Current State of Bridge Deterioration in the U.S.—Part 1

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This two-part article discusses bridge deterioration in the United States. Major findings of the National Bridge Inventory data analysis are presented in Part 1 to better understand the current status of the U.S. bridges in terms of bridge population, material type, structure type, deck protection systems, and traffic volume. Part 2 (February 2012 MP) will address types of bridge deterioration caused by corrosion for reinforced concrete, steel, and prestressed concrete bridges. Some emerging technical challenges are also presented.

According to a Federal Highway Administration (FHWA) corrosion cost study in 2002, the estimated total annual direct cost of corrosion in the United States is $276 billion, or 3.1% of the nation’s Gross Domestic Product (GDP). The average direct cost of corrosion for highway bridges is $8.3 billion per year, including $3.8 billion for replacing structurally deficient bridges over a 10-year period. Indirect costs to the users can be more than 10 times the direct cost of corrosion.

Analysis of National Bridge Inventory Data

The FHWA annually updates the National Bridge Inventory (NBI) database of the bridges longer than 20 ft (6.1 m) on public traffic roads based on mandatory biennial inspection reports submitted by all state departments of transportation and federal agencies. The FHWA uses the NBI data to submit a biennial report on the condition of the nation’s bridges to Congress and identify bridges to rehabilitate or replace with federal aid under the Highway Bridge Replacement and Rehabilitation Program. While the NBI database contains individual bridge condition data for more than 30 years, it is not set up to assess bridge performance over time, nor is it able to track historical condition changes of individual structural elements in each bridge. Furthermore, the database does not provide sufficient details concerning bridge deterioration. The good news is that the FHWA’s Long-Term Bridge Performance (LTBP) program will start monitoring data from hundreds of bridges, and we will take advantage of them for better understanding of the bridge deterioration process. A sophisticated bridge management system (BMS), being developed as part of the LTBP...
program, will enable us to analyze the collected data in various ways and also develop the deterioration models predicting overall bridge performance.

With recognized limitations of the NBI database, the “structurally deficient” (SD) condition rating is a better indicator than the “sufficiency rating” (%) and “functionally obsolete” (FO) rating in the NBI database that describe the structural integrity of a bridge. This is because SD refers to a bridge as having a condition rating of 4 (poor) or less for any part of the deck, superstructure, and substructure that suffers from advanced section loss, deterioration, spalling, or scour. The other source of a SD rating is the structural evaluation and waterway adequacy appraisal. Therefore, the NBI and SD data are analyzed in an attempt to quantify some trends and key snapshots related to bridge deterioration in the United States. Since bridge count alone does not give a complete picture concerning bridge volume, the deck area information included in the recent NBI data is also incorporated whenever available.

**Bridge Population**

The latest NBI data as of December 2010 indicate that there are 604,485 bridges, including 130,846 culverts and a total deck area of $3.5 \times 10^8$ m$^2$. These figures grew from 572,198 bridges in 1992 and $3.1 \times 10^8$ m$^2$ deck area in 2000. The same data classify 69,223 bridges ($11.5\%$) and $3.1 \times 10^7$ m$^2$ deck area ($8.8\%$) of the entire bridge population as structurally deficient. Significant progress has been made to reduce the number of SD bridges despite many obstacles such as the increasing number of older bridges, shrinking financial resources, diminishing buying power, and a surge of traffic volume. Figure 1 shows a bar chart for age distribution of the U.S. bridges by count and by deck area in five-year increments. The mean age of the current U.S. bridge population is \~41 years. Overlaid in the same figure are two cumulative curves for the count and deck area, respectively. The median age falls in the 40- to 44-year age group by count or the 35- to 39-year age group by deck area. Bridges newer than 49 years, particularly \<9 years, carry a larger deck area per bridge than the older bridges.

Figure 2 shows a bar chart for the SD bridges. Each bar within an age group represents a percentage of the SD bridges with respect to total bridges included in the group. The SD cumulative curves are
The mean age of the U.S. SD bridges is ~62 years. Approximately 21% of the bridges in the mean age group are structurally deficient. The median age of the SD bridges lies between 60 and 64 years by count and between 50 and 54 years by deck area. The 10-year difference between the SD curves for the count and deck area indicates that the bridges with larger decks (i.e., newer bridges) deteriorate at faster rates. The percentage of the SD bridges constructed by adding individual percentages calculated from the SD bridges within an age group with respect to the nation’s total SD bridges.

