0.0001651 T^2$	
Deck Arch	$CR = 7 - 0.0209106 T - 0.0007879 T^2 + 0.0000051 T^3$	

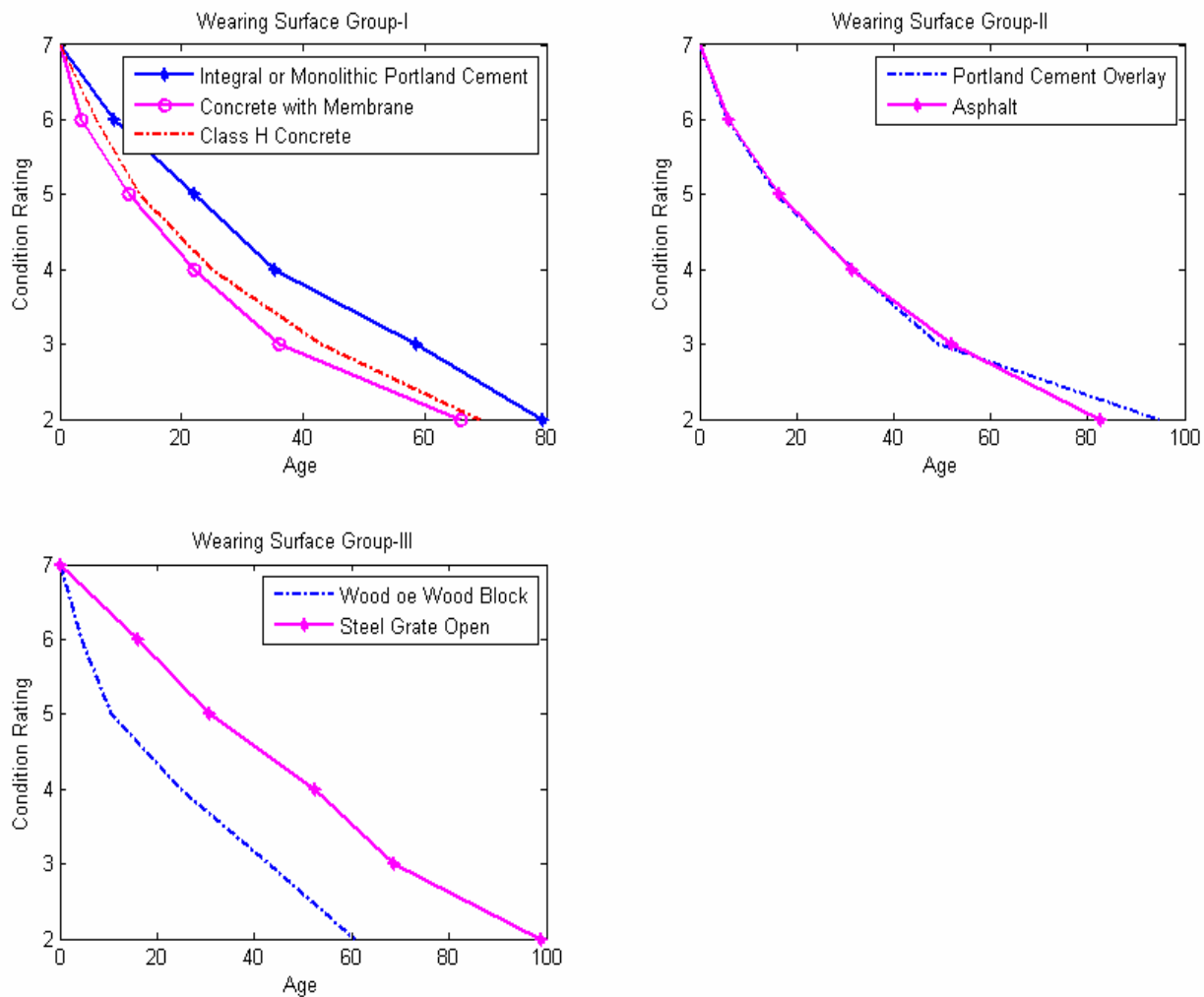


Figure 4-47: Deterioration curves for Wearing Surface Design Types.

Table 4-22: Deterioration Equations for Wearing Surface Design Types.

