

Investigation of Early Timber–Concrete Composite Bridges in the United States

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Summary

The use of timber–concrete composite (TCC) bridges in the United States dates back to circa 1925. Two different TCC systems were constructed during this early period. The first system included a longitudinal nail-laminated deck composite with a concrete deck top layer. The second system included sawn timber stringers supporting a concrete deck top layer. Records indicate that most of the TCC highway bridges were constructed between 1930 and 1960. The current U.S. National Bridge Inventory (NBI) database indicates that there may be well over 1,000 of this bridge type still in service. This paper will review and discuss the current conditions of several TCC bridges that remain in service today. This will be based on the information given in the NBI and other relevant documents, complemented with information provided by 25 field inspections undertaken during June 2016 in the Pacific Northwest states of Oregon and Washington.

Keywords: timber-concrete, timber bridges, bridge inventory, composite systems, longevity.

1. Introduction

1.1 Historic Background

TCC structures first appeared in the United States in the early 20th century [1, 2]. At that time, the use was for bridges, and this development was motivated by a shortage of steel that urged builders to use other available structural materials or combinations of such materials [3]. The first reported TCC bridge in the United States dates back to circa 1925 [4].

This structural composite bridge solution combining two different materials became more common in the United States in the 1940s [5], and from there, it spread around the world. In the 1950s, TCC structures started to be applied to bridge construction in other locations, such as Australia and New Zealand [6, 7]. However, in other parts of the globe, this structural solution was ignored until quite recently. Since the beginning of the 1990s, TCC bridges have been increasingly used mainly in some northern and western European countries, such as Finland, Switzerland, France, Germany, and Austria [8–12], and also in the South American countries of Brazil [13] and Chile [14].

Records indicate that most of the TCC highway bridges in the United States were constructed between

1930 and 1960. The current USA NBI database indicates that there may be well over 1,000 of this bridge type still in service after many decades. The study presented in this paper provided the opportunity to conduct inspections of more than 25 TCC bridges in the Pacific Northwest states of Oregon and Washington. Analysis of the inspection information revealed that several structures are quite large multiple-span trestle-type bridges, some still carry significant daily traffic counts, and many remain in surprisingly good condition. These findings will be analyzed and discussed in this paper. There will also be a review of the relevant literature, and the current conditions of several TCC bridges that remain in service today will be described.

1.2 Bridge Superstructure Systems

From early times, multiple systems and configurations have been used for bridges. In general, these can be grouped in two categories: T-beam and timber deck (slab). Both TCC systems were constructed during the early period of TCC bridge design. The first system included sawn timber stringers supporting a concrete deck top layer. The second system included a longitudinal timber (nail-laminated) deck composite with a concrete deck top layer (Figure 1) [15].

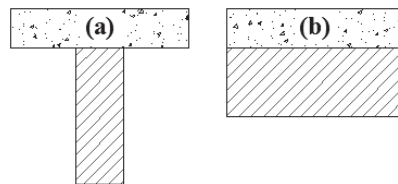


Fig. 1. TCC bridge configuration (a) T-beam; (b) slab [15]

