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Development of a Bridge Replacement Guide for County Engineers, Phase I

By

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UTCA Theme: Management and Safety of Transportation Systems

Prepared by

UTCA

University Transportation Center for Alabama
The University of Alabama, The University of Alabama at Birmingham, and
The University of Alabama in Huntsville

UTCA Report 99101
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University Transportation Center for Alabama

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16. Abstract

With over one-third of county bridges in Alabama rated as structurally deficient or functionally obsolete, and replacement funds increasingly scarce, the development of cost-effective replacement strategies is critical. To accomplish this goal, it would be helpful to know how various types of bridges and their components deteriorate, how many years they can serve, and which advantages and disadvantages they have in the area of durability performance.

A critical aspect of bridge rehabilitation and replacement is to determine the most appropriate time for bridgerepair and replacement. This can be done by evaluating the durability performance of various county bridges as well as establishing reasonable bridge deterioration models for them and their components.

This report outlines the progress of the first year of this two-year project and gives the deterioration rates of the common bridge types located on the Alabama County road system. Specifically, seven bridge superstructure types were considered in this study along with three different deck types. The 1999 National Bridge Inspection Inventory served as the basis of development.

Results from this first phase will be combined with cost data obtained from the second phase of this project with the end product of this research being a "Bridge Replacement Guide for County Engineers". This initial phase has defined the bridge deterioration rates of common superstructure types.

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Executive Summary

With over one-third of county bridges in Alabama rated as structurally deficient or functionally obsolete, and increasing scarcity of replacement funds, the development of cost-effective replacement strategies is critical to ensure the optimal use of available funds. To accomplish this goal, it would be helpful to know how various types of bridges and their components deteriorate, how many years they can serve, and which advantages and disadvantages they have in the area of durability performance.

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1.0 Introduction

This report summarizes work completed for the first year of this two-year project aimed at providing a bridge replacement guide for county engineers. The guide is being developed by a team of researchers from the University of Alabama based on bridge performance and replacement trends as determined by the Structural Inventory and Appraisal (SI&A) database, surveys of transportation engineers across the state, and available literature. Alabama Department of Transportation (ALDOT) officials are also involved in selecting and organizing the content of the guide and providing information, which will be contained in the guide.

The end product of this research effort will be the "Bridge Replacement Guide for County Engineers." This guide will give an overview of the different types of bridge superstructures and substructures, and will review the advantages and disadvantages of each type including economical span ranges, the construction and labor needs, and other economic considerations.

The original proposal included a schedule of work to be completed the first year. These tasks, as given in the original proposal, and the status of work on each task at the end of year one are listed below.

First year schedule as originally proposed

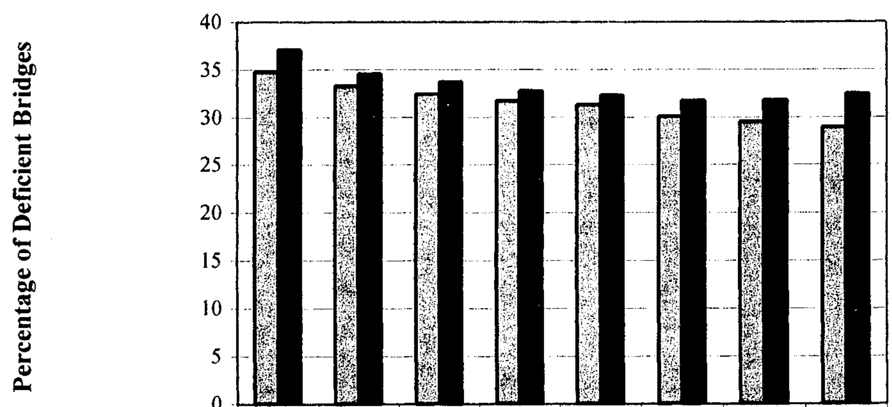
1. Establish Project Review Committee (Done)
2. Obtain Preliminary Data (Done)
3. Review Bridge Replacement Policies and Procedures (Done)
4. Design Bridge Replacement Guide Prototype (In Progress)
5. Present Prototype to Review Committee (Rescheduled)
6. Collect Lifecycle Cost Data (In Progress)

Some changes to the original plan have been made as the research has progressed. For instance, the Structural Inventory and Appraisal (SI&A) database has been used much more extensively than originally planned as it provides valuable insight into the performance of existing bridges. Therefore, the main thrust of the work this year involved determining the relative performance of different bridge superstructures and substructures based on the SI&A database, and obtaining cost information for common bridge types. The remainder of this report summarizes the deterioration models developed for the different bridge types. This was the primary effort of Phase I of the project.