Wearing Surface	Group-I	
	Integral or Monolithic Portland Cement	$CR = 7 - 0.1178904 T + 0.0012462 T^2 - 0.0000070 T^3$
	Concrete with Membrane	$CR = 7 - 0.3488945 T + 0.0211688 T^2 - 0.0005196 T^3$
	Class H Concrete	$CR = 7 - 0.0417046 T + 0.0022971 T^2$
	Group-II	
	Portland Cement Overlay	$CR = 7 - 0.1517338 T + 0.0019529 T^2 - 0.0000097 T^3$
	Asphalt	$CR = 7 - 0.1215795 T + 0.0008883 T^2 - 0.0000019 T^3$
	Group-III	
	Wood or Wood Block	$CR = 7 - 0.1686718 T + 0.0020122 T^2 - 0.0000092 T^3$
Steel Grate Open	$CR = 7 - 0.0726944 T + 0.0004775 T^2 - 0.0000039 T^3$	

CONCLUSIONS

The New York State Department of Transportation (NYSDOT) maintains an inventory of over 17,000 highway bridges across the State. These bridges are inspected biennially, or more often as necessary. Bridge inspectors are required to assign a condition rating for up to 47 structural elements of each bridge, including 25 components of each span of a bridge, in addition to the general components common to all bridges. The objective of the research has been to carry out an extensive filtering / reconditioning of the inspection data, identify methods to calculate deterioration rates for bridge elements and develop a computer program to calculate deterioration rates for bridge elements.

Several filters have been developed and implemented to remove inspection data affected by rehabilitation, inspector subjectivity, and abnormal sudden drops in ratings, and miscoding of inspection ratings (most miscodings of inspection ratings are typically corrected during the NYSDOT bridge inspection QC and QA procedures). In addition to filters described above, reconditioning algorithms have been developed to correct element rebuilt year information (if the element has been rebuilt) using work history data and construction practices at the time of bridge built year. The filtered inspection data shows predominantly deteriorating behavior representing actual deterioration process.

In order to investigate effects of numerous factors, e.g., AADTT, climate, DOT regions, ownership, design types, etc., on the deterioration rates, a versatile cascading approach has been developed to classify bridge elements on the basis of selected factors. The cascading approach generates classes of bridges based on classification factors selected. These classes can be analyzed to calculate deterioration rates. Various algorithms have been investigated to calculate deterioration rates. Based on outcome of this investigation and discussions with NYSDOT's Technical Working Group members, Markov Chain and Weibull-based approaches have been used to develop the computer program for deterioration rate calculations. The computer program uses an updateable inspection database and generates polynomial equations of desired orders for deterioration rates.

A detailed case study has been carried out to compare Markov chain and Weibull-based approaches for deterioration rates. Since the Weibull-based method utilizes actual scatter in duration data for a particular rating and considers this duration as a random variable, it has been found to be more reliable for calculating deterioration rates for bridge elements. Hence, Weibull-based method has been used to generate deterioration curves for all bridge elements.

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APPENDIX A: K-MEAN CLUSTERING ALGORITHM

K-mean clustering algorithm iteratively partitions a set of data points into K groups by minimizing the sum of intra-group sum of distances between group members and group centers over all groups. If S is the set and we wish to partition the data into K groups, $s_i, i \in (1, 2, \dots, K)$, K-mean clustering algorithm will minimize the quantity in Eq.(A-1).

$$V = \sum_{i=1}^K \sum_{x_j \in S_i} (x_j - \mu_i)^2 \quad (\text{A-1})$$

where there are K clusters $S_i, i = 1, 2, \dots, K$, and μ_i is the [centroid](#) or mean point of all the points $x_j \in S_i$.

The basic algorithm consists of the following steps:

1. Decide the value K as the number of groups
2. Choose K points as initial centers
3. Assign each data point into the group whose center is nearest.
4. Re-compute the center of each group
5. Repeat step 3 and 4 until either no point has been assigned to a new group or reassignment won't decrease the sum of distance.

In order to apply K-mean clustering algorithm, we need to make the following decisions on the choice of different options:

1. What is the appropriate number of clusters, K ?
2. How to choose the initial group centers?
3. What kind of distance measurement to use?

In some circumstances, we can get an idea as to how many clusters we are expecting from other relevant information. In other situations, where we don't know K in advance, we can try a different K in a broad range and select the one that is most appropriate. One simple criterion is to select the one that yields the smallest sum of the distance and where each group has at least two members. The intention of the second condition is to make sure that we don't end up with each data point as being the only member of its group, in which case the sum of distances is zero. This condition will also prevent the algorithm generating empty clusters during the iteration.