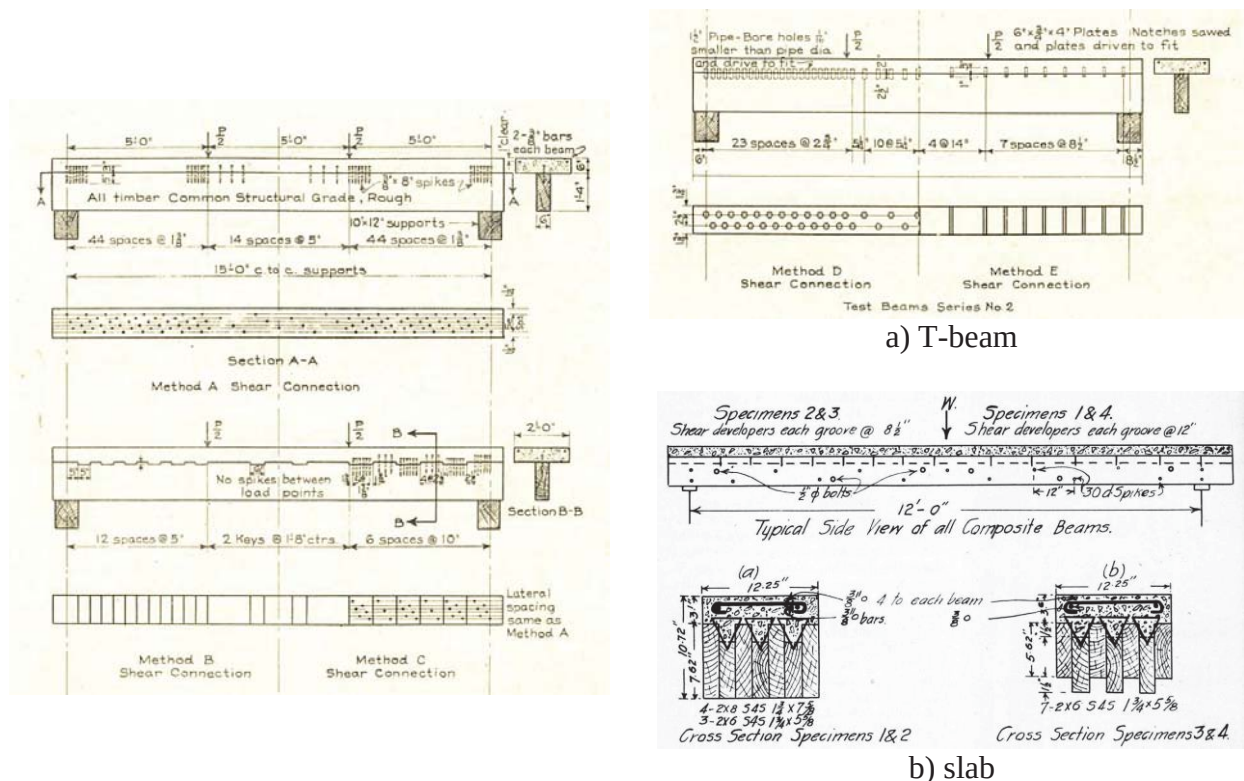


Fig. 2 Connection systems tested in the United States in the 1930s: (a) T-beam; (b) slab [16, 17]

In the design and performance of TCC bridges, a key issue is the connection system, which has a direct influence on both the serviceability limit state (SLS) and the ultimate limit state (ULS). From early times, specific connection systems, such as steel spikes or notches, have been tested and used, and some traditional timber connection systems are still used today (Figure 2).

The type of connection used depends on the specific conditions and requirements of the bridge, usually low-demand structures can be designed with simple conventional connection systems, whereas high-demand structures require the use of high performance connections such as notches or notches combined with steel fasteners [18].

1.3 Reasons for Using TCC

The use of TCC for bridges was motivated by different reasons. Among those, some of the most relevant were connected to the need for rehabilitation and improvement of the existing timber bridges to allow their continuation in service or even to upgrade their load capacity because of new load requirements. The deck could be a new composite or a concrete deck overlaid on top of the existing nail-laminated deck, as was done for a large number of bridges in U.S. Route 66 (Figure 3).



Fig. 3 TCC bridge along US Route 66 in California

During the two world wars of the 20th century, large amounts of steel were consumed in the manufacture of armaments, leading to a significant scarcity of reinforcement steel required for a concrete deck superstructure. During that time, TCC systems were seen as an interesting alternative, because a good portion of the steel could be replaced by timber [15]. These motivations are in line with the number of bridges built and research efforts, which had a clear peak in this historic period.

Nowadays, the motivations to use TCC in bridges are slightly different, with aesthetic issues and sustainability considerations becoming increasingly important from the bridge owners perspective [19].

1.4 Research in the United States

The use of TCC bridges started as an upgrade of timber bridges. However, increasing demand for TCC bridges has raised many issues that need to be resolved to allow the wide use of this system for new construction. Timber and concrete have completely different short- and long-term technological behaviors. The basics of the design could be addressed using basic knowledge from the mechanics of

materials, but specific issues, such as the connections (Figure 2) or the long-term performance, could not.

This situation motivated the development of extensive research programs, conducted at different U.S. locations, all focusing on TCC for bridge applications. Among these are three research institutions that have attracted significant resources, which resulted in an important base of knowledge: University of Illinois-Champaign [20], Oregon State Highway Department [17], and George Washington University in Washington, DC, which focused on a patented system [4].

These early research efforts addressed different topics that were critical for the development of TCC systems, such as connection systems, composite effects, cyclic performance, friction between timber and concrete, and long-term performance of the composite. Collectively, these research efforts paved the way for the extensive use of TCC in bridges that has occurred since that time.