2.0 Background

A large number of county bridges in Alabama are in need of major rehabilitation or replacement. According to a 1999 bridge report from the Federal Highway Administration (FHWA, 1999), approximately 32.53% (5,086 bridges) of Alabama bridges were either structurally deficient or functionally obsolete. As seen in Figure 2-1, since 1992 the annual percentages of deficient bridges in Alabama have been higher than the national average. Also, there has been an increase in the number and percentage of deficient bridges in Alabama in three years leading up to 1999.

Bridges are typically built with an expected design life of 50 years and most have mid-life rehabilitation. Hence, the average service life of many bridges is near 70 years. This means that, in 1999, bridges built before 1930 were nearing the end of their expected life while bridges built between 1960 and 1970 were close to their mid-life rehabilitation. Figure 2-2 shows the results of inquiries from Alabama NBI database, which indicated that 433 (6.24%) of county bridges were built before 1930. 1518 bridges (21.89%) were constructed between 1930 and 1950, and they are reaching their estimated service life. 1271 bridges (18.32%) were built during 1960 through 1970, and they are now in need of their mid-life rehabilitation. Sometimes, however, the best option is not to perform major rehabilitation, but rather to simply replace the bridge with a modern bridge with increased load carrying capability.



	1992	1993	1994	1995	1996	1997	1998	1999
National Bridges	34.80	33.37	32.49	31.81	31.40	30.17	29.60	29.04
Alabama Bridges	37.18	34.62	33.73	32.81	32.40	31.78	31.85	32.53

Year

Figure 2-1. Comparison of percentage of deficient bridges in the United States and Alabama

	<1900	1900~ 1909	1910~ 1919	1920~ 1929	1930~ 1939	1940~ 1949	1950~ 1959	1960~ 1969	1970~ 1979	1980~ 1989	1990~ 1999
Number	3	137	66	227	786	732	1,564	1,271	785	637	728
Percentage	0.04%	1.98%	0.95%	3.27%	11.33	10.55	22.55	18.32	11.32	9.18%	10.50

Construction Period (Year)

Figure 2-2. Number of county bridges in Alabama, by construction period

3.0 Methodology

The methodology employed in this study involved several steps, i.e., determining the primary determinants of deterioration, processing National Bridge Inventory (NBI) data, evaluating bridge deterioration performance and modeling deterioration behavior of county bridges. The first two steps were designed to effectively compare the durability performance of various county bridges.

3.1 Primary Determinants of Deterioration

The condition deterioration of a bridge is generally affected by design, construction and environment factors. In other words, the condition rating (CR) of a bridge or component of the bridge would be expressed as a functional form of age (X_1), design factors (X_2), construction factors (X_3), and environment factors (X_4) as shown below.

$$CR = f(X_1, X_2, X_3, X_4) \tag{3.1}$$

The bridge design factors include structural type, skew, number of spans and wearing surface. The construction factors involve construction method and material, and construction quality. The environmental factors include traffic level, location, maintenance, etc. It would be desirable to involve all these variables in evaluating the CR of bridge, but this is not feasible or necessary. Not all variables are available or measurable, and the records of bridge inspections (NBI data) have their limitations. For instance, freeze thaw, precipitation and construction methods are not available from NBI data. Therefore, most previous studies of bridge deterioration utilized only for those factors that are in the date base and affect the condition and deterioration rate of bridge such as age, structural type and average daily traffic (ADT). Similarly, this study ignored the effect of construction and environment factors when evaluating the deterioration performance of county bridges. Two variables, age and structural material, were regarded as determinants of bridge deterioration through the study.

3.2 Data Processing

The purpose of this step is to form complete and homogenous data subsets for the desired analysis. The original database used in this study is the 1999 Alabama County Bridge Database obtained from the Alabama National Bridge Inventory as obtained from the Maintenance Bureau of the State of Alabama Department of Transportation. The records of these data represent a snapshot of the condition of all county bridges in Alabama as recorded in the inventory at a certain time in 1999 rather than time-series data that would perfectly present the bridge condition as it may have changed over time. This study will not deal with the continuous condition of an individual bridge at successive times in history. Those time-series data were desired but were not readily available. Bridges with similar characteristics that experience similar environmental conditions and routine maintenances should deteriorate at a similar rate with time. Hence, this study assumes that the time-series data of each type of bridge can be replicated from the available time-snapshot data.

3.2.1 Data Filtering

Eight procedures of data screening were conducted to exclude unwanted data and incomplete records to improve the homogeneity of the data subsets analyzed. Each procedure or step used to filter the data is described below along with the rationale for its use.

<u>Step 1: Only trace the condition of structures less than 76 year old, in this case built during 1925 through 1999.</u> The Federal Highway Administration mandates that main artery highway bridges be designed for 75-year service and the United States replaces its bridges on average at 70 years (Ramey, et al. 1997). Therefore, this study only traces the condition of county bridges being less than 75 years old, in this case built after 1924.

