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COST COMPARISON OF TIMBER, STEEL, AND PRESTRESSED CONCRETE BRIDGES

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ABSTRACT: This study was undertaken to investigate the economics of timber bridge superstructures versus traditional steel/concrete and prestressed concrete alternatives in the short-span range of 20 to 60 ft (6.1–18.3 m). Only superstructure costs were considered because substructure and abutment costs are highly site-specific. A lack of definitive data regarding service lives and maintenance costs precluded a life-cycle cost study; thus, only initial costs were compared. Representative superstructure designs were obtained for timber, steel/concrete, and prestressed concrete bridges at 20-, 40-, and 60-ft spans. Five to six northern New England general contractors performed cost estimates on these designs. Also, nine timber bridge designs, three at each span length, received cost estimates from three timber bridge suppliers. Results from general contractors indicated that timber was cost competitive with steel/concrete and was less expensive than prestressed concrete. Results from timber bridge suppliers showed more impressive distinct initial cost advantages for timber over both steel/concrete and prestressed concrete. The study indicated the initial cost effectiveness of modern, short-span timber bridges in northern New England.

INTRODUCTION

Considerable interest has been shown recently for new-generation timber bridges and their potential ability to ameliorate the serious infrastructure problem in the United States. In particular, timber appears particularly well suited to low-volume, short-span bridges that are common in rural settings. Accordingly, timber bridge publications have been issued, timber bridge conferences have been held, demonstration bridges have been built, and research is being performed to advance timber bridge technology. Yet definitive cost information on timber bridges as alternatives to steel and concrete bridges is not available in the open literature. From the perspective of a decision maker, this information gap discourages serious consideration of timber as a structural material for short-span bridges.

This study was undertaken to investigate the economics of timber bridge superstructures versus steel/concrete and prestressed concrete alternatives in the short-span range of 20–60 ft (6.1–18.3 m). The study was conducted in a systematic manner to ensure that rational timber/steel/concrete cost comparisons could be made. The results should be considered specific to northern New England, but a similar approach would be appropriate for other regions of the United States.

PREVIOUS COST STUDIES

There are two well-known cost studies in the literature that involve timber bridges. The first, by Verna et al. (1984), focused on installations of timber

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bridges in western Pennsylvania. Case studies were presented for highway bridge reconstruction projects involving a deck replacement over steel stringers and a beam and deck replacement using existing abutments. In one case study involving only a deck replacement the initial cost of glued-laminated timber deck was found to be about one-half that of reinforced concrete or open steel grid, and the timber deck was assigned an expected life of 50 years, while concrete and steel decks were both assigned service lives of 15 years. The difference in service life estimates was said to be a function of the relative resistance of timber to corrosion from deicing chemicals. The bridge was a 61-ft (18.6-m), two-lane span with AASHTO HS-20-44 truck loading.

The second case study in Verna et al. involved superstructure replacement on a 54-ft (16.5-m), two-lane span with unspecified design loading. Prestressed concrete box beams and timber beams/deck were considered as alternatives. The two superstructure alternatives were found to be nearly equal in terms of initial cost, but timber was found to be less expensive overall because of lower abutment costs. It is clear that both case studies were site-specific.

The second published cost study was conducted by Hill and Shirole (1984) and involved a historical study of 3,692 bridge replacements constructed in Minnesota from 1973 to 1983. The paper contained square-foot construction costs for each year of the study derived from contract data for several different types of concrete, steel, prestressed concrete, and timber bridges both on and off state trunk routes. Also presented were ranges of initial costs for each bridge type in each year, and an average of those costs. The data were not organized by span length, however, and no information on site and abutment conditions was provided. While results indicated relatively low construction costs for timber bridges in some years, concrete slabs and prestressed concrete systems were very cost competitive in other years. Thus, no consistent conclusion regarding the relative initial costs of the different bridge types could be obtained from the Hill and Shirole data.

With these two cost studies prominent in the literature, the writers felt that it would be appropriate to complement them with another approach that is described next.

