ANALYSIS OF THE PRESTRESSED BRIDGE INVENTORY: HISTORY, POPULATION, AND PERFORMANCE CURVES

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ABSTRACT

This study investigates prestressed concrete bridge superstructures through the use of data contained in the National Bridge Inventory (NBI). A statistical description of the prestressed concrete bridge inventory is provided and related to the entire bridge population as well as the identification of the use of prestressed superstructures historically. Performance curves for multi-beam or girder bridges were developed for prestressed bridges as well as their steel counterparts that represent the average superstructure condition rating versus time considering data for the past 35 years.

Conclusions drawn from this investigation are that prestressed superstructures represent a significant portion of the bridge inventory, especially within the structure types of multi-beam or girder and box girders; that the use of prestressed structures has grown both in number and in variety of location over the past half century; and that the performance of prestressed bridges is superior to that of their steel counterparts.

Keywords: Bridges, Prestressed Concrete, Performance, Superstructure Rating

INTRODUCTION

Prestressed concrete represents a large portion of the nation's bridge inventory, and is one of the three most popular material types for bridge superstructure construction. In fact, it has been identified that prestressed concrete bridges have been gaining popularity[1]. The historically increasing use of precast concrete can be attributed to many different factors including aesthetics[2], durability, competitiveness with other materials[1], and economy[3].

This study investigates the use of prestressed concrete within the United States. This is primarily done through the investigation of the National Bridge Inventory (NBI) data. This investigation includes data currently tabulated by the Federal Highway Administration (FHWA) as well as independent analysis of raw data. Unless otherwise noted within the manuscript, the data utilized was current at the end of 2002. Items of investigation include the historical use of prestressed concrete for bridge construction, growth in use (both numerically and spatially), and performance of prestressed bridges.

USE OF PRESTRESSED CONCRETE

At the end of 2002, the NBI contained information on approximately 591,000 bridge structures located throughout the country[4]. One parameter identified for each structure is the type of material that is utilized for construction of the main superstructure[5]. There are ten different categories that can be utilized for this classification. Two of these are prestressed concrete and prestressed concrete continuous, the only difference lying in the continuity of the superstructure. This category includes prestressed and post-tensioned types of concrete construction. The breakdown of the entire inventory into the ten different material types is provided in Table 1. This data indicates that a large portion of the bridges, 120,453 or approximately 20.4% of the entire inventory, are constructed of prestressed concrete. Additionally, this data indicates that 81,284 bridges were classified as structurally deficient, and of these structures, only 3,959 or approximately 4.35% were identified as constructed with prestressed concrete. When compared to their percentage of the entire inventory, this lesser percentage of deficient bridges indicates the durability of prestressed concrete as a building material for bridge superstructures.

STRUCTURE TYPES UTILIZING PRESTRESSED CONCRETE

In addition to material type, the NBI data further identifies bridges based on the type of structural system employed. There are 23 different possibilities utilized for structure type within the NBI reporting system. The prestressed portion of the NBI data was analyzed, and is broken out into the different structure types in Table 2. Only the structure types that represent at least 1% (rounded) of each prestressed material type are provided. The structure types not utilized each account for less than 0.5% of their respective inventories. As shown, each structure type is indicated in the approximate percentage of the overall prestressed portion under consideration. The structure types of stringer /multi-beam or girder and box beam or girders (multiple) are by far the most populated for prestressed concrete bridges. Likewise, the same can be said for the prestressed concrete continuous bridges with the addition of the structure type box beam or girders (single or spread).

Table 1 Bridge Inventory by Material Type

Material type	Entire Inventory		Structurally Deficient	
	No.	%	No.	%
Concrete	164,321	0.278	14,942	0.184
Concrete Continuous	75,672	0.128	4,807	0.059
Steel	146,706	0.248	40,108	0.493
Steel Continuous	48,121	0.081	4,542	0.056
Prestressed Concrete	103,202	0.175	3,660	0.045
Prestressed Concrete Continuous	17,251	0.029	299	0.004
Wood	32,363	0.055	12,228	0.150
Masonry	1,869	0.003	409	0.005
Aluminum / Iron	1,167	0.002	233	0.003
Other	389	0.001	56	0.001
Total	591,061		81,284	

Table 2 Prestressed Bridges by Structure Type

Structure Type	Prestressed	Prestressed Continuous
Slab	9%	1%
Stringer /Multi-Beam or Girder	43%	63%
Tee Beam	7%	4%
Box Beam or Girders (Multiple)	33%	19%
Box Beam or Girders (Single or Spread)	3%	12%
Culvert	3%	> 0.5%
Segmental Box Girder	> 0.5%	1%
Channel Beam	1%	> 0.5%

HISTORICAL USE OF PRESTRESSED CONCRETE FOR BRIDGES

Data describing the NBI from 1992 thru 2002 was obtained to investigate the change in use of prestressed concrete as a material for bridge superstructures[4]. This data, combined and presented in Table 3, indicates the change in the total bridge inventory, the prestressed concrete and prestressed concrete continuous portions of the inventory, and their respective percentages. This analysis shows a consistent, relative increase in use of prestressed concrete (including continuous) as a material for the main superstructure of bridges over this ten-year period.