Different schemes could be used in choosing the initial cluster centers. For example, K points could be chosen at random from the original dataset, or we can choose K points uniformly in the range of the original dataset. A third option will be to conduct a preliminary clustering phase based on 10% of random sample and use the K -centers from the initial phase for the clustering of the whole dataset. As K-mean clustering algorithm can only guarantee to find a local optimum, the choice of initial cluster center will affect the clustering quality to a very large extent. Hence, a randomized version is more beneficial. More specifically, for each K , the algorithm is run several times, each time with a different set of initial centers. The results of each run are compared and the one with minimum sum of distance is chosen.

To calculate distances measurement, we can use squared Euclidean distance, sum of absolute distance (a.k.a. city block distance), or distance based on probabilistic model.

APPENDIX B: UPDATING THE DATABASE

The database file “highway bridges.mdb” can be updated on the basis of the procedure presented below. The electronic version of this file is available in “Database Update Scheme” folder under the “Documents” folder of the computer program package.

1. Updating the Database

- 1) Before updating, backup the original database.
- 2) Make a copy of “Update.mdb” which is located in “\database”, and rename the new database to a name that indicates it is a newly made database, for example, highway bridges (12_12_2007).mdb.
- 3) Import the updated raw tables from the current bridge database (CurrentWinboltsInAccess.mdb) into the new database (in the previous example, highway bridges (12_12_2007).mdb). (See section 2 to know the definition of raw tables)
- 4) Determine which year is the latest year that the database should be updated to, for example, open table RC21, sort the column “Year” in a descendant order, and find out which year is the latest year. Suppose the latest year is 2008.
- 5) Click the “Module” from the left bar of ACCESS main window. Click Design on the module “UPDATE HIGHWAY BRIDGE DATABASE”, find the “init” sub-procedure. Change the following line
endYear = 2004
to
endYear = 2008
- 6) Click the “Macro” from the left bar of ACCESS main window. Run the Macro “Update Database”.
- 7) It takes time to update (it may last more than 1 hour depending on the power of the computer). Watch the message displayed in the status bar of ACCESS to know what is going on. Finally, when you see a message “Complete updating database!” in the status bar, the update is done. A log file (update.log) which is located in the same folder as the database records what has happened during the update.
- 8) Copy the updated database to “\NYSDOT Highway Bridges Package\Software\Executables\Main Program\Data” directory and rename it to “highway bridges.mdb”. This database will then be used by the deterioration program. It is recommended that the original “highway bridges.mdb” file be backed up before replacing with the updated database, in case any error occurs.

2. Raw Tables and Generated Tables

Raw tables are the tables that are originally in the database. New data is collected and is added into raw tables from time to time. For example, whenever a certain kind of work is done on a specific bridge, a new record is added into RC21.

Before importing the new raw tables, the old raw tables must be deleted or the imported tables will not be named correctly.

The raw tables are as follows:

BHISTORY*

RC01

RC02

RC03

RC04

RC05

RC06

RC07

RC12

RC13

RC15

RC16

RC17

RC19

RC21

SHISTORY*

SUBSETS

* At the time of this report, the “CurrentWinboltsInAccess.mdb” file only contained historical data dating back to 2003. These two Tables may need to be generated from the Paradox database in order to have all of the historical data.

Generated tables are the tables created based on those raw tables by running queries, macros or scripts in modules. Generated tables are then to be analyzed by the deterioration program.

The generated tables are as follows:

TBL_## WORK (## is the full name of an element)

TBL_##_HIGHWAY BRIDGES (## is the full name of an element)

TBL_##_HIGHWAY BRIDGES_HANDLED (## is the full name of an element)

TBL_##_HIGHWAY BRIDGES_COMBINED DATA (## is the full name of an element)

NUMBER OF YEARS ## (## is the abbreviated name of an element)

DeltaT ## (## is the abbreviated name of an element)

ClassificationAADTT

ClassificationDesignType

ClassificationMaterialType

ClassificationSalt

ClassificationSnow

Note: ClassificationClimate is to be updated manually. ClassificationDOTRegion, ClassificationFeatureCarried, ClassificationFeatureCrossed are no longer included in the database since these three tables are not used by the deterioration program.

Refer to “MetaDataElementGrouping.ini” located in “\Software\Executables\Main Program” to know what tables and fields are used for different classification criteria.