2. TCC Bridge Inventory

2.1 Locations

The discussion from this section is based on information provided by NBI from 2016 [21]. The total number of timber bridges still in service and codified as TCC in the United States is 1,644. Some bridges may appear in the database as TCC structures but were originally constructed as narrow timber stringer bridges and were later widened with concrete components to achieve double-lane roadways. These enlarged bridges that combine timber and concrete in a noncomposite manner are sometimes mistaken for true TCC bridges (Figure 4) within the NBI. Additional field bridge studies will help clarify these discrepancies in the future.



Fig. 4 Timber bridge enlarged with concrete members that has been wrongly codified as a TCC bridge

According to NBI, in 2016, TCC bridges were in service all over the United States, in a total of 33 states, from the North to the South as well as from the East to the West coast. The locations of all of these TCC bridges included in the inventory are plotted in Figure 5. It is not clear why these remaining TCC bridges are distributed in such a clustered fashion in so many regions of the United States. These regions may have been where large bridge construction efforts were undertaken to initially build the network of highways during the 20th century (Figure 6).

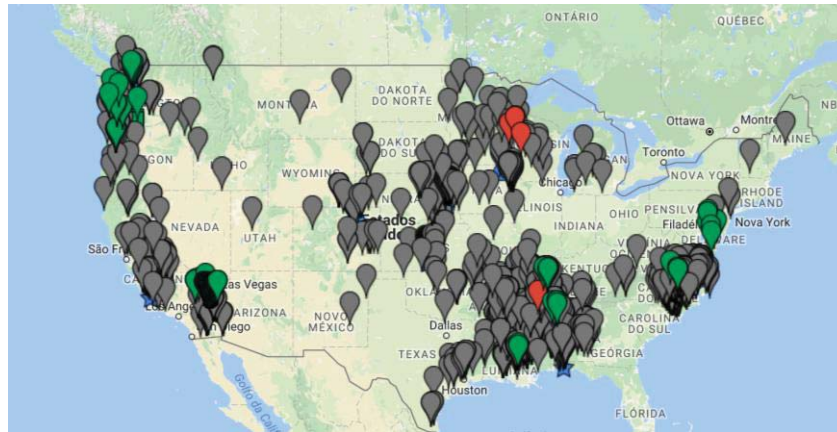


Fig. 5 Location of the timber–concrete composite highway bridges in the United States as reported in NBI (green – confirmed; red – not confirmed; grey – no information)

In addition to data mining of the NBI database, other searches focused on supplemental information from independent sources, such as bridge inspection reports or other relevant bibliographies [22–24]. This provided a method to confirm NBI data for a total of 98 bridges, of which an overwhelming majority (93 percent) were validated as being true TCC bridges.

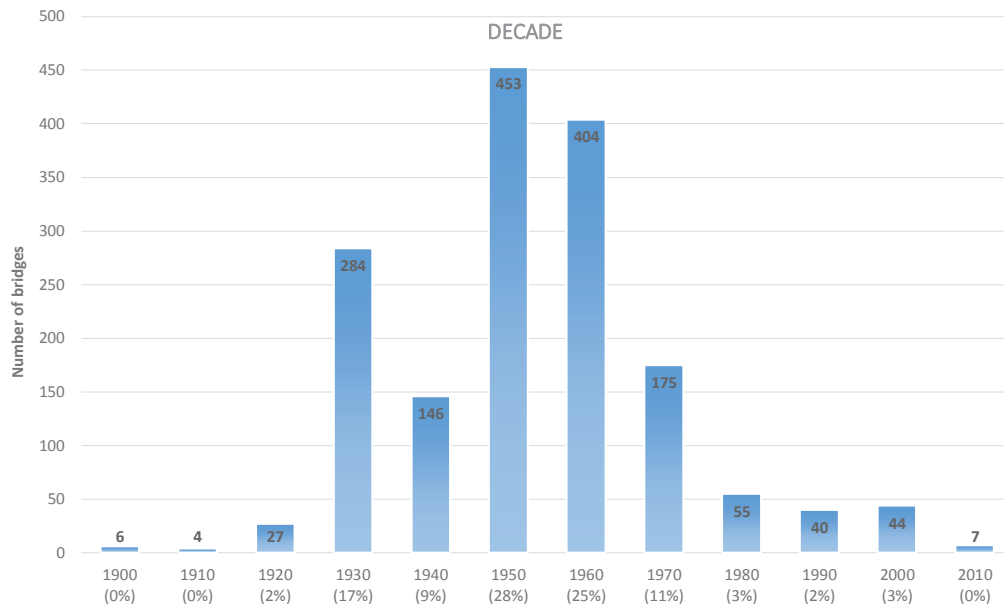


Fig. 6 Number of TCC bridge currently in service by construction decade

Figure 7 shows that in only 6 states, there are more than 100 bridges in service, whereas in 15 states there are less than 10 bridges. The state with a largest number of bridges is clearly North Carolina with close to 400 bridges, almost a quarter of the total number. Despite such a wide distribution of the TCC bridge within the United States, there are only a few hotspots with a high concentration of these structures still in service.