<u>Step 2: Limit structures to county bridges only. Other structures like culverts, tunnels, etc. were eliminated from the data subset.</u> The objective of this project is to develop a county bridge replacement guide, therefore only the durability of county bridges in Alabama rather than other structures like culverts, tunnels, etc. was considered.

<u>Step 3: Limit bridge types to seven predominate types.</u> Queries of 1999 NBI data reveal that most county bridges have stringer/multi-beam or girder systems. In fact, roughly 60% of county bridges built in the last 75 years utilize main spans of this type. In addition, slab, tee beam, and channel beam types account for an additional 27.2% of the total county bridges. This study, therefore, only traced the deterioration performance of these predominating structural types of county bridges.

<u>Step 4: Only the county bridges that have the same type of main spans as approach spans, or have no approach spans were left in the data subset.</u> The NBI database did not separately assign CRs for main spans and approach spans of a bridge. The consistency of structural types of main spans and approach spans is very important in the study to obtain accurate CRs for specific bridge types. Hence, only the county bridges, which have the same type of main spans as approach spans or have no approach spans, were considered in this study.

<u>Step 5: Eliminate county bridges from the study that were coded as rehabilitated county bridges.</u> For the purpose of developing a general deterioration model and predicting the service life of non-rehabilitated county bridges, those coded as reconstructed bridges in the data set were eliminated from the study.

<u>Step 6: Limit deck types of bridges to Concrete Cast-in-Place, Concrete Precast Panels and Timber.</u> Based on the inventory, there are three governing deck types as indicated by Item 107-Deck Structure Type. They are concrete cast-in-place (50%), concrete precast panels (19.3%) and timber (28.5%). The records of county bridges with other deck types were eliminated from data set.

Step 7: Eliminate county bridge records that contain missing or miscoded information for CR of the deck, superstructure or substructure. Not all bridges involved in the 1999 NBI database have complete records. This study investigated the longevity performances of major bridge components, i.e., deck, superstructure and substructure. Hence, the study removed the records of county bridges from the data set if they had missing or miscoded information about the CRs of these components.

Step 8: Exclude those bridges that were not coded as rehabilitated bridges but had most likely been reconstructed. After seven steps of data filtering, the data set involved 4,287 records. According to the preliminary analysis of this data set, it appeared that several reconstructed county bridges still remained in the database. Tables 3-1 and 3-2 show the number of bridges sorted by age & deck CR, and the number of bridges sorted by age & superstructure CR, respectively. Obviously, some old bridges in these tables, which were coded as non-reconstructed bridges, have most likely received some maintenance work in order to maintain relatively high CRs. Therefore, while it was a judgment call, more filtering rules were developed to eliminate those bridges, which were most likely to have received major rehabilitation.

Standard practice at ALDOT is to automatically lower the CR of all components to 8 after the first year in operation (Ramey, et al., 1997). While it is likely that some bridges, which are five to ten years old, could have a CR of 9 (excellent condition), the probability of a bridge having CR of 9 after 30 years of service should be very small unless rehabilitation had occurred. We deleted those bridges, which were more than 30 years old and had a CR of 9 from the study as it is expected that these bridges have seen some type of rehab work.

1. Basing on Auburn University study (Ramey, 1997), the bridge ages at first significant deterioration (CR<8) for bridge components and subcomponents in Alabama, in most case, were 35 to 45. Hence, those bridges being more than 45 years old with CR >=8 were eliminated from the study.
2. Generally speaking, we could not expect that the CR of a bridge 65 or more years old to be greater than 5 if this bridge had never been reconstructed. Accordingly, those bridges more than 65 years old with CR >=6 were eliminated from the study.
3. Using linear interpolation ((45+65)/2=55 when CR=7), this study deleted the bridges that were more than 55 years old with CR>=7.

The highlighted cells in the top left side of Tables 3-1 and 3-2 indicate bridges, which were eliminated by these filtering rules.

Table 3-1. Numbers of County Bridges by Age and Deck CR

Bridge Age	Condition Rating									
	9	8	7	6	5	4	3	2	1	0
71~75	0	3	7	20	17	8	6	1	0	1
66~70	1	2	18	37	39	10	5	2	0	0
61~65	2	8	32	91	109	51	15	2	0	1
56~60	4	23	50	58	56	31	8	2	1	9
51~55	2	7	57	84	49	32	14	1	1	0
46~50	5	19	111	193	116	43	21	4	0	2
41~45	3	20	139	188	92	23	10	2	0	1
36~40	2	28	166	139	71	24	9	2	1	1
31~35	1	22	110	98	53	27	7	1	1	2
26~30	1	31	94	97	33	14	3	2	0	0
21~25	0	58	94	56	20	10	5	0	0	0
16~20	1	72	91	34	15	9	1	0	0	1
11~15	4	123	76	27	13	3	0	0	0	2
6~10	48	221	60	11	2	1	0	0	0	0
1~5	123	85	7	4	1	0	0	0	0	0