There are 23 types of elements (see table “MetaDataElement” in the database)

Following table shows the full name and abbreviated name of each element:

Element Full Name

Element Abbreviated Name

ABUTMENT BACKWALL	ABW
ABUTMENT BEARINGS	AB
ABUTMENT JOINTS	AJ
ABUTMENT PEDESTAL	AP
ABUTMENT STEM	ABS
ABUTMENT WINGWALL	AWW
DECK CURBS	DC
PIER BEARINGS	PB
PIER CAP	PC
PIER CAP TOP	PCT
PIER COLUMN	PCM
PIER FOOTING	PF
PIER JOINTS	PJ
PIER PEDESTAL	PP
PIER RECOMMENDATION	PR
PIER STEM	PS
PRIMARY MEMBERS	PM
RAILING	R
SECONDARY MEMBERS	SM
SIDEWALK or FASCIA	SF
STRUCTURAL DECKS	SD
SUPERSTRUCTURE RECOMMENDATION	SR
WEARING SURFACE	WS

For each element, the following four types of tables are created in order:

TBL_## WORK
TBL_##_HIGHWAY BRIDGES
TBL_##_HIGHWAY BRIDGES_HANDLED
TBL_##_HIGHWAY BRIDGES_COMBINED DATA

Usually, TBL_## WORK is created based on RC21; TBL_##_HIGHWAY BRIDGES is created based on TBL_## WORK; TBL_##_HIGHWAY BRIDGES_HANDLED is created based on TBL_##_HIGHWAY BRIDGES; TBL_##_HIGHWAY BRIDGES_COMBINED DATA is created based on TBL_##_HIGHWAY BRIDGES_HANDLED.

Basically, TBL_## WORK shows the work that has been done for a specific element; TBL_##_HIGHWAY BRIDGES shows pre-filtered ratings among years of each bridge; TBL_##_HIGHWAY BRIDGES_HANDLED shows post-filtered ratings among years of each bridge; TBL_##_HIGHWAY BRIDGES_COMBINED DATA shows the ratings versus ages of each bridge.

TBL_##_HIGHWAY BRIDGES_COMBINED DATA is used as the basis for Markov Chain analysis when running the software.

NUMBER OF YEARS ## is the intermediate result to DeltaT ## which means DeltaT ## is created based on NUMBER OF YEARS ##. NUMBER OF YEARS ## is created based on the TBL_##_HIGHWAY BRIDGES_HANDLED.

DeltaT ## is used as the basis for Weibull analysis when running the software.

3. The Updating Procedure

When running the macro “Update Database”, it calls the function “updateDatabase” which is located in the module of “UPDATE HIGHWAY BRIDGE DATABASE”.

The steps for the whole update procedure are as follows:

```
'Remove all the tables of TBL_XX ,DeltaT XX,NUMBER OF YEARS XX if
these tables exist in the database
removeAllGeneratedTables

'Create all tables of TBL_XX ,DeltaT XX,NUMBER OF YEARS XX
createAllGeneratedTables

'Update each element
'For each element, 4 types of tables are updated in order
'1) TBL_XX WORK
'2) TBL_XX_HIGHWAY BRIDGES
'3) TBL_XX_HIGHWAY BRIDGES_HANDLED
'4) TBL_XX_HIGHWAY BRIDGES_COMBINED DATA
'note: PRIMARY MEMBERS and STRUCTURAL DECKS should be updated first
since other elements may use their handled table

'update PRIMARY MEMBERS
updatePM

'update STRUCTURAL DECKS
updateSD

'update ABUTMENT BACKWALL
updateABW

'update ABUTMENT BEARINGS
updateAB

'update ABUTMENT JOINTS
updateAJ

'update ABUTMENT PEDESTAL
updateAP

'update ABUTMENT STEM
```

updateABS

'update ABUTMENT WINGWALL

updateAWW

'update DECK CURBS

updateDC

'update PIER BEARINGS

updatePB

'update PIER CAP

updatePC

'update PIER CAP TOP

updatePCT

'update PIER COLUMN

updatePC

'update PIER FOOTING

updatePF

'update PIER JOINTS

updatePJ

'update PIER PEDESTAL

updatePP

'update PIER RECOMMENDATION

updatePR

'update PIER STEM

updatePS

'update RAILING

updateR

'update SECONDARY MEMBERS

updateSM

'update SIDEWALK or FASCIA

updateSF

'update SUPERSTRUCTURE RECOMMENDATION

updateSR

```
'update WEARING SURFACE  
updateWS
```

```
'Update DeltaT tables  
[NUMBER OF YEARS AT EACH CR].main startYear, endYear
```

```
'Update Classification## tables  
updateClassificationTables
```

