A Viable Alternative: Fiber-Reinforced Polymer

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Abstract – This paper presents an illustration of the potential cost savings of fiber-reinforced polymer composites over steel-reinforcement based on a life cycle cost analysis. In 2008, the American Association of State Highway and Transportation Officials officially acknowledged the use of fiber-reinforced polymer composites through a publication of standards for its use on bridge decks. If used, fiber-reinforced polymer composites serve to eliminate the potential for corrosion, decrease repair time and increase the life of structures significantly, which correlates to savings across the board. As such, the objective of this paper is to prove that fiber-reinforced polymer composites are economically feasible regardless of their high initial cost. Through a Life Cycle Cost analysis, this paper proves that when comparing a bridge deck with fiber-reinforced polymer composites to a bridge deck with steel-reinforced concrete, the former becomes the cheaper alternative in 20 years.

Keywords: FRP, SRC, BridgeLCC, Bridge Decks

INTRODUCTION

In 2008, the American Society of Civil Engineers issued a letter grade of D to the infrastructure of the United States of America [4]. With an ever increasing demand on our infrastructure, increasing costs of labor, and decreasing federal funding, it is clear that a solution is needed. If not, the consequences could be financially burdening and potentially dangerous. The U.S. Federal Highway Administration evaluated and rated around 200,000 bridges and reported that that one in four bridges are either structurally deficient or functionally obsolete and of those bridges, 25% were over 50 years old, which is the average design life of a bridge [6].

Currently, the majority of bridges in the United States of America use steel-reinforcement as a means of strengthening concrete to meet standards. This is known as steel-reinforced concrete, or SRC. Although the steel reinforcement is physically protected by the concrete surrounding it, aggressive environmental factors cause the concrete around the bars to spall, and as a result allow the steel to deteriorate. This is highly evident in the decks of bridges, which are generally greatly impacted by surrounding environmental factors. By looking at Figure 1, it comes evident that bridges are often put into extreme environments mainly from water, salt and large vehicles. As a result, bridge decks have to be maintained much more often than any other portion of the bridge structure. According to the Strategic Highway Research Program (SHRP) the cost to America's Bridges currently stands at $20 billion dollars and is expected to increase at approximately $500 million a year [6]. The primary reason for this structural deterioration is corrosion [1].

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