2.2 Date of Building

As previously mentioned, the TCC bridges started to be built in the early 20th century, and the information available indicates 1924 as the year of construction for the oldest TCC bridge. In the NBI, there are a few bridges built before the 1920s decade that were codified as TCC, but these were probably mistakenly entered into the NBI as being true TCC structures. One example is located in Rockford, Illinois, and was reportedly constructed in 1901. This bridge was inspected, and it was indeed a timber bridge but had a small concrete deck extension added later and had no signs of the TCC system (Figure 8).

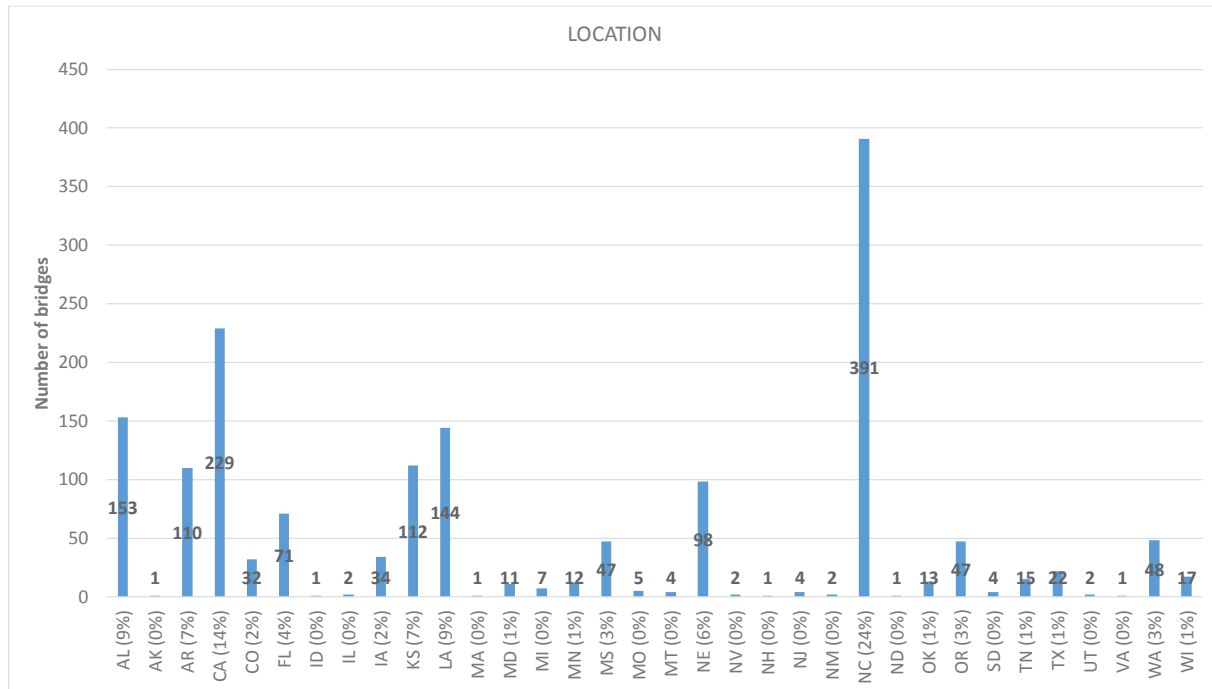


Fig. 7 Number of TCC bridges in service by state



Fig. 8 Bridge in Rockford, Illinois, built in 1901 codified in the NBI as TCC



Fig. 9 Modern TCC bridge built in Singbboet Slough, Washington

Analysis of TCC bridges by construction decade clearly shows that large-scale construction started in the 1930s with the large majority of the bridges being built by the 1970s (92%). In the early years, solid

timber T-beam sections and solid timber decks were primarily constructed. Beginning around 1950, newer engineered wood products (for example, glulam beams) started to be used, which allowed larger spans and new configurations [25].

Although most of the TCC bridges were built between 1930 and 1970, they were still built in more recent decades as well. Modern motivations and bridge characteristics are rather different, but the use of composite systems to improve mechanical performance and durability is still a driving wheel to the adoption of this bridge solution (Figure 9) [15].