STUDY PLAN

The approach herein was to eliminate site-specific cost items from the comparison of timber, steel/concrete, and prestressed concrete short-span bridge prices. Therefore, only superstructure costs were considered, as these were least dependent on site-specific factors. As shown in Fig. 1, bridge design parameters were: 20-, 40-, and 60-ft (6.1-, 12.2-, and 18.3-m) single spans; two 12-ft- (3.7-m-) wide lanes; AASHTO HS-25 truck loading; timber guardrails; and a 2-in. (51-mm) asphalt overlay.

Bridge superstructure designs were obtained for each span length from timber bridge suppliers for timber, from the New Hampshire Department of Transportation for concrete/steel, and from the literature ("Precast" 1980) for prestressed concrete. Representative timber bridges were longitudinal deck at 20 ft (6.1 m) and longitudinal stringer/transverse deck at 40 and 60 ft (12.2 and 18.3 m). Representative steel/concrete bridges were reinforced concrete slab at 20 ft, and steel stringer/concrete slab at 40 and 60 ft. Rep-

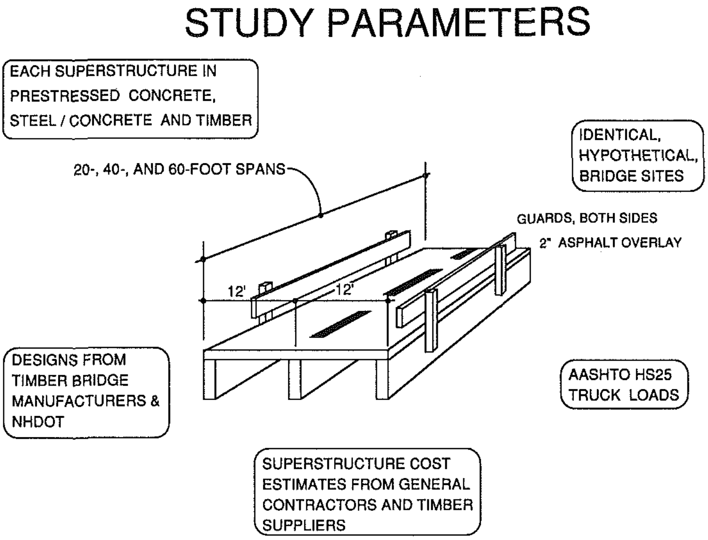

FIG. 1. Study Parameters

resentative prestressed concrete bridges were deck beam (hollow-core slab) at 20 and 40 ft, and box beams at 60 ft. Thus, from the numerous superstructure designs reviewed, nine representative designs were selected for construction cost estimates from several general contractors in northern New England: timber, steel/concrete, and prestressed concrete superstructures at each of the three spans: 20, 40, and 60 ft. Detailed drawings of these selected superstructure designs are presented in Cundy (1989).

Once the representative designs were selected, multiple cost estimates for each of the nine designs were obtained by procedures summarized in Fig. 2. Six northern New England general contractors with bridge construction experience agreed to furnish superstructure cost estimates. In all cases they were instructed to specify their overhead, profit, and material markup rates, to assume construction sites with no unusual complications, and to assume that the construction site was in close proximity to their home office. For the timber designs the contractors were instructed to use material prices from the timber bridge supplier who furnished the representative designs; thus, the contractors were asked to supply only material markups, labor, and erection costs. For the steel/concrete designs the contractors supplied complete material, labor, and erection costs. For the prestressed concrete designs the contractors used prestressed concrete beam prices from a large New England supplier, combined with their own material markup, labor, and erection costs. The intent behind these cost estimate procedures was to reduce the time burden on the contractors who were contributing to this study on a voluntary basis.