Table 3-2. Number of County Bridges by Age and Superstructure CR

Bridge Age	Condition Rating									
	9	8	7	6	5	4	3	2	1	0
71~75	0	0	6	19	22	9	6	0	0	1
66~70	0	2	22	46	27	10	5	2	0	0
61~65	2	3	37	93	104	55	14	2	0	1
56~60	3	22	45	67	51	29	13	2	1	9
51~55	1	6	57	82	61	28	9	2	1	0
46~50	3	9	118	191	113	52	19	6	0	3
41~45	2	21	164	175	76	27	8	4	0	1
36~40	1	33	172	129	71	25	9	2	1	0
31~35	1	22	98	96	74	21	6	1	1	2
26~30	1	27	107	81	41	13	2	3	0	0
21~25	0	56	112	44	21	5	4	1	0	0
16~20	1	90	81	29	17	5	0	0	0	1
11~15	4	147	54	20	18	3	0	0	0	2
6~10	46	229	60	5	2	1	0	0	0	0
1~5	117	89	3	6	4	1	0	0	0	0

Table 3-3 summarizes each of the eight steps used to filter the data, and the number of bridges remaining in the database before and after by each step. Through these procedures of data screening, the records in the database were reduced from 10,079 to 3,814. These composed the final data subset used for evaluating the condition and deterioration performance of county bridges in Alabama.

Table 3-3. Summary of Data Filtering

Filters	Records Contained Before Filter	Records Contained After Filter
1. Only trace the condition of structures less than 76 year old, in this case built during 1925 through 1999.	10,079	9,544
2. Limit structures to county bridges only. Other structures like culverts, tunnels, etc. were eliminated from the data subset.	9,544	6,643
3. Limit bridge types to seven predominate types*.	6,643	5,178
4. Only the county bridges that have the same type of main spans as approach spans, or have no approach spans were left in the data subset.	5,178	5,072
5. Eliminate county bridges from the study that were coded as rehabilitated county bridges.	5,072	4,439
6. Limit deck types of Concrete Cast-in-Place, Concrete Precast Panels and Timber.	4,439	4,320
7. Eliminate county bridge records that contain missing or miscoded information on the CR of the deck or superstructure.	4,320	4,287
8. Exclude those bridges that were not coded as rehabilitated bridges but had most likely been reconstructed.	4,287	3,814

Note: * seven predominate types are

1) Concrete Slab;
2) Concrete Stringer/Multi-beam or Girder;
3) Concrete Tee Beam;
4) Concrete Channel Beam;
5) Steel Stringer/Multi-beam or Girder;
6) Prestressed Concrete Stringer/Multi-beam or Girder; and
7) Timber Stringer/Multi-beam or Girder.

3.3 Evaluation of Deterioration Performance

This step involved determining the deterioration performance of the bridges identified in the filtered subset obtained from the previous step. To evaluate the durability of bridges, the emphasis was placed on its components rather than on the overall bridge condition rating. The poorest performing major component of a bridge will tend to dictate the overall bridge condition. Hence, this study merely evaluates the deterioration rates of the major bridge components, i.e., deck, superstructure and substructure. The evaluation of longevity performance for individual types of decks as well as superstructures was also performed. As mentioned, the variables bridge age; structural material and type were identified as the key determinants of bridge deterioration. Unfortunately, the NBI database obtained rarely provided effective entries of material or type of the substructure components, as most fields describing the material or type of substructure components were coded as "N" or "??", which means not applicable or no information. Hence, this study only traces the average CR of all substructures regardless of type.

To gain a better understanding of how various county bridges are performing in longevity, several comparisons were conducted. These involved 1) comparison of deterioration performance for deck, superstructure and substructure; 2) comparison of deterioration performance for concrete, steel, prestressed concrete and timber county bridges; and 3) comparison of deterioration performance for major kinds of stringer/multi-beam or girder county bridges.

3.4 Deterioration Modeling

One of the primary objectives of the study is to develop a bridge deterioration model, i.e., a model of the county bridge CR versus age curve, which can be used to predict the service life of major components of non-rehabilitated county bridges in Alabama. By determining the point where a deterioration curve indicates that a county bridge or its component has reached an unserviceable condition, an estimate of its service life can be made. A review of the existing bridge deterioration models identified the following methods: 1) Linear regression; 2) Bilinear regression; 3) Non-linear regression employing exponential or logarithmic functional form; and 4) Markovian model.

The deterioration models developed for Alabama county bridges employ the two-parameter exponential functional form, i.e., $Y=\lambda e^{-\beta X}$. The main reason this study employed the exponential model is that it captures the nature of bridge deterioration that takes the convex functional form, with deterioration rate slowing with age. The linear and bilinear fittings are simple tools for simulating the bridge deterioration over time, but the bridge deterioration rate is different at various age periods instead of constant. The Markovian model increases the computational complexity of bridge management network in order to accurately predict bridge deterioration performance. And employing logarithmic function is also a feasible way to model the behavior of bridge deterioration, but this study did not utilize it because the coefficients of deterioration (R^2s), which measured the goodness of fit of alternative functional forms, indicated that the exponential form provided the best fit of the data in this study.

