Estimating Life-cycle Cost of West Virginia Fiber Reinforced Polymer (FRP) Bridge Decks

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Abstract

The main objective of the research was to study the economic viability of West Virginia Fiber Reinforced Polymer (FRP) bridge decks. Life-cycle cost of those bridge decks were estimated for conducting such analysis. Three main differences that distinguish the way the life-cycle cost of FRP deck was estimated are: (1) the manufacturing cost of a FRP bridge deck was estimated using learning curve theory; (2) cost savings in support structures when FRP is chosen as opposed to the alternative bridge deck was modeled; and (3) the service life was estimated based on factor method to minimize the subjectivity of the estimates. The three case studies for West Virginia FRP deck projects show that based on the estimated life-cycle cost, FRP decks are financially viable under certain conditions.

Keywords
Life-cycle cost, Fiber Reinforced Polymer (FRP), Service life

1. Introduction

The Life -cycle Cost (LCC) of a Fiber Reinforced Polymer (FRP) bridge deck was estimated and compared to one of Steel Reinforced Concrete (SRC) bridge deck. This study seeks to quantify the costs associated with both systems with the main objective to analyze the viability of FRP for case study bridges.

The LCC of bridge deck consists of Initial Costs, Maintenance/Anticipated Repair Costs, and Disposal Costs. Each includes two major components: Agency Costs and User Costs. Agency Costs include all direct costs, i.e. material costs, labor costs, transportation costs. User Costs are costs associated with lost time for the drivers of the vehicles, higher vehicle operation costs and increased accident rates. These costs can be sizable, depending on the total installation time as well as expected delay time. The expected delay time is a function of average daily traffic and length of the affected road work. The expected delay time multiplied by the value of user's time reflects the cost for driver as result of losing his production time; its' multiplication with vehicle operation cost per unit time reflects increased vehicle operation cost [1].

The Life-cycle Cost Analyzer – a tool developed to estimate the life-cycle cost of both FRP and SRC bridge decks - determines total life-cycle costs as well as the annual average costs of the bridge deck alternatives during the service life. Since FRP bridge decks and SRC bridge decks have different life spans, the equivalent annual cost or annuity method was chosen as it can be applied for any combination of two different service lives. This approach was performed by determining a fixed study period based on the life of the bridge superstructure. For medium bridges, the study period can range from 50 -70 years while for large bridges the study period can be 100 years. Based on the given study period, the life-cycle cost per square foot of the two alternate bridge decks are calculated and compared.

2. Case Studies

The three case study bridges are Goat Farm Bridge, La Chein Bridge and Katy Truss Bridge, all are located in West Virginia. These single span bridges are among the 13 West Virginia FRP bridge deck projects. The designs, cost related data and inspection records for these bridges were obtained from WVDOT as well as through correspondences with WV Bridge Engineers. The detail results for Katy Truss bridge deck and general conclusions for the three bridges are discussed.

2.1. Inputs

FRP bridge deck cost/square feet for those three bridges based on the learning curve formula [4] were $67.5, $62.6 and $55.8 respectively for Katy Truss, La Chein and Goat Farm , while average SRC bridge deck cost for North Eastern States is $25/sq ft [2]. All of input costs are converted to the bridge deck project years using Consumer Price Index, i.e. year 2003, 2001, and 2000 for Goat Farm, La Chein and Katy Truss respectively. The basic case inputs for Katy Truss (2000 values) are as follows:

Table 1. Inputs for Katy Truss

BRIDGE GEOMETRY			**DETAIL OF WEARING SURFACE**		
Span of Bridge	91.3	ft	Material	polymer concrete overlay	
Out to Out Bridge Width	14.3	ft	Weight	3	psf
Number of Span	1		Cost	3.2	$/sq ft
TRAFFIC AND ACCIDENT INFORMATION			**STRINGER PROPERTIES**		
Average Daily Traffic (=ADT)	700	vehicles/day	FRP Bridge Deck	W27 × 146	
Normal Traffic Speed	55	mph	SRC Bridge Deck	W27 × 161	
Normal Accident Rate	0.268	per million-vehicle-miles	Stringer Cost	1.3	$/lb
Traffic Speed during Construction	45	mph			
Accident Rate during Construction	0.463	per million-vehicle-miles	**DISCOUNT AND INFLATION RATES**		
Average Cost per Accident	29,018	$	Discount Rate	2.78%	
Hourly Vehicle Operating Cost	8.4	$/hr			
Hourly Time Value of Driver	14.0	$/hr	**ENVIRONMENTAL CONDITIONS**		
			Freeze Thaw Cycles	moderate	
DETAIL OF DECK					
Thickness of Deck	8	inches	**OTHER COST INFO**		
Self weight of FRP Deck	16	psf	Gasoline	1.5	$/gallon
Cost of FRP Deck	67.5	$/sq ft	Landfill	11.3	$/ton
Self weight of SRC Deck	100	psf	Inspection cost	397	/occasion
Cost of SRC Deck	26.5	$/sq ft	In Depth Inspection Cost	706	/occasion
FRP Reference Service Life	70	yrs	Study Period	60	yrs
SRC Service Life	30	yrs			

2.2. Results

Each cost component was broken down into agency costs and user costs. The analysis was performed based on cost/sq ft of each bridge deck alternative during study period. The results of life-cycle cost analysis for Katy Truss Bridge are summarized in Table 1.