The second column from the left in Fig. 2 requires further discussion, i.e., the timber bridge cost estimates derived from material costs from timber bridge suppliers, plus their own crew time estimates, plus labor rates from R. S. Means (1989) adjusted for a New Hampshire location. These addi-

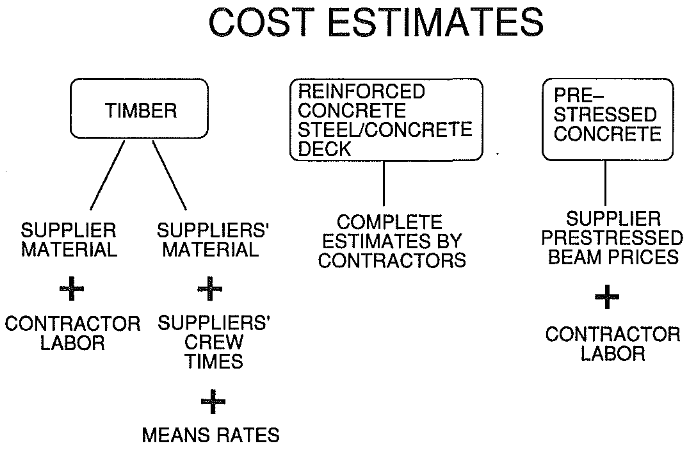

FIG. 2. Methods for Obtaining Bridge Superstructure Cost Estimates

tional timber bridge cost estimates were derived from designs from three independent timber bridge suppliers, whereas designs from only one of these timber bridge suppliers were used for the previously discussed cost estimates from the general contractors. The reasons for including these additional cost data were to investigate variations between competing timber bridge suppliers and to view price differences between timber bridges with contractor labor versus those based on labor estimates from the timber bridge suppliers themselves. It was felt that unfamiliarity with timber bridges could possibly amplify contractor labor estimates in comparison with their estimates of more familiar bridge materials such as steel and concrete.

The original intent of this study was to perform life-cycle cost comparisons of timber, steel/concrete, and prestressed concrete bridges. Consideration of long-term factors such as maintenance costs and service life makes the life-cycle approach a preferred method for making economic comparisons between bridge alternatives. However, the writers could not find adequate maintenance cost and service life data to support a valid life-cycle cost study. Not only were widely conflicting estimates of bridge service lives found in the literature [e.g., Verna et al. (1984) versus Dunker et al. (1987)], but accurate maintenance cost estimates were equally elusive. In fact, a Federal Highway Administration report on the development of economical low-volume road bridges ("The development" 1987) summarizes the dilemma as follows: "The selection of an economical alternative should be based on service life and life-cycle cost. But, the information needed to make such a selection is currently not available and attempts to incorporate the limited amount of existing information in a systematic selection process would have no validity." Thus, this study was limited to a comparison of initial costs. A detailed discussion of the life-cycle cost issues is included in Cundy (1989).

Despite the clear conceptual advantages of life-cycle costing, it should be noted that initial costs are often the primary decision criteria for bridge selections in rural municipalities. Reasons for emphasizing initial costs include limited capital budgets and unfamiliarity with life-cycle costing techniques. For these reasons, there is still practical value in comparing only initial costs.

STUDY RESULTS

Five timber bridge suppliers who use domestic timber species agreed to participate in this study; three of them submitted usable data. Of the eight general contractors contacted in the states of New Hampshire, Vermont, and Maine, six responded. The response rate overall was surprisingly high, especially when considering that the parties were not paid for their participation in this study. A presentation and discussion of the resulting cost data follows.

Data were box-plotted using a technique described by Tukey (1977). As shown in Fig. 3, 50% of the data nearest to the median fall in the box-shaped "interquartile range." The extent of the interquartile range gives an indication of the spread in the data. The median, rather than the mean, was chosen as a measure of "center" since, unlike the mean, it is relatively insensitive to extremes in any small fraction of the data (Hamilton 1990). The position of the median within the box aids in determining skewness. A median located in the lower portion of the box, for example, indicates that the data are skewed toward the high end of the interquartile range. Due to the small sample sizes (n = 3–6) and the nonrandomized selection of contractors and other sources of cost data in this study, it was not deemed appropriate to undertake a more sophisticated statistical treatment of these data.