A QuickBasic program, Regr.bas, was written to estimate the unknown parameters and errors including standard deviation, covariance and R^2 for variables applied to selected data sets. In addition, the program can also perform regression analysis utilizing linear, power and logarithmic functions. Only the exponential function, however, was employed in the study.

This study developed exponential models of deterioration performance for decks, superstructures, substructures, and individual types of bridge components. In addition, it also predicted general service time for various types of bridge components utilizing the developed deterioration models. Several comparisons of longevity performance will be conducted among the major bridge components.

4.0 Findings and Results

Findings of Phase I of this study are presented below as a series of figures. Each figure shows the condition rating of the bridge as a function of bridge age. Condition ratings, CR, are one digit numbers representing the condition of the bridge as compared to its new condition. A CR of 9 represents new or excellent condition and 3 representing serious condition. Table 4-1 gives the brief description of each condition rating.

Table 4-1 Description of condition rating, CR

Condition Rating, CR	Description
9	Excellent condition
8	Very good condition - no problems noted
7	Good condition - some minor problems
6	Satisfactory condition - structural elements show minor deterioration
5	Fair condition - all primary structural elements are sound but have minor section loss, cracking, spalling or scour
4	Poor condition - advance section loss, deterioration, spalling or scour
3	Serious condition - loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	Critical condition - advanced deterioration of primary structural elements. Bridge should be closed.
1	Imminent failure - bridge is closed to traffic but corrective action may put bridge back in light service
0	Failed condition - out of service; beyond corrective action.

Figure 4-1 shows the deterioration rate of Alabama county bridges as determined by condition rating as a function of time for the three most common concrete deck types. As shown in the figure both cast-in-place and precast concrete decks have held their condition rating better than timber decks.

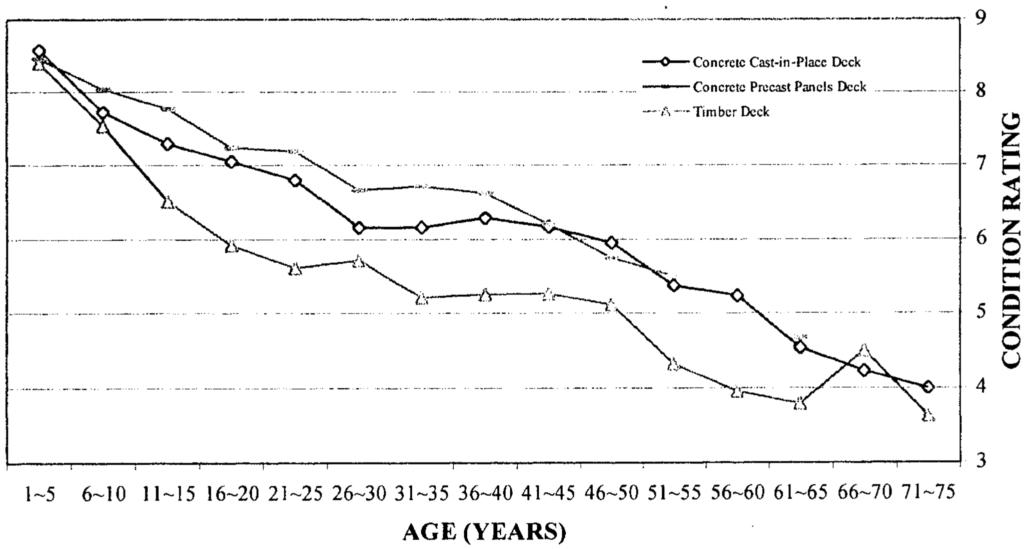


Figure 4-1. Average deck CR versus age for the predominate deck types

Figure 4-2 shows how the different superstructures types have performed. Plots are shown for the seven most common superstructure types. As shown, concrete bridges have generally performed the best.