2.2.1. User Costs

The user costs for FRP bridge deck are less than the ones for concrete bridge deck. For this case study, the user costs for FRP for the installation and the disposal processes were 16% and 6 % of the corresponding costs for concrete, because of the big difference in time required to perform those activities. User costs for maintenance activities are $0.83/sq ft and $1.01/sq ft for FRP and concrete bridge respectively. These figures were obtained based on assumption that both bridge decks share the same maintenance and anticipated repair schedules. On the contrary, initial construction activities only account for 17 % of total user costs of FRP bridge deck but play significant role for concrete, i.e. it accounts for 35% of SRC user costs, as illustrated in Figure 1 and 2. If we considered delays, i.e. opening a concrete bridge deck needs more than estimated, the user costs during installation for SRC will increase tremendously. Under this situation, the user costs for FRP will be much lower than the one for a SRC deck.

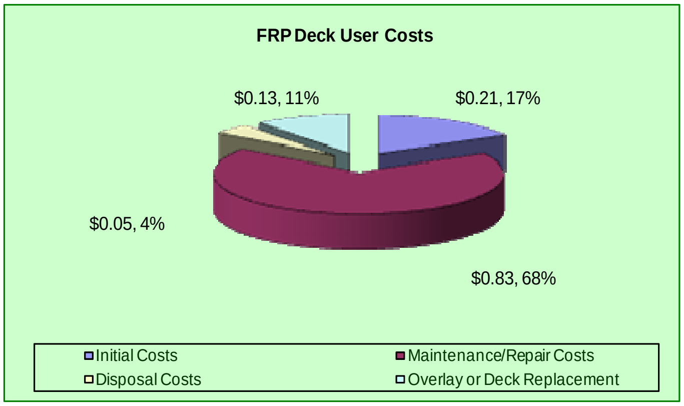

Figure 1. The User Cost Distribution of FRP Bridge Deck

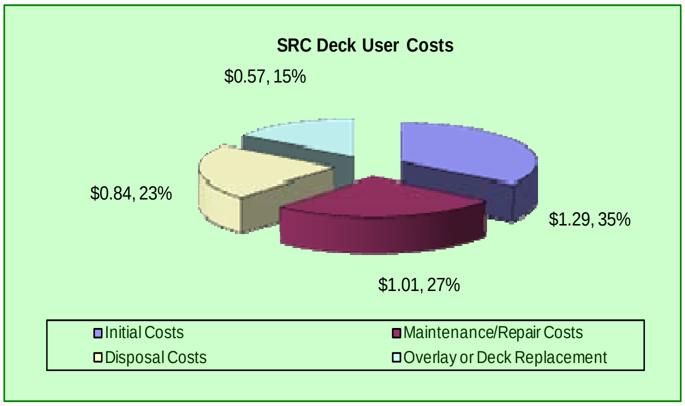

Figure 2. The User Cost Distribution for SRC Bridge Deck

2.2.2. Agency Costs

The agency life-cycle costs for the FRP deck was higher than the corresponding costs for the concrete deck. The largest agency cost component of FRP deck is the initial costs (manufacturing and installation costs), which account for about 85 % of the total agency cost as depicted in Figure 3. Hence, FRP bridge deck costs play an important role in determining the economic viability of FRP bridge deck. In this case study, the combination between manufacturing cost and substructure cost savings enable FRP to be financially viable compared to concrete. Understanding that cost/sq ft of FRP is a sensitive input, the effects of this input are discussed in section 2.3.

2.2.3. Total Costs

The life-cycle cost/ sq ft of FRP bridge deck for study period 60 years if cost saving considered was $62.74 while that for the SRC bridge deck was $67.65. Hence, under basic scenario, the FRP bridge deck was more economical than the concrete deck for Katy Truss bridge project.

This shows that FRP decks can compete with concrete deck if the FRP deck material and when the PC overlay meets the specific durability requirements. Based on the life-cycle cost distribution, the main benefit of using FRP deck was in the user cost during construction and replacement. The high initial cost of FRP deck is the main concern for this application. Cost savings from superstructure when FRP chosen, reduced maintenance frequency as well as FRP's longer service life are the three important inputs that could balance this out to make FRP competitive to SRC [3]. The three case studies supported this conclusion. FRP is a viable alternative for both Goat Farm bridge deck and La Chein bridge deck when all three advantages of FRP combined. As additional note, FRP Goat Farm FRP bridge deck is competitive even when reduced maintenance frequency has not been implemented.