Figs. 4, 5, and 6 include box-plotted initial cost data for 20-, 40-, and 60-ft bridge superstructures, respectively. Box plots are included at each span length from general contractor cost estimates for timber, steel/concrete, and prestressed concrete bridges, as well as a box plot of prices from other timber bridge suppliers based on their material costs and their manhour estimates multiplied by appropriate labor rates from Means (1989). These last box plots (far right in Figs. 4–6) are included to compare the effects of

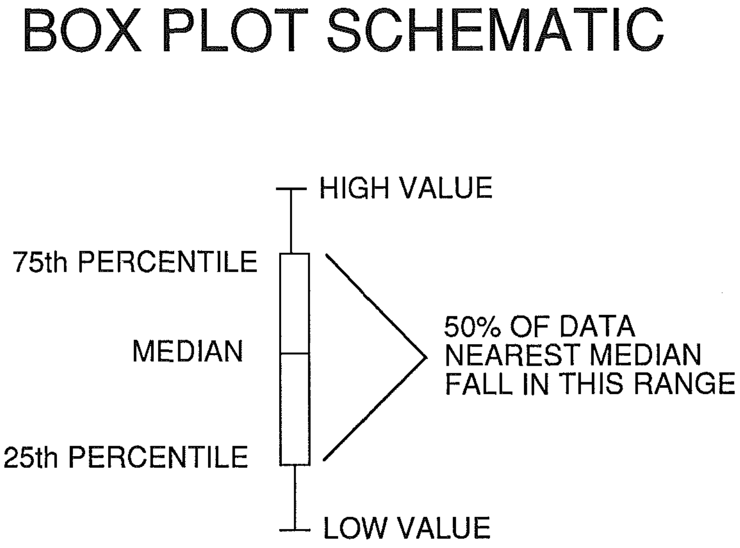

FIG. 3. Box Plot Schematic

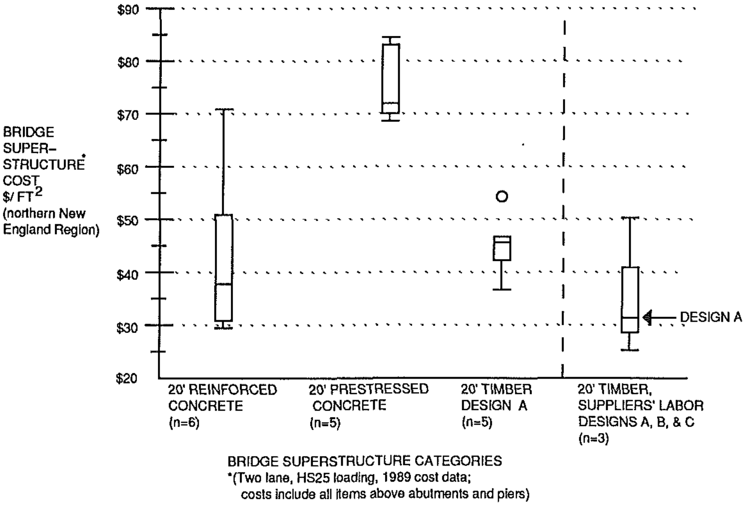

FIG. 4. Superstructure Costs from Contractors for 20-ft (6.1-m) Bridges

contractor and supplier labor costs for timber bridges. Note that these last box plots are based upon different designs from three timber bridge suppliers (designs A, B, and C in Figs. 4–6), whereas the other timber bridge box plots are for one representative timber bridge design (design A) that received cost estimates from five to six general contractors. The exact position of design A in the distribution of timber bridge costs with supplier labor is shown in each appropriate box plot in Figs. 4–6. Thus, the reader can compare directly the contractor versus supplier cost estimates specifically for design A.