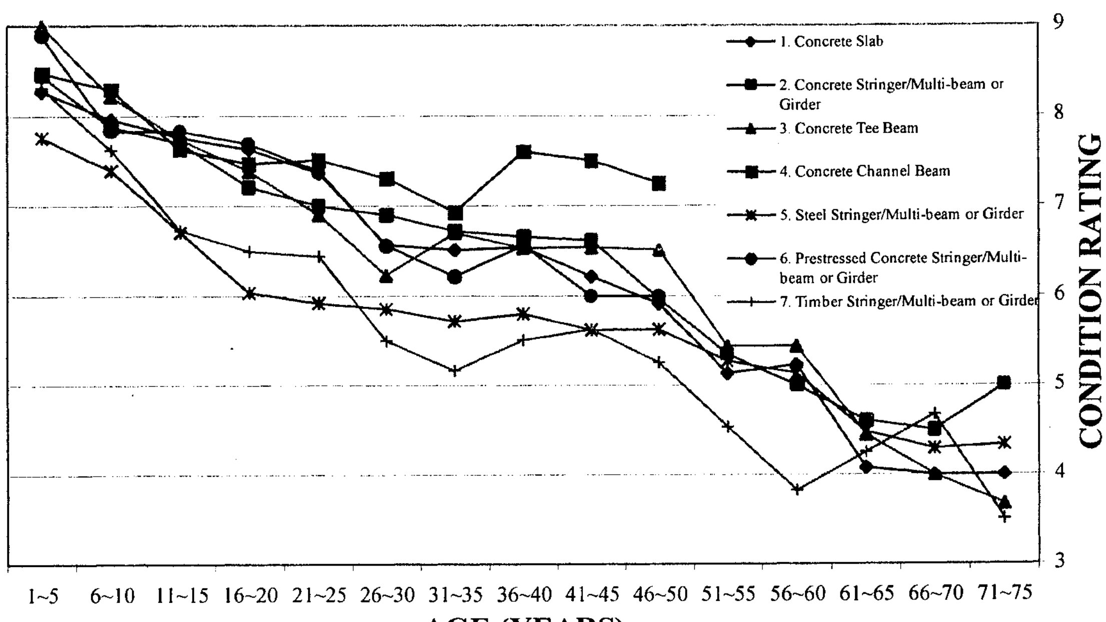


Figure 4-2. Average CR of superstructures versus age for seven types of county bridges

Figure 4-3 shows the results for bridge substructures. In this case no effort was made to separate substructure types. Therefore, this figure represents a mix of design and material types.

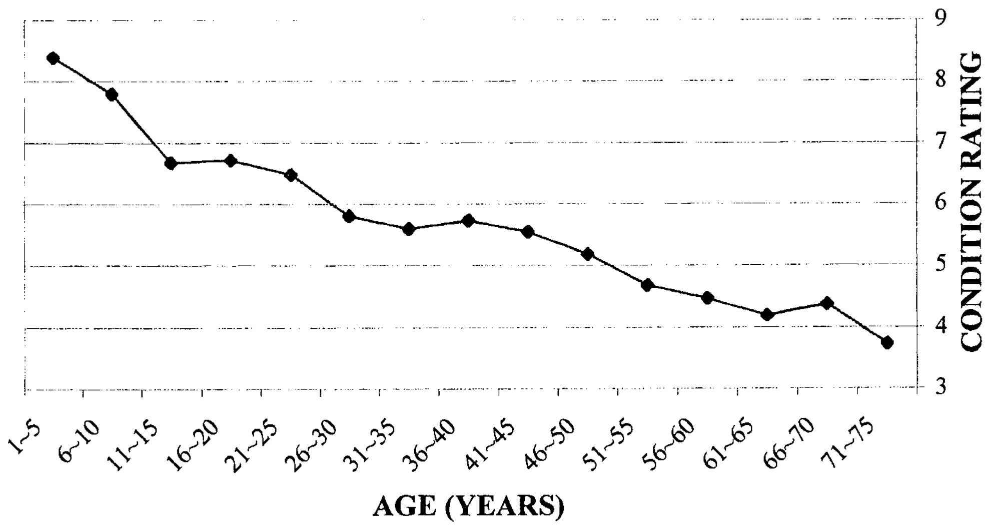


Figure 4-3. Average CR of substructures versus age

When all bridge decks, superstructures and substructures are plotted together, Figure 4-4 results. This figure shows superstructure and decks deteriorate at nearly the same rate, with substructures CRs dropping slightly faster with time.