Note that PRIMARY MEMBERS and STRUCTURAL DECKS should be updated before other elements since TBL_PRIMARY MEMBERS_HIGHWAY BRIDGES_HANDLED and TBL_STRUCTURAL DECKS_HIGHWAY BRIDGES_HANDLED may be used to update other elements. This is automatically handled by the Macro Modules if all of the elements are updated simultaneously.

During the update, you can watch the message displayed on the status bar located at the bottom of ACCESS window. You can also open the log file “update.log” in “database” to find out what has been done during the update. If an error occurs during the update, it will prompt you a message and show you where the error comes from. The error is also recorded in the “update.log”.

4. Additional Comments

1) The “Update.mdb” is used as a template database. Starting from this database, you can create many future databases when new data are imported. Basically, you can import raw tables containing new data into “Update.mdb” and run the update macro, so that you get a full functional database.

2) The queries located in the “Query” of ACCESS window work as templates because they could be updated too. The script will execute “QRY_## WORK” to generate table TBL_## WORK and execute “QRY_##” to generate table TBL_##_HIGHWAY BRIDGES. In many cases, there are two kinds of QRY_## WORK queries, namely, QRY_## WORK1 and QRY_## WORK2. QRY_## WORK1 is to insert records into empty TBL_## WORK table, QRY_## WORK2 is to append records into TBL_## WORK table.

When running the update macro, it only executes QRY_## WORK1 and the query statement in QRY_## is dynamically updated to the latest year. For example, in the original “Update.mdb”, the query statement of QRY_ABUTMENT BACKWALL is to generate records up to 2004, but if you change the latest year to 2007 in the module script, the query statement will be automatically modified so that it can generate records up to 2007.

3) If you just want to update a single specific element, open the “Module” in the ACCESS window, click from the menu “Tool->Macro”, locate the exact update sub-procedure (e.g., updateAB) in the pop-up window, and click “run”.

4) When a new database is ready, copy the database to “\NYSDOT Highway Bridges Package\Software\Executables\Main Program\Data” directory and rename it to “highway bridges.mdb”. This database is to be used by the deterioration program.

APPENDIX C: UNINSTALLING THE COMPUTER PROGRAM

The computer program has been developed for Windows XP environment. Hence, the computer program should be uninstalled through “Add or Remove Programs” in “Control Panel”. However, it has been observed that sometimes uninstallation of the program starts giving the error “MATLAB Component Runtime Could not delete the MCR files”. This problem has been observed only on NYSDOT computers and may be because of NYSDOT Network/security settings. In order to uninstall the program if it gives the error mentioned above, the users should follow the following steps:

- a. A user with administrative privileges needs to be logged in to perform the following steps.
- b. Select Run under the “Program” menu. Type “regedit” in the “Run” windows
- c. The “Registry Editor” window will open. Please back up the “Registry” file before proceeding further.
- d. Under “Edit” menu on “Registry Editor”, select “Find..” option. Type “Mathworks” in the “Find” box and select “Find Next..” from the “Edit” window.
- e. When the program locates any folder/subfolder having entry related to “Mathworks”, delete the entire folder. In case your computer has Matlab installed separately, you need to check every search on “Mathworks” to make sure it does relate to “Matlab Runtime Component” before deleting it. Continue “search and delete” process till all entries corresponding to “Mathworks” are deleted.
- f. Repeat the above “search and delete” process in Steps c and d using the search word “Matlab”. Delete every entry that corresponds to “Matlab Runtime Component”. If the result of search contains a reference to several directories, including that to “Matlab Runtime Component”, only delete the “Matlab Runtime Component” portion.
- g. When the above step is finished, close the “Registry Editor” window and restart the computer.
- h. Open “Add or Remove Programs” in the “Control Panel”. If “Matlab Runtime Component” entry is still present, click on “uninstall” button to remove “Matlab Runtime Component”.
- i. Once “Matlab Runtime Component” has been removed, you can start to reinstall the latest version of the program by following the installation instructions on the program CD.