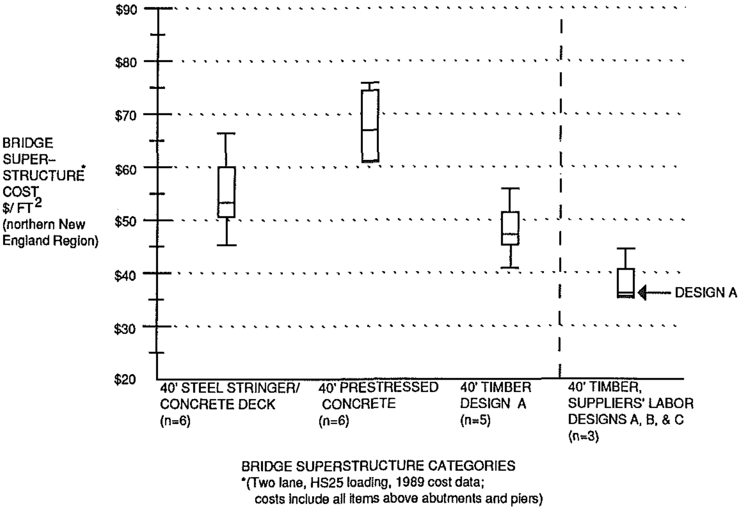

FIG. 5. Superstructure Costs from Contractors for 40-ft (12.2-m) Bridges

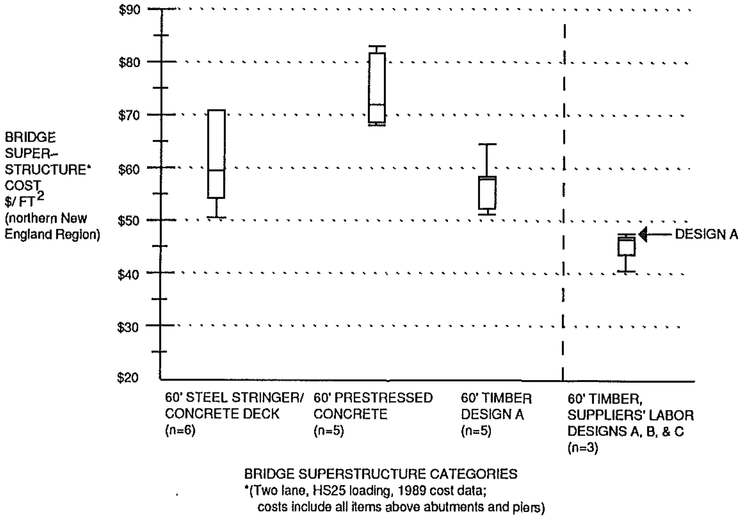

FIG. 6. Superstructure Costs from Contractors for 60-ft (18.3-m) Bridges

Referring to Fig. 4, the lowest median price for 20-ft bridge superstructures is the reinforced concrete flat slab, probably because of relatively low labor rates in northern New England. The median price for reinforced concrete is \$37.90/sq ft, timber (from contractor estimates) is \$46.12/sq ft, and prestressed concrete is \$72.39/sq ft. Considering reinforced concrete as the base price, timber is 22% higher and prestressed concrete is 91% higher. The timber prices show a narrow interquartile range and a mild outlier on the high side. While the median price for reinforced concrete is lower than the timber median, the reinforced concrete data show positive skewness toward higher prices. The median price of the 20-ft timber bridge with contractor labor is 46% higher than comparable timber bridges with supplier labor.

For the 40-ft superstructures in Fig. 5, timber with contractor labor has the lowest median cost at \$47.12/sq ft, followed by steel stringer/concrete deck at \$53.76/sq ft and prestressed concrete at \$67.04/sq ft. Using the median timber cost as a base, steel/concrete is 14% higher and prestressed concrete is 42% higher. Timber prices show the narrowest interquartile range and some positive skewness toward higher prices. The median price of the 40-ft timber bridge superstructure with contractor labor is 30% higher than comparable systems with supplier labor.

For the 60-ft superstructures in Fig. 6, timber with contractor labor has the lowest median cost at \$57.87/sq ft, followed by steel stringer/concrete deck at \$59.27/sq ft and prestressed concrete at \$72.37/sq ft. Using the median timber cost as a base, steel/concrete is 2% higher and prestressed concrete is 25% higher. Timber prices show the narrowest interquartile range and a strong negative skewness toward lower prices. The median price of the 60-ft timber bridge superstructure with contractor labor is 24% higher than comparable systems with supplier labor.