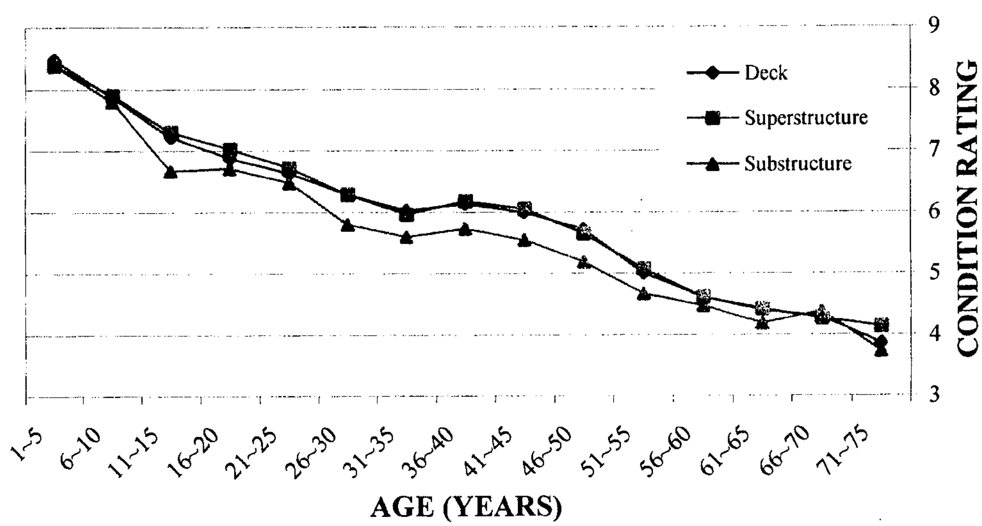


Figure 4-4. Average CR of decks, superstructures, and substructures versus age

Additional plots can be used to compare material types. For example, Figure 4-5 shows the comparison of superstructures where the primary material is concrete, steel, prestressed concrete, or timber.

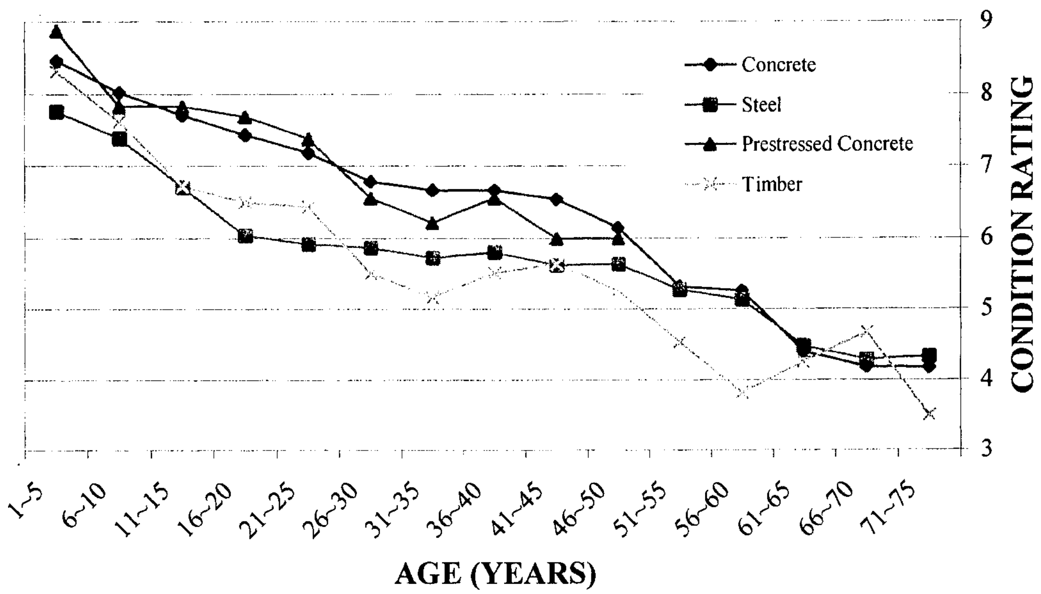


Figure 4-5. Comparison of average CR of superstructures for concrete, steel prestressed concrete and timber county bridges

4.1 Condition and Deterioration Analysis

Based on the analysis of 3,814 county bridges in the data subset, the deterioration performances of all major components took the form of a slightly convex function over time, as indicated in Figures 4-1 though 4-5. The worst performing major component was the substructure, and the best performing was the superstructure, which was just better than the deck, as shown in Figure 4-4.

As for deck deterioration, the timber decks performed the worst, while the concrete precast panels decks performed the best, doing slightly better than concrete cast-in-place decks. The timber decks had a steeper deterioration rate than others when they were less than 20 years old, but they deteriorated at a similar rate in their remaining lifetimes. There is a good possibility that many of the timber decks were replaced after 20 to 25 years, as this is common practice for many Alabama counties.

According to the analysis of CRs of superstructures, if we exclude the concrete channel beams as well as prestressed concrete stringer/multi-beam or girders because these only had

50 years of inspection records, timber stringer/multi-beams or girders performed the worst, while concrete stringer/multi-beams or girders performed the best. The steel and timber stringer/multi-beam or girder superstructures exhibited significant deterioration at their early life, especially for steel stringer/multi-beam or girder superstructures. The interesting thing is, however, the steel stringer/multi-beam or girder design type performed almost as well as most concrete superstructures since all concrete superstructures, except channel beams, had a higher deterioration rate.

The comparison of concrete, steel, prestressed concrete, and timber county bridges revealed that the major components of steel bridges exhibited signs of deterioration at an earlier age, but they had the lowest deterioration rate among all bridge components more than 20 years old. All in all, the longevity performances of steel bridges were basically identical to those of concrete bridges. The timber bridges performed the worst and reached failure (CR=4) at the earliest age. Observations of the data subset indicate that additional inspection records of prestressed concrete county bridges that are 50-75 years old are necessary to objectively evaluate their longevity performance. However, by examining the foregoing figures, it can be concluded that prestressed concrete bridges perform as well as concrete bridges for the first 50 years.