Table 2. Life-cycle Cost Comparison for Katy Truss Bridge

Bridge Deck Alternative	FRP	SRC	FRP	SRC
ADT (vehicles/day)	700	700	700	700
Total Area (sq ft)	1305.59	1305.59	1306	1306
Study Period (yrs)	60	60	60	60
Service Life (yrs)	60	30	60	30
Deck Cost ($/sq ft)	$67.5	$26.5	$67.5	$26.5
	LCC Costs	**LCC Costs**	**Cost/Sq Ft**	**Cost/Sq Ft**
Initial Costs				
Agency Costs	$90,673	$41,179	$69.45	$31.54
User Costs	$269	$1,681	$0.21	$1.29
Cost Savings	$22,508		$17.24	
Total Initial Costs	$68,434	$42,860	$52.42	$32.83
Maintenance/Repair Costs				
Agency Costs	$8,449	$9,132	$6.47	$6.99
User Costs	$1,089	$1,319	$0.83	$1.01
Total Maintenance/Repair Costs	$9,539	$10,451	$7.31	$8.00
Overlay or Deck Replacement				
Agency Costs	$2,176	$18,089	$1.67	$13.86
User Costs	$170	$738	$0.13	$0.57
Total Maintenance/Repair Costs	$2,346	$18,828	$1.80	$14.42
Disposal Costs				
Agency Costs	$1,528	$15,087	$1.17	$11.56
User Costs	$67	$1,101	$0.05	$0.84
Total Disposal Costs	$1,595	$16,189	$1.22	$12.40
TOTAL LIFE CYCLE COST				
Total Agency Costs	$80,318	$83,487	$61.52	$63.95
Total User Costs	$1,595	$4,840	$1.22	$3.71
Grand Total	$81,913	$88,327	$62.74	$67.65

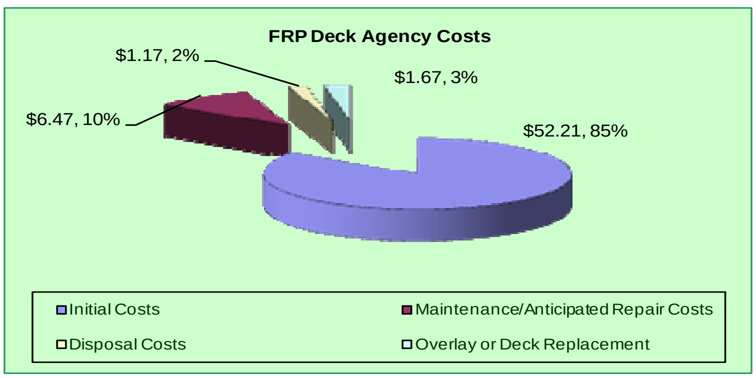

Figure 3. The Agency Cost Distribution of FRP Deck

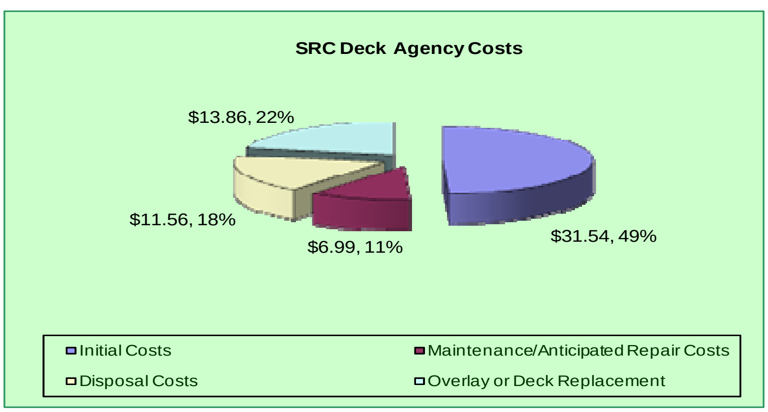

Figure 4. The Agency Cost Distribution of SRC Deck

2.3. Sensitivity of Key Inputs

Sensitivity analysis was performed to study the sensitivity of key inputs to the conclusion, i.e. FRP deck viability as an alternate to SRC deck. The sensitivity analysis was done by re-computing the costs for FRP bridge deck by changing one parameter at a time to determine the level at which that the total life-cycle cost of the FRP bridge becomes competitive or uncompetitive. Some of the important results are as follow:

1). The relationship between FRP bridge deck and LCC cost/sq ft is depicted in Figure 5. LCC for FRP deck cost reflects the effects of structural cost savings. Maximum FRP bridge deck to remain competitive with SRC deck is $72.4/sq ft. If SRC deck costs less than the assumed value, the maximum cost of FRP deck would decrease. In this example, when SRC deck costs $25/sq ft, FRP will only be competitive given its cost less than $70.1/sq ft. The basic assumption of the results was the assumed same maintenance schedules for the two bridge decks. If the FRP maintenance cost is lower (as expected), the competitiveness of FRP bridge deck increases significantly.