The median bridge superstructure prices per square foot are plotted against

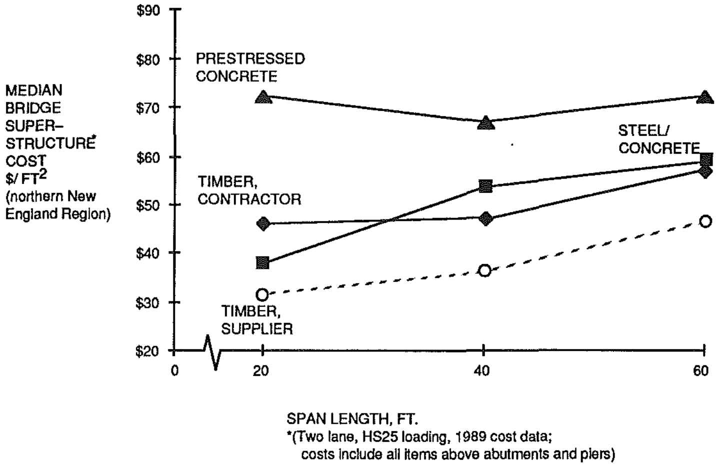

FIG. 7. Median Bridge Superstructure Cost versus Span Length

span length in Fig. 7. The solid lines connect median prices based on five to six contractor cost estimates of each of the representative timber, steel/concrete, and prestressed concrete designs. The dashed line connects median prices of three separate designs (at each span length) and related labor estimates from the respective timber bridge suppliers. Median prices for prestressed concrete bridge superstructures are relatively flat in the 20–60-ft (6.1–18.3-m) span range, while timber and steel/concrete show modest cost increases per square foot of deck area as span length increases. In no case is there an abrupt change in cost per square foot in the 20–60-ft span range, with the exception of a large (41%) cost increase from the 20-ft concrete flat slab to the 40-ft steel stringer/concrete slab system. The low cost for the 20-ft concrete flat slab is attributed to relatively low labor costs for cast-in-place concrete in northern New England.

A general observation from Fig. 7 is that short-span bridge superstructures in northern New England are most expensive if they are built of prestressed concrete, but less expensive if they are built of steel/concrete or timber. If timber bridge cost data with contractor labor are used, then short-span timber bridges are roughly comparable in cost to steel/concrete alternatives. However, if timber bridge cost data with supplier labor are used, then short-span timber bridges show distinct cost advantages over both steel/concrete and prestressed concrete alternatives. There is, in fact, reason to believe that more realistic square foot prices for timber bridges might actually lie between those obtained from general contractors and those from the timber bridge suppliers themselves. This is because northern New England contractors currently have little experience with modern timber bridges and would tend, therefore, to overestimate the labor costs. Once the contractors gain more experience with timber bridges it would be reasonable to expect contractor labor prices to approach more closely those from timber bridge suppliers. If so, contractor-built short-span timber bridges in northern New England would have clear initial cost advantages over concrete/steel and prestressed concrete alternatives.

CONCLUSIONS

The bridge superstructure initial cost data obtained in this study were credible because identical criteria were applied to all designs, and site-specific bridge cost items were systematically excluded. Resulting cost data from multiple sources contained very few outliers. The quality of the data made initial cost comparisons for northern New England possible, but lack of bridge maintenance cost data and widely varying estimates of bridge service lives made defensible life-cycle cost comparisons impossible.

In the short-span range of 20–60 ft (6.1–18.3 m), timber bridge superstructures with contractor labor were cost competitive with steel/concrete and were significantly less expensive than prestressed concrete. (Relatively low labor rates for cast-in-place concrete in northern New England worked to the advantage of steel/concrete bridge superstructures in this study.) When considering labor estimates from timber bridge suppliers (as opposed to contractor labor estimates), timber superstructures showed distinct initial cost advantages over both steel/concrete and prestressed concrete. This gap between contractor and supplier cost estimates could be narrowed by successful timber bridge demonstration projects and increased general contractor experience with modern timber bridge technology.

The data in this study has indicated the initial cost effectiveness of modern, short-span timber bridges in northern New England. In order to proceed with a life-cycle cost study, there is a strong need for accurate service life data and periodic maintenance costs for all short-span bridge types. This is especially true for modern timber bridges that do not have substantial historical records. Timber bridges should be given the opportunity to compete for a long-term position in the American bridge inventory.

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