4.2 Deterioration Modeling

The functional relationship between the bridge component CR and age for various types of county bridge components and projected age at CR=4 are tabulated in Table 4-2. The first column gives the deterioration equation where Y is the condition rating and X is the age for the bridge in years. The second column gives the age of the bridge when the condition rating reaches 4 as determined by the deterioration equation.

Note that the equation for concrete channels, predicts that it will take 245 years for this bridge superstructure type to reach a condition rating of 4. Obviously that would be a very optimistic prediction, but the actual age to reach CR=4 will be much less. These bridge types have only been in existence for the past 40 years and the data is rather scattered. In fact, Figure 4-2 shows the bridges older that 36 years have higher condition ratings than those at age 30. This anomaly will be investigated further, although it does appear that these bridge types are among the best performers.

Table 4-2 lists the order of bridge components that performed from the best to the worst are as follows:

1) Concrete Channels (need further investigation)
2) Prestressed Concrete Stringer/Multi-beam or Girder Superstructures
3) Concrete Stringer/Multi-beam or Girder Superstructures
4) Concrete Precast Panels Decks
5) Steel Stringer/Multi-beam or Girder Superstructures
6) Concrete Cast-in-Place Decks
7) Concrete Tee Beam Superstructures
8) Concrete Slab Superstructures

9) Timber Stringer/Multi-beam or Girder Superstructures
10) Timber Decks

Other general observations of this table are as follows:

1) Among the three major bridge components, superstructures performed the best, and substructures performed the worst;
2) The structural systems of Stringer/Multi-beam or Girder Superstructures, except for Timber Stringer/Multi-beam or Girder Superstructures, exhibited excellent durability performance;
3) Except for timber structures, the expected average service lifetimes of all other types of decks and superstructures were greater than 70 years, the age on average at which the United States replaced it bridges (Ramey, 1997).

Table 4-2. Deterioration Function Predicted Service Lifetime of Various Bridge Components

Component	Deterioration Function*	Age at CR=4
Deck	$Y=8.5209e^{-0.0102X}$	74.3
Concrete Cast-in-Place	$Y=8.5264e^{-0.0095X}$	79.7
Concrete Precast Panels	$Y=8.7140e^{-0.0089X}$	87.5
Timber	$Y=7.6752e^{-0.0102X}$	63.9
Superstructure	$Y=8.5019e^{-0.0099X}$	76.1
Concrete Slab	$Y=9.0925e^{-0.0109X}$	75.2
Concrete Stringer/Multi-beam or Girder	$Y=8.6643e^{-0.0087X}$	88.9
Concrete Tee Beam	$Y=9.2240e^{-0.0109X}$	76.7
Concrete Channel Beam	$Y=8.1463e^{-0.0029X}$	245
Steel Stringer/Multi-beam or Girder	$Y=7.4772e^{-0.0075X}$	83.7
Prestressed Concrete Stringer/Multi-beam or Girder	$Y=8.7079e^{-0.0085X}$	91.3
Timber Stringer/Multi-beam or Girder	$Y=7.9720e^{-0.0103X}$	66.7
Substructure	$Y=8.1424e^{-0.0102X}$	69.6

***Where Y equals the condition rating and x is the age of the bridge in years.**

5.0 Conclusions

Based on previous studies and the results of this study, age, and structural material and type are the primary determinants of deterioration. According to the analysis and modeling of data sets, the life expectancy of Alabama county bridges on average is approximately 70 years, i.e., the predicted service time of substructures. In addition, the study revealed that prestressed concrete bridges performed the best in durability, while timber bridges performed the worst. Steel bridges and timber bridges exhibited significant deterioration at an early age. However, the steel bridges performed as good as most concrete bridges in longevity. The conclusions reached here excluded concrete channel beam bridges, as this bridge type is relatively new and its performance characteristics will not be known for several more years.

The condition and deterioration analysis, coupled with the development of deterioration models for Alabama county bridges, has made it possible for a bridge management system to assist in the decision making regarding bridge maintenance, rehabilitation, and replacement.

However, the reliability of analysis and modeling depends on the quality of the available data and detailed information of each rehabilitation. It is also dependent on recorded CRs that are based on bridge inspectors' personal judgments and are highly subjective. In addition, due to the shortcoming that many rehabilitation activities, apparently, have not been recorded in the bridge database, the models produce certain trends that do not agree with commonly held expectations. In other words, the hidden effects of considerable maintenance activity cannot be excluded from the determination of the model coefficients.

It is believed that the reliability of the models will be greatly increased if a more-complete and accurate database is secured by establishing modern bridge management systems in the near future. Fortunately, this activity is underway, but it will take several more years before enough historic data becomes available.

6.0 References

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