2.3 Use and Configuration

Almost all TCC bridges in service are part of national highways, but there is also a small number of highway pedestrian or overpass structures as is shown in Figure 10.

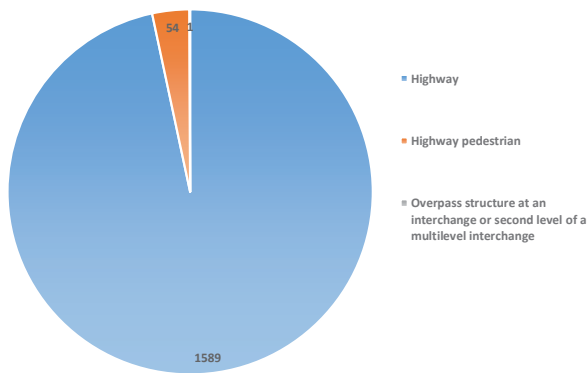


Fig. 10 Number of TCC bridges currently in service by type of use

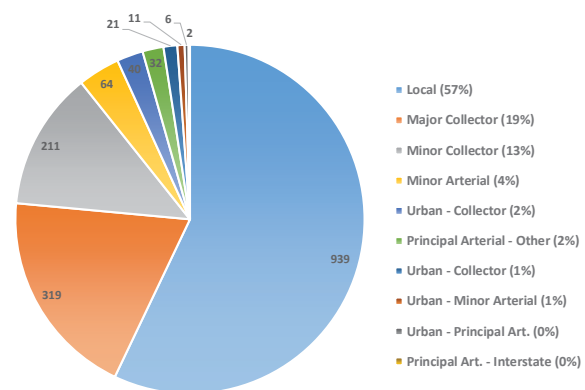


Fig. 11 Number of TCC bridges currently in service by functional class

Among the highway bridges, the large majority are in local, major collectors, and minor collectors (89%), leaving the other types, such as urban arterial and collectors, almost residual (Figure 11). This is well in line with the type of technical solution and motivations for the use of TCC bridges in the early literature. This information is consistent with the annual expected low volume of traffic for these bridges (Figure 12). Indeed, less than 10% of the bridges have an annual traffic count higher than 10 million vehicles.

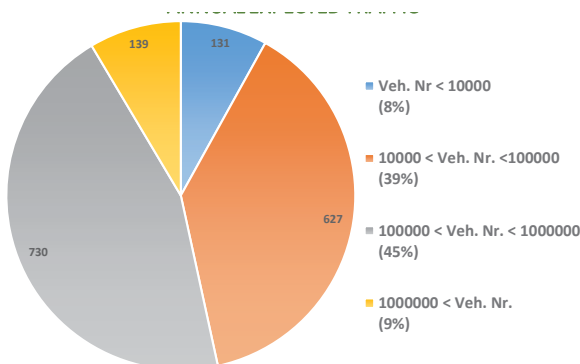


Fig. 12 Number of TCC bridges currently in service by annual traffic



Fig. 13 TCC bridge in a high traffic road, built in 1934 in the city of Portland, Oregon

In spite of this fact, it is important to mention bridges such as the Vermont viaducts in Portland (Figure 13) that carry an average daily traffic of 16,000 vehicles per day, have been in service for 83 years, and

are in good condition without significant intervention. This fact clearly shows that this type of bridge offers a robust and highly durable solution even in highly demanding traffic situations.