### TABLE 1

<table>
<thead>
<tr>
<th>Category</th>
<th>Unit</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
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<tbody>
<tr>
<td>Structure type</td>
<td>Count</td>
<td>Stringer/multi-beam or girder (249,165 or 41%)</td>
<td>Culvert (130,846 or 22%)</td>
<td>Slab (80,333 or 13%)</td>
<td>Box beams or girders (58,728 or 10%)</td>
<td>Tee beam (35,801 or 6%)</td>
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<tr>
<td>Deck area</td>
<td>Stringer/multi-beam or girder (2.1E+08 m² or 61%)</td>
<td>Box beam or girders (4.2E+07 m² or 12%)</td>
<td>Slab (2.5E+07 m² or 7%)</td>
<td>Tee beam (1.7E+07 m² or 5%)</td>
<td>Truss (1.1E+07 m² or 3%)</td>
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</tr>
<tr>
<td>SD structure type</td>
<td>Count</td>
<td>Stringer/multi-beam or girder (37,710 or 54%)</td>
<td>Slab (6,519 or 9%)</td>
<td>Truss (6,445 or 9%)</td>
<td>Tee beam (4,595 or 7%)</td>
<td>Box beam or girders (3,606 or 5%)</td>
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<td>Deck area</td>
<td>Stringer/multi-beam or girder (1.5E+07 m² or 48%)</td>
<td>Truss (3.6E+06 m² or 12%)</td>
<td>Box beam or girders (3.5E+06 m² or 11%)</td>
<td>Girder and floor beam (2.2E+06 m² or 7%)</td>
<td>Tee beam (2.2E+06 m² or 7%)</td>
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<td>Deck structure</td>
<td>Count</td>
<td>CIP concretes (361,161 or 60%)</td>
<td>N/A (113,286 or 19%)</td>
<td>Precast panel (52,203 or 9%)</td>
<td>Timber (46,530 or 8%)</td>
<td>Other (13,726 or 2%)</td>
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<tr>
<td>Deck area</td>
<td>CIP concrete (3.0E+08 m² or 86%)</td>
<td>Precast panel (2.5E+07 m² or 7%)</td>
<td>N/A (7.9E+07 m² or 2%)</td>
<td>Timber (5.1E+06 m² or 1%)</td>
<td>Other (4.9E+06 m² or 1%)</td>
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<td>Deck protection system</td>
<td>Count</td>
<td>None (345,728 or 57%)</td>
<td>N/A (108,550 or 18%)</td>
<td>Unknown (71,724 or 12%)</td>
<td>Epoxy-coated reinforcing (70,866 or 12%)</td>
<td>Other (3,410 or 0.6%)</td>
</tr>
<tr>
<td>Deck area</td>
<td>None (2.0E+08 m³ or 56%)</td>
<td>Epoxy-coated reinforcing (7.9E+07 m³ or 22%)</td>
<td>Unknown (6.1E+07 m³ or 17%)</td>
<td>N/A (1.0E+07 m³ or 3%)</td>
<td>Other (2.6E+06 m³ or 0.7%)</td>
<td></td>
</tr>
<tr>
<td>Deck wearing surface</td>
<td>Count</td>
<td>Bituminous (189,614 or 31%)</td>
<td>Monolithic concrete (182,004 or 30%)</td>
<td>N/A—No deck (93,198 or 15%)</td>
<td>None (43,186 or 7%)</td>
<td>Gravel (23,409 or 4%)</td>
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<tr>
<td>Deck area</td>
<td>Monolithic concrete (1.7E+08 m² or 47%)</td>
<td>Bituminous (7.3E+07 m² or 22%)</td>
<td>None (4.3E+07 m² or 12%)</td>
<td>Latex-modified concrete (1.1E+07 m² or 5%)</td>
<td>Integral concrete (1.5E+07 m² or 4%)</td>
<td></td>
</tr>
</tbody>
</table>

\(^{a}\)CIP concrete = cast-in-place concrete

Usage and span length data of three construction materials.

The figure illustrates the percentage of bridges with various construction materials over time, showing the trends in deterioration and the relative performance of different materials.
either by count or by deck area increases linearly with time starting from an age group of 25 to 29 years. In addition, the two cumulative SD curves start to climb up sharply from an age group of 35 to 39 years. The percentage of SD bridges is likely to increase with age, and the current mean age group of 40 to 44 years is estimated to have twice the number of SD bridges—from 10 to 20%—when they reach 60 years. This projection assumes that some bridges will be removed from the NBI and all the bridges receive routine maintenance treatments during their lifetime.

Material Type

The NBI data classify construction materials used in the main span, which can be either simply supported or continuous. The most popular material types are reinforced concrete, steel, and prestressed concrete, in that order. The post-tensioned bridges are included in the prestressed concrete category. As of 2010, a total of 576,309 bridges and $3.5 \times 10^8$ m$^2$ of deck area are constructed with these three materials. Figure 3 shows historical usage of them. Some other materials include timber, masonry, aluminum, wrought iron, and cast iron. The most popular deck material is cast-in-place concrete (Table 1).

Reinforced concrete has been the most frequently used material by count, but the corresponding deck area is the lowest among the three materials. The second choice of material by count is steel. Although the number of steel bridges has been steadily declining since 1992, steel still supports the largest percentage of deck area. The number of the prestressed concrete bridges has grown in the last eight years and its deck area accounts for 36% of total deck area in 2010.