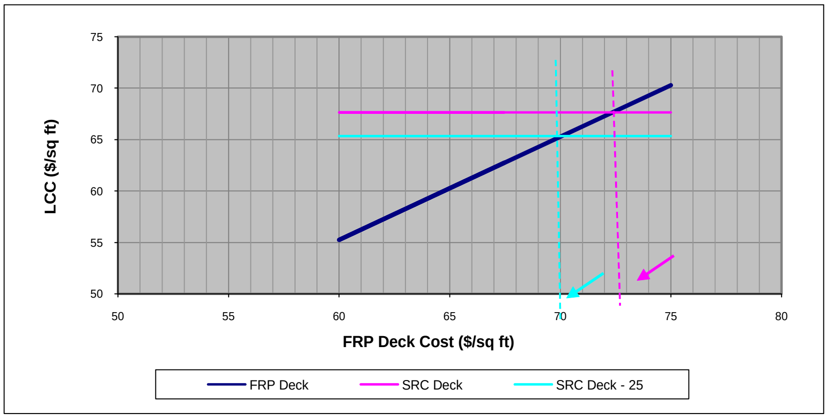

Figure 5. Effects of FRP Cost/Sq ft on Life-cycle Cost

2) The relationship between Average Daily Traffic (ADT) and its LCC is observed better for La Chein bridge deck case study. If only cost saving and longer service life are considered, FRP deck is not financially viable for this bridge deck project. However, if ADT expected to increase to 100 vehicles/day, FRP will become competitive as a result of higher percentage of user cost. The relationship between ADT and percent of user cost for this bridge deck is illustrated in Figure 6.

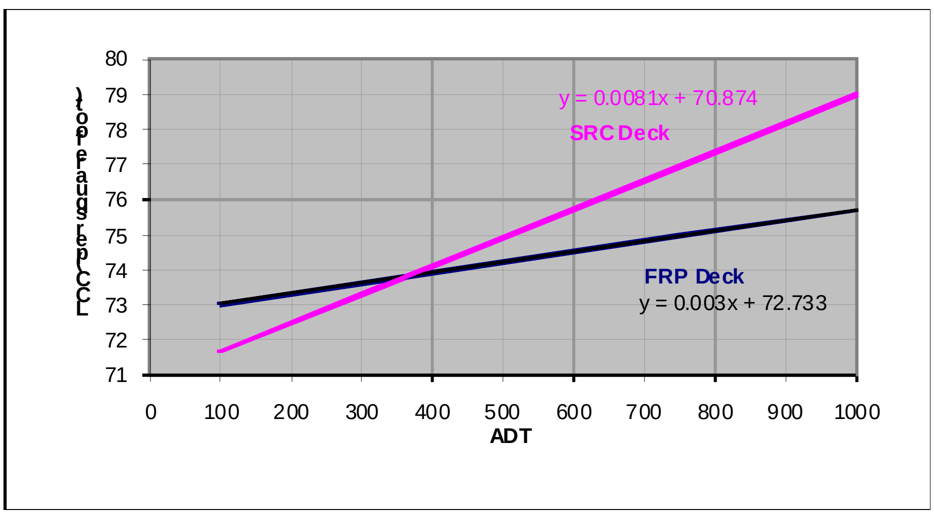

Figure 6. ADT and FRP Percent User Cost

3. Summary and Conclusions

Life-cycle cost of FRP bridge deck includes initial costs, maintenance and repair costs and disposal costs. Traditionally, initial cost of bridge deck consists of manufacturing cost, transportation cost and erection cost. Based on this approach, the initial costs of fiber reinforced polymer (FRP) bridge decks are expected to be higher than the one of the traditional steel reinforced concrete (SRC) bridge decks because of FRP deck expensive manufacturing cost. Since weight of an FRP deck approximately 20-25 percent that of a SRC deck, the weight reduction would have an effect on the initial costs as the structure to support the deck would be reduced. The major reductions would be in that for the steel bridge girders/beams/rollers required to support the bridge deck. This saving, referred as cost savings, is included in the initial cost analysis when considering an FRP deck as opposed to a SRC deck. The combination of higher service life and initial cost savings result in more competitiveness of FRP deck. Another key parameter for FRP competitiveness is the maintenance cost. Combination of those advantages and less required maintenance frequency for FRP deck as predicted by the experts lead us to financial viability of FRP decks.

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