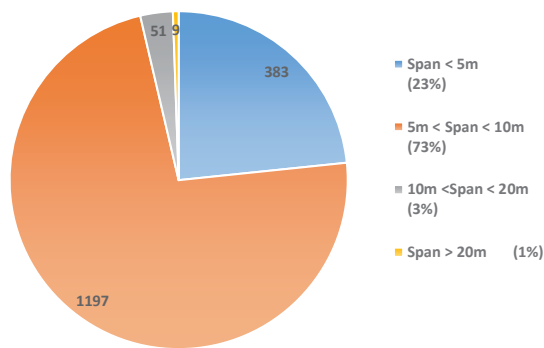


Fig. 14 Number of TCC bridge in service by maximum span length

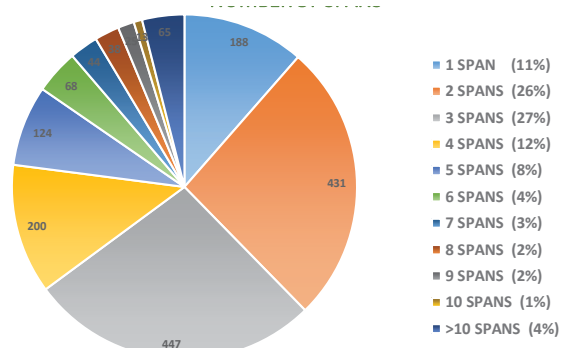


Fig. 15 Number of TCC bridge in service by number of spans

The large majority of the TCC bridges built in the United States are trestle-type bridges, being single spans and relatively short and being in many cases standard spans (around 5 m) (Figure 14). The larger total spans are possible to overcome through the use of multiple standard spans (Figure 15). The NBI indicates that almost two-thirds (65%) of TCC bridges have between 2 and 4 spans. According to the NBI, there are, however, 65 bridges that have more than 10 spans, which necessarily leads to long total span bridges. Indeed, the NBI indicates that there is a total of 80 bridges that have total length longer than 50 m, and the longest total span for a TCC bridge is reported to be 192 m.

3. Condition Rate

In the NBI, the condition of various bridge components must be inspected every 2 years, namely the deck, superstructure, and substructure. Figure 16 gives the TCC bridge conditions for these three components. According to the grading scale (where 1 denotes a failed bridge, and 9 denotes a brand new bridge), a condition rating 5 and above is considered to be good condition, whereas a condition rating of 4 and below indicates that there are structural deficiencies present that can compromise the normal use and safety of the bridge.

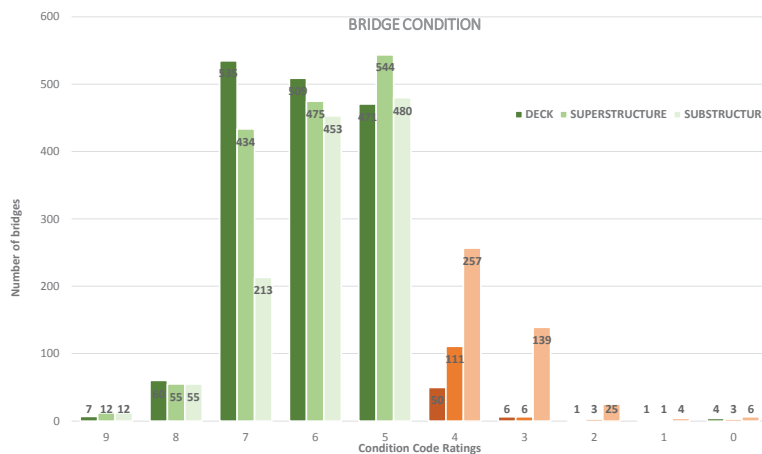


Fig. 16 Condition of TCC bridges in service according to NBI

According to the NBI condition ratings for TCC bridges, the large majority of the bridge superstructures are in good condition. The bridge deck condition ratings, where the composite system is

used, is the component with the highest ratings, whereas the substructure condition ratings are typically lower. This is not surprising because the deck is the component for which using TCC systems provides the largest benefit in durability, while the substructure, because of constant contact with soil and water, is the bridge component for which the TCC solution has the lowest impact in improving the overall bridge structure durability. Only a small percentage of the total number of TCC bridges in service have a deck condition rating lower than 5, indicating the great benefit of a properly designed concrete overhang detail toward the overall durability of a TCC bridge structure.

4. Conclusions

Construction of TCC bridges began in the early 20th century and have been a success story for nearly a century. Indeed, the NBI indicates the existence of a large number of these bridges in service today in the United States, with some in excess of 83 years old and located in high traffic demand roadways. Evidence indicates that only minor repairs or rehabilitation efforts took place during the many decades in service, which demonstrates the robustness and durability of this structural solution for bridge construction. Many TCC bridges were inspected recently, and the findings confirmed their excellent condition after a long period of satisfactory service under high traffic demands.

On the other hand, it is clear from the inspections that good drainage detailing is critical to achieving a long service life with low maintenance costs. Poor detailing is clearly connected to higher degradation and, in many cases, early replacement of the bridge components.

The total number of TCC bridges that have been built in the United States is unknown. However, the large number of bridges still in service, under completely different service conditions — type of traffic, climatic conditions, daily amount of traffic, technological solutions (for example, connections, wood-based products, spans, and substructures) — constitute a live experimental batch in place for almost a century. The results available from these case studies prove that TCC bridges are a technical solution with great potential for bridge construction. The wide range of examples also prove that this technology was very useful in the past but also has enormous potential for use in the future.

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