The inset in Figure 3 represents the 2003 NBI data concerning the main span materials reported in a National Cooperative Highway Research Program (NCHRP) synthesis report. This figure shows that reinforced concrete structures are mainly used for the shortest span lengths. On the other hand, the steel bridges are used to carry longer spans and their percentage jumps for the span lengths over 150 ft (46 m) or longer. The prestressed concrete bridges are used primarily for intermediate span lengths between 50 and 150 ft (15 and 46 m). These data indicate that, on average, the steel bridges are much larger than both the reinforced concrete bridges and the prestressed concrete bridges.

Figure 4 shows the SD bridge data grouped by the three materials. While the number of SD steel bridges has been
and prestressed concrete counterparts. As compared to the reinforced concrete, particularly transverse cracks, and vibration which results in more deck cracks, participation for the poor condition of steel bridges to the span length. One possible explanation for the span length longer than 150 ft are more likely to get the SD rating than those with shorter spans. Deterioration of the prestressed concrete bridges is not sensitive to deterioration. The inset in Figure 4 also represents data in the NCHRP synthesis report. The steel bridges having a span length of <50 ft suffer the most from deterioration, followed by those with 50 to 99 ft (30 m) and 200 to 249 ft (61 to 76 m) span lengths. The reinforced concrete bridges with a span length longer than 150 ft are more likely to get the SD rating than those with shorter spans. Deterioration of the prestressed concrete bridges is not sensitive to the span length. One possible explanation for the poor condition of steel bridges is related to their less stiff superstructure, which results in more deck cracks, particularly transverse cracks, and vibration as compared to the reinforced concrete and prestressed concrete counterparts.

The effect of salts on structural deficiency was investigated by analyzing the 2010 SD data in two groups of 12 southern states vs. 16 Northeast and Midwest states. The latter group is regarded as heavy salts users and the former group uses little. The bridges along the coastline in both groups are subjected to marine exposure. Figure 5 shows an interesting trend. The number of the SD reinforced concrete bridges and prestressed concrete bridges in the northeast and midwest states is almost twice that of the southern states. The percentage of SD steel bridges is identical for both groups, however. It indicates that the deterioration of both the reinforced and the prestressed concrete bridges is closely related to exposure to chloride ions, but the deterioration of the steel bridges is not.

**Structure Type and Deck Protection Systems**

As shown in Table 1, the most dominant structure type is made with stringer/multi-beam or girders. The same type of bridges also has the largest SD bridges among all the U.S. bridges. Other types of bridges include slab, box beams or girders, and tee beams excluding culverts. Each makes up more than 5% of the SD bridges.

Table 1 lists the main deck protection systems identified in the 2010 NBI database. About 57% of the bridge decks by count as well as by deck area do not have any deck protection system and more than 10% of the decks have unknown systems. More than 70,000 decks or 7.7 x 10^6 m^2 deck area contain epoxy-coated reinforcing steel (ECR), which is the most popular deck protection system in the United States. Bituminous overlays and monolithic concrete are two primary wearing surfaces on the bridge decks.

**Traffic Volume**

The largest number of bridges serves the Non-National Highway System (NNHS) with average daily traffic (ADT) of 0 to 10,000 vehicles. These bridges account for 75% by count or 38% by deck area of the bridge inventory. This group also has the largest number of SD bridges by count and the second largest SD by deck area. The National Highway System (NHS) bridges with ADT of 0 to 50,000 vehicles make up ~17% by count and 36% by deck area. This group has the least SD bridges by count and also by deck area, however.

Figure 6 is plotted using selective data from a special report. According to the report, 77% of the bridges are located on rural roads and they handle 23% of total ADT. The bridges located in the urban areas make up the difference, for a total of 100% in each category. Among them, the number of the urban interstate highway bridges is only 4.7% of the U.S. bridges, but they carry ~35% of total ADT. The highway systems serving the rural areas have more SD bridges as they have a higher number of bridges and much lower ADT compared to the urban bridges. Conversely, fewer urban bridges carry a very high traffic volume and are
less likely to become structurally deficient. This trend strongly suggests that the percentage of SD bridges in rural bridges is influenced by the total number of rural bridges, not by ADT. Also, the urban bridges with a high volume of traffic are likely to get more attention/investment on maintenance to minimize the impact of traffic interruptions, resulting in better bridge conditions; whereas the rural bridges do not get the same level of attention, which leads to more SD bridges.

Conclusions

Based on the analysis of the NBI data, the U.S. bridges with all of the following characteristics are the most likely to be structurally deficient: (1) age 50 years or older; (2) simply supported steel stringer/multi-beam superstructure; (3) <50-ft span length; (4) cast-in-place reinforced concrete deck without any deck protection system; (5) black reinforcing steel; (6) non-NHS with ADT of 0 to 10,000 vehicles; and (7) located in the rural local area. This finding suggests that the current state of the U.S. bridge deterioration characterized by the number of SD bridges can be improved if more maintenance resources and attention are given to preserve many old small steel bridges in the rural areas.

References


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