Additionally, a further analysis of the data available[4] for prestressed concrete (including continuous) bridges was completed to identify any trends in their use over the past several decades. This analysis was performed on the entire set of data within the prestressed bridge inventory. The results of this investigation are shown in Table 4. The analysis utilized seven different categories for identification, six of which were age groupings with the final category representing those structures that had invalid or missing dates of initial construction. This analysis indicates a growing trend in the construction of prestressed concrete bridges. The data for prestressed concrete continuous bridges is particularly evident of this trend. For these types of structures, the trend has been growth throughout their history. The data represented in Tables 3 and 4 suggests that while the use of prestressed concrete for bridge superstructures is still popular and growing, prestressed concrete continuous structures, in particular, are becoming increasingly more accepted and utilized. This is evident by the fact that 35% of all prestressed concrete continuous bridges within the NBI were constructed in the 1990's.

Table 3 Historical Bridge Inventory

Year	Inventory	Prestressed Concrete		Prestressed Concrete Continuous		Total
	No.	No.	%	No.	%	%
1992	572,524	76,238	13.32%	9,386	1.64%	14.96%
1993	574,056	78,456	13.67%	10,136	1.77%	15.43%
1994	576,292	82,059	14.24%	10,897	1.89%	16.13%
1995	582,901	85,678	14.70%	11,728	2.01%	16.71%
1996	581,832	89,153	15.32%	12,398	2.13%	17.45%
1997	582,985	91,598	15.71%	13,257	2.27%	17.99%
1998	583,203	93,575	16.05%	14,092	2.42%	18.46%
1999	585,760	96,119	16.41%	14,837	2.53%	18.94%
2000	587,550	98,403	16.75%	15,531	2.64%	19.39%
2001	589,950	100,955	17.11%	16,279	2.76%	19.87%
2002	591,061	103202	17.46%	17251	2.92%	20.38%

Table 4 Prestressed Bridges by Year of Construction

Year of Construction	Prestressed	Prestressed Continuous
Pre 1960	8.00%	3.00%
1960-1969	18.00%	8.00%
1970-1979	22.00%	21.00%
1980-1989	24.00%	27.00%
1990-1999	24.00%	35.00%
2000-2002	4.00%	5.00%
No Date	> 0.5%	> 0.5%

SPATIAL GROWTH OF PRESTRESSED CONCRETE BRIDGES

Additional analysis was completed utilizing the age data described previously and summarized in Table 4. This analysis combined this information, along with the location of each structure, through the use of a Geographic Information Systems (GIS) software package. For this integration, the latitude and longitude of each structure was required. Currently, this information is a standard entry contained in the set of data that is reported to the NBI for each structure. An initial analysis, as well as current literature[6], indicated that many of the structures were missing this data. Therefore, it was necessary to employ a method of associating each structure with a latitude and longitude describing its particular location. Similar to other research[6], this was accomplished through the use of Federal Information Processing Standards (FIPS) County Codes, which are issued by the National Institute of Standards and Technology (NIST)[7]. This information provides a code for each county and state recognized within the United States. This same coding information is part of the routine NBI reporting procedures. Therefore, the latitude and longitude of each bridge could be established by the county in which it was located. Additionally, each county has a longitude and longitude available from the United States Census Bureau[8].

With this data, each structure within the contiguous 48 states was mapped to a specific latitude and longitude. This mapping was completed for each of the prestressed concrete bridges identified within the NBI data. All bridges were located in this manner. Therefore, the analysis completed with the use of this data represents bridge location by state and county. The analysis was completed to show general growth trends, both in numbers of structures and spatial growth over the past several decades, and does not depict each structure in the inventory. Analyses of prestressed concrete and prestressed concrete continuous structures were completed independently so that each could be studied separately. For prestressed concrete continuous bridges, the results are shown in Figure 1 thru Figure 3. For prestressed concrete structures, results are shown in Figure 4 thru Figure 6. General trends are definitely visible through analysis of these figures. In particular, each of the two types of structures have seen growth in number and spatial distribution within the United States.

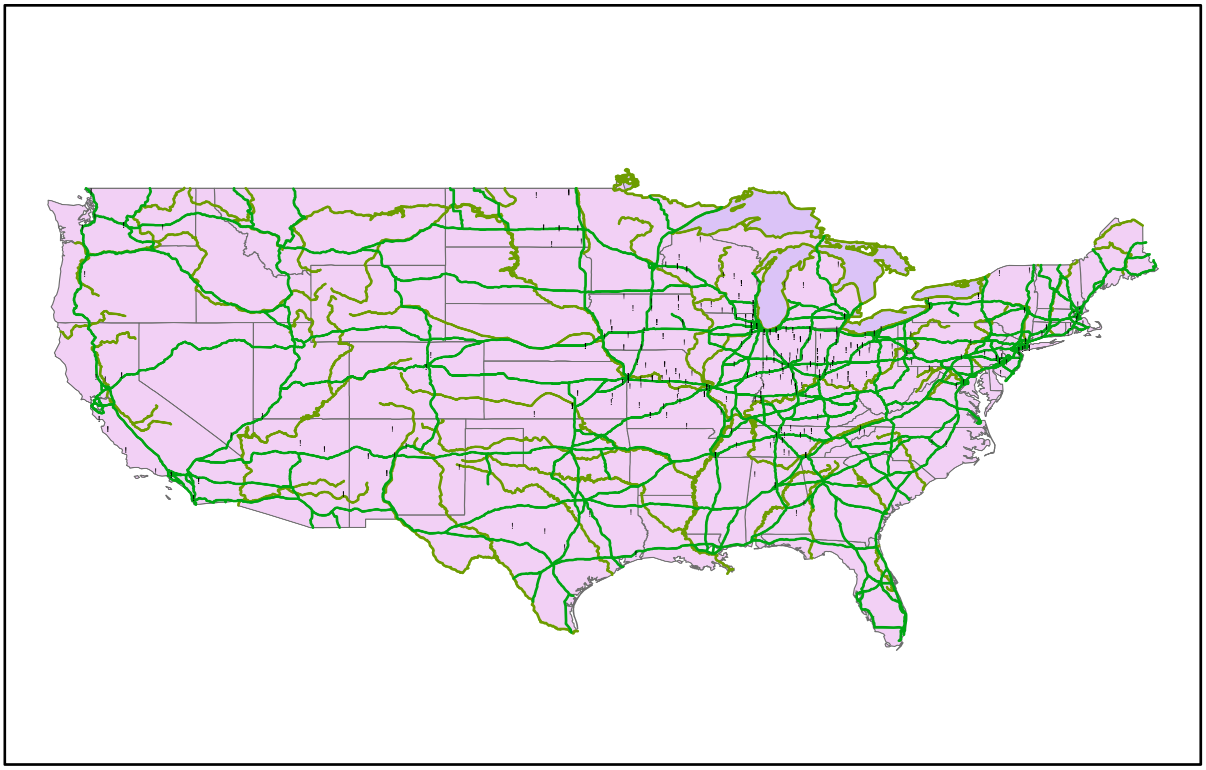

Fig. 1 Location of Prestressed Concrete Continuous Bridges Prior to 1960

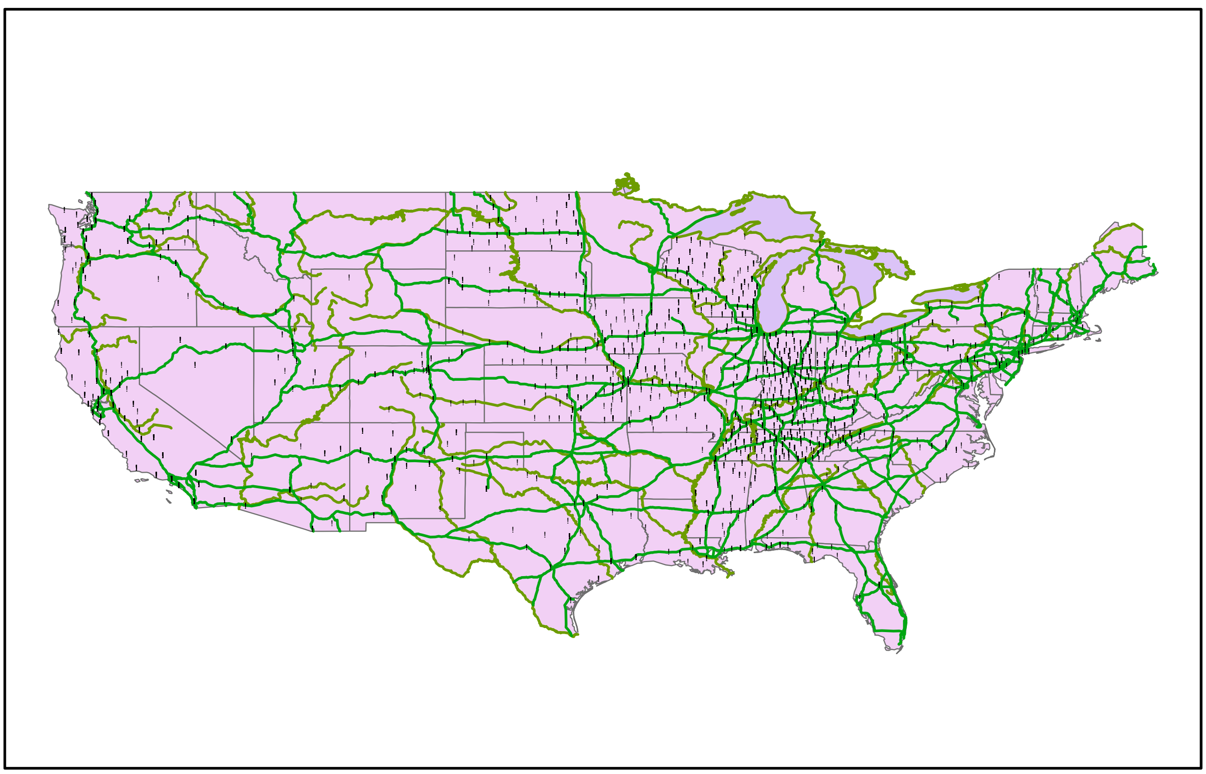

Fig. 2 Location of Prestressed Concrete Continuous Bridges Prior to 1980

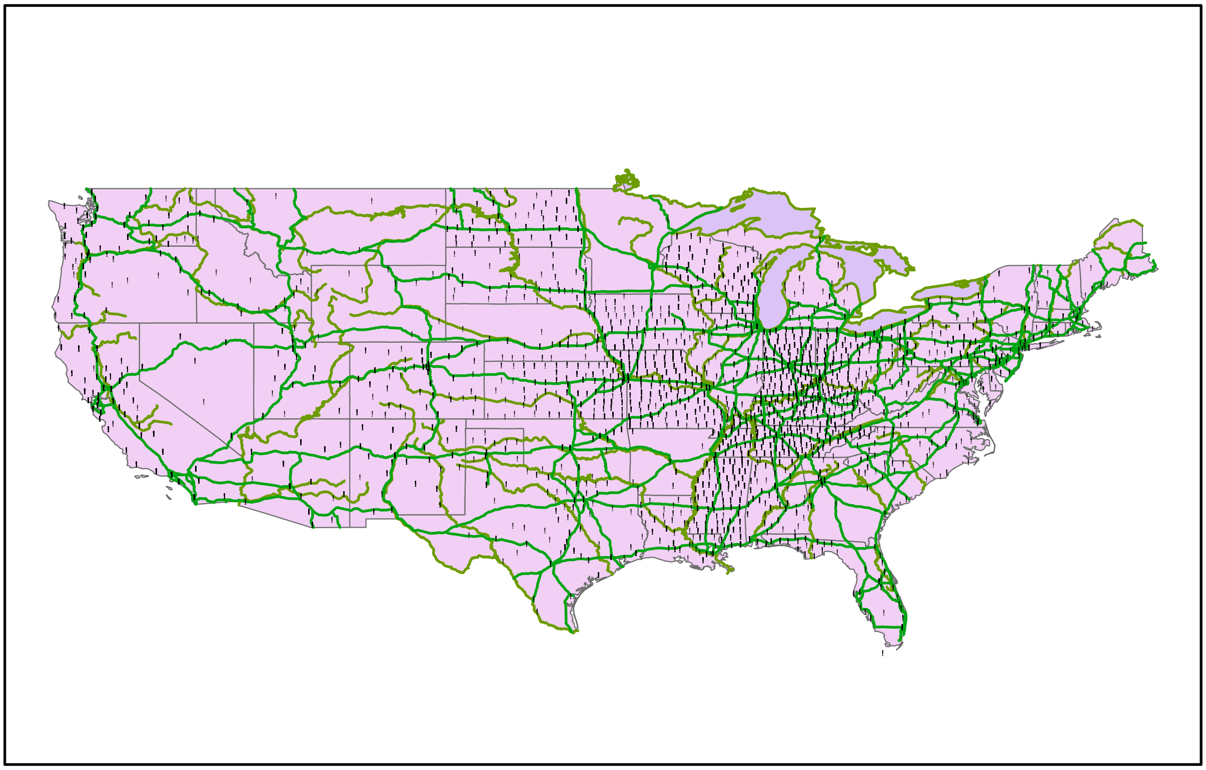

Fig. 3 Location of Prestressed Concrete Continuous Bridges thru 2002

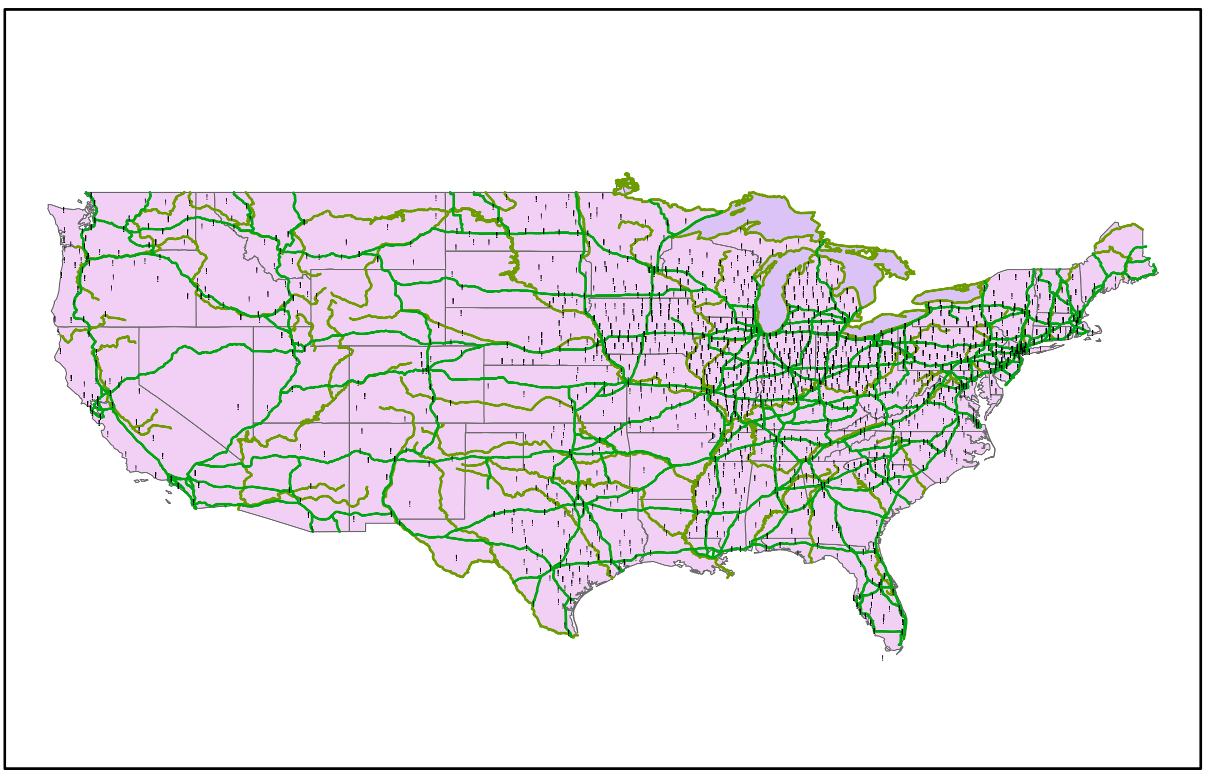

Fig. 4 Location of Prestressed Concrete Bridges Prior to 1960

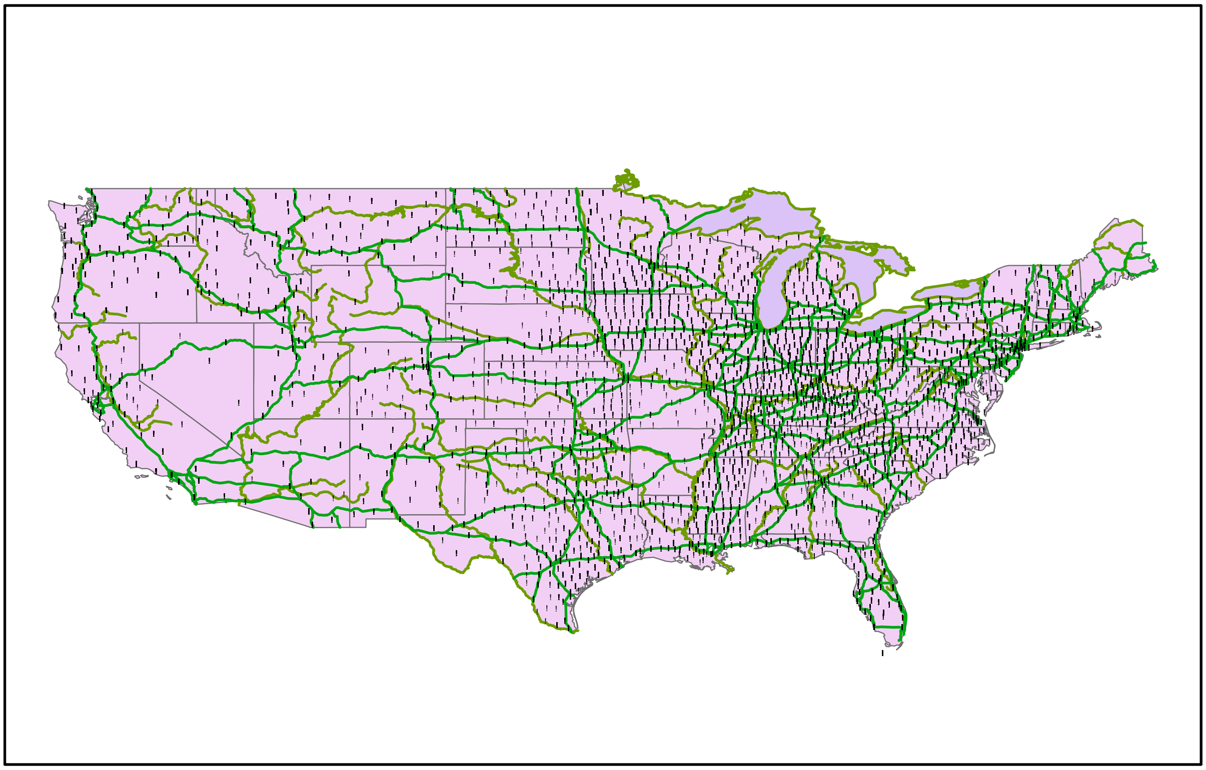

Fig. 5 Location of Prestressed Concrete Bridges Prior to 1980

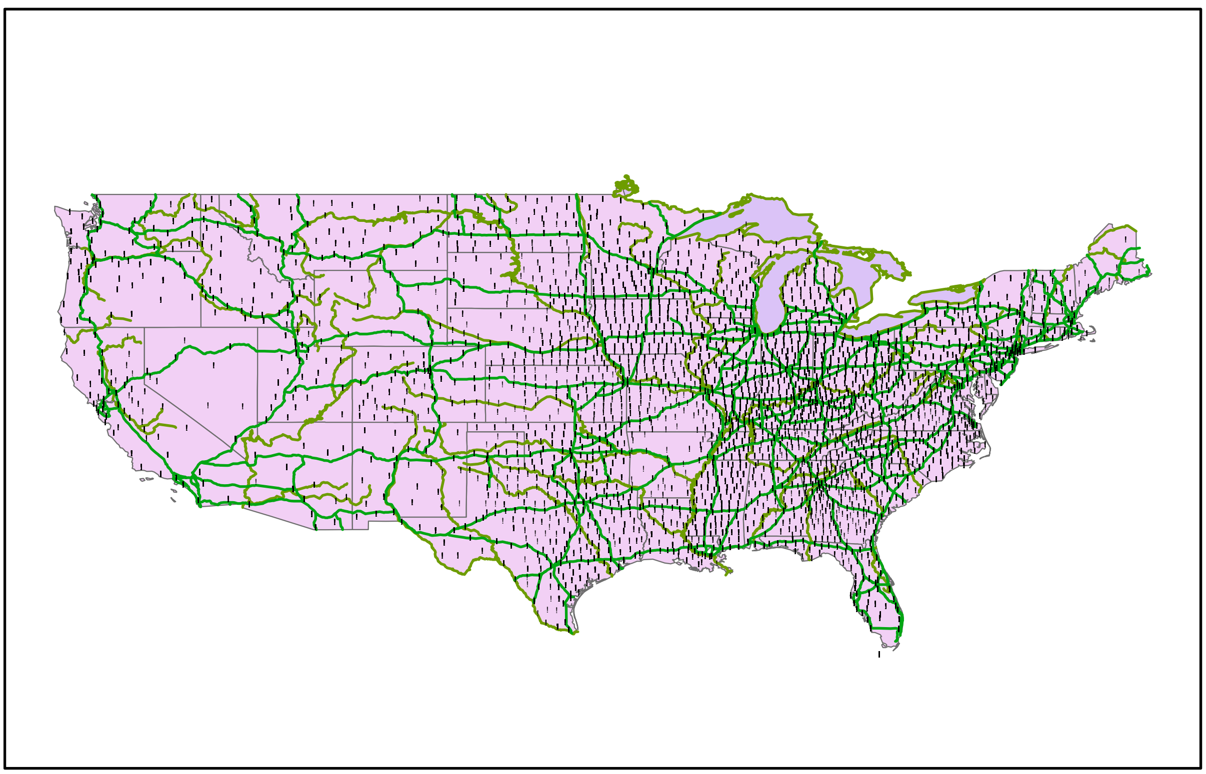

Fig. 6 Location of Prestressed Concrete Bridges thru 2002

PERFORMANCE OF PRESTRESSED CONCRETE

In an attempt to compare the performance of prestressed bridge superstructures to that of other material types, performance curves were created for prestressed concrete and prestressed concrete continuous structures as well as their steel counterparts. An additional parameter that was included in this analysis was that only structures with one of these four material types and only the structure type of stringer /multi-beam or girder were utilized. Initially, all prestressed and steel bridges indicted as stringer /multi-beam or girder structure types were included in a data set. Initial data analysis removed all structures that had been reconstructed at some point during their service lives and as well as those without valid entries for initial construction dates and superstructure condition ratings. Subsequently, bridges in each of the different material categories were grouped by year of construction. Subsequent to grouping, the superstructure condition rating for all of the structures in each group were averaged and then plotted versus age to provide a general idea of the performance of the specific material type. This was completed for the four different material types under consideration. Each material type was then fitted with a second order polynomial so that easy visual comparison could be made and that general conclusions could be ascertained about each group's performance over time. Figure 7 depicts the curves developed for prestressed concrete and steel and Figure 8 depicts the curves of steel continuous and prestressed continuous structures. Higher order polynomial fitted lines were investigated, but as each of the figures show, the second order fitted lines provide coefficients of correlation (R^2) all greater than 0.96. Also, Figure 7 provides analysis for structures up to 45 years in age whereas; Figure 8 considers structures up to 35 years of age. These age limits were set at these specific levels due to the small numbers of structures at the various subsequent age levels

These curves each offer a comparison of performance between prestressed concrete bridges and their steel counterparts. Figure 7 indicates that the prestressed concrete bridges perform superior to their steel counterparts across all portions of the 45-year interval shown. However, it is worth noting that even though the performance of the prestressed concrete bridges is better, it appears as though at some age the two performance curves may cross. As for the steel and prestressed concrete continuous bridges, Figure 8 indicates that continuous prestressed concrete and steel bridges perform in a similar manner initially, with steel having a slight edge, but that over time, the performance of the prestressed concrete bridges diverges from that of their steel counterparts. This increased performance is especially evident between the 20 and 35-year marks. The basic conclusion that can be drawn from this technique is that initially, an advantage cannot be given to either of the materials based on performance of the superstructure, but as the bridges age, the continuous prestressed concrete bridges out perform their steel counterparts.

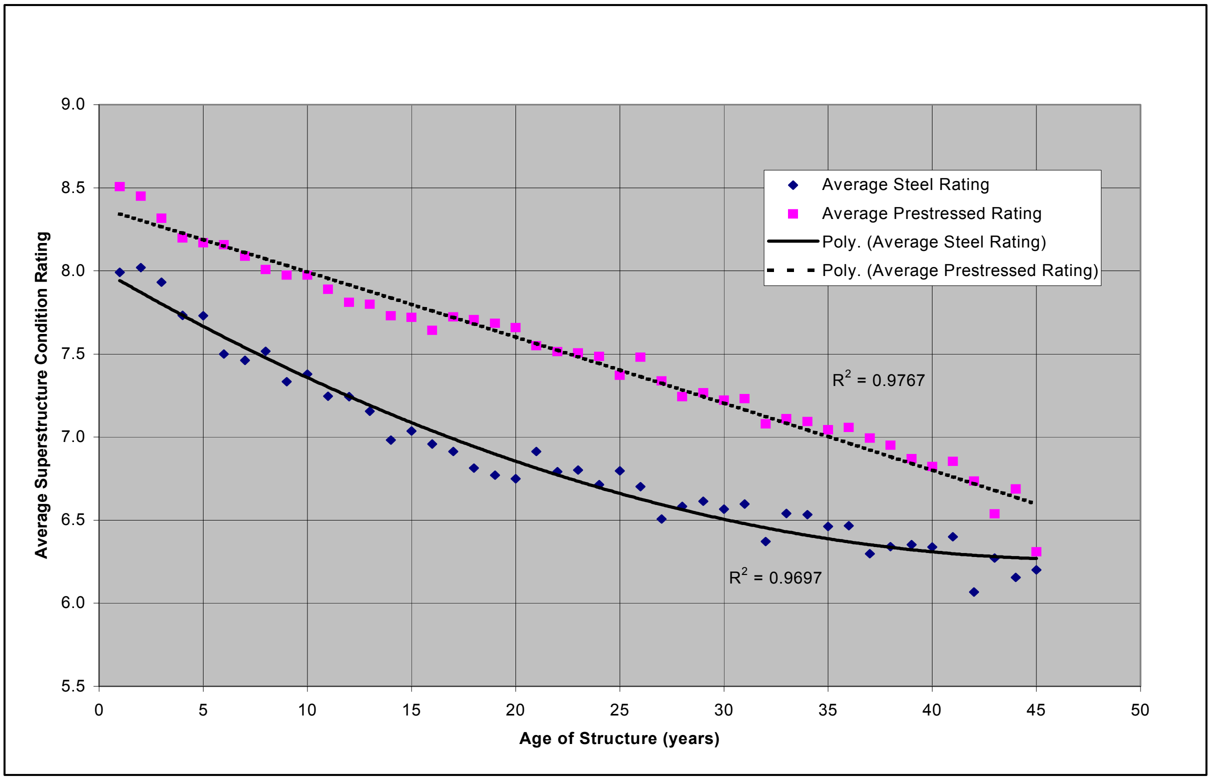

Fig. 7 Performance Comparison - Prestressed and Steel Bridges

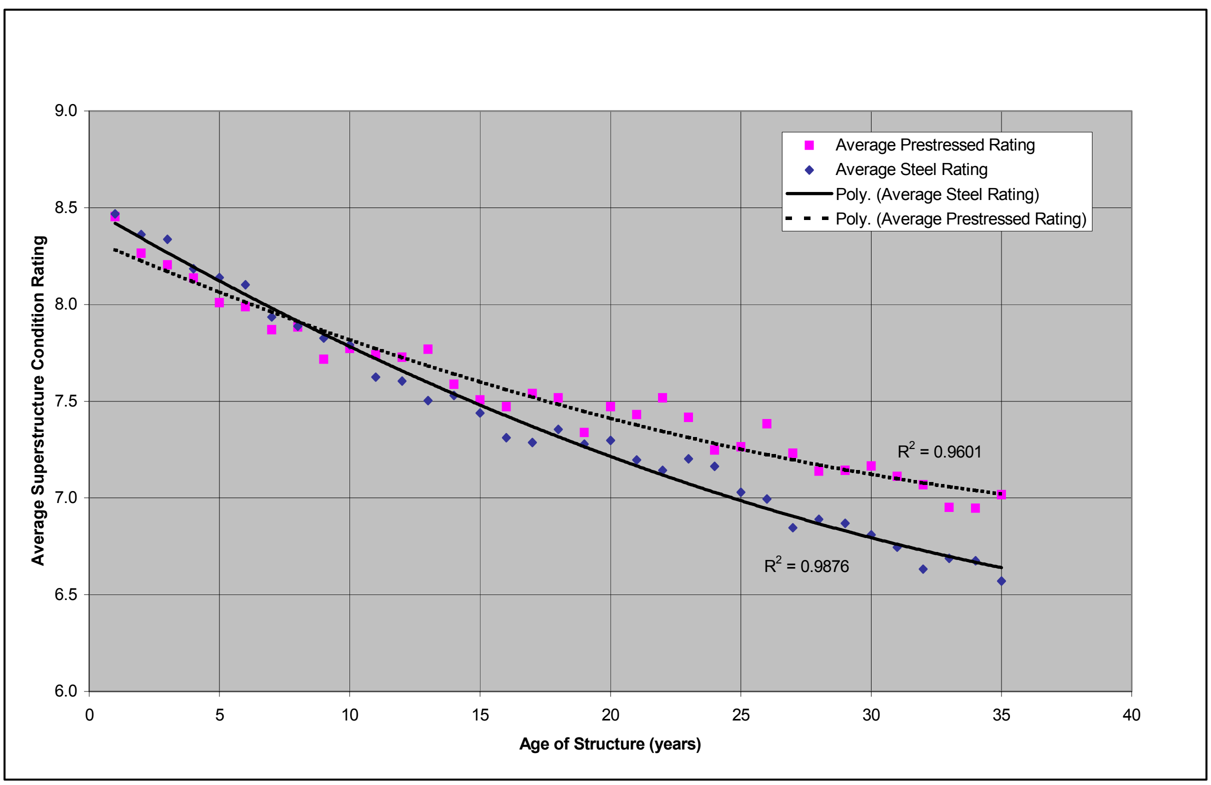

Fig. 8 Performance Comparison – Prestressed Continuous and Steel Continuous Bridges

CONCLUSIONS

Bridges employing prestressed concrete superstructures represent a significant portion of the bridge inventory in the United States. Analysis of the National Bridge Inventory shows that the use of prestressed concrete, particularly on structures with a continuous superstructure, has been on the rise. Additionally, the spatial distribution across the United States of these bridge types has grown. The cause to this effect is the superior performance of prestressed bridges to that of their steel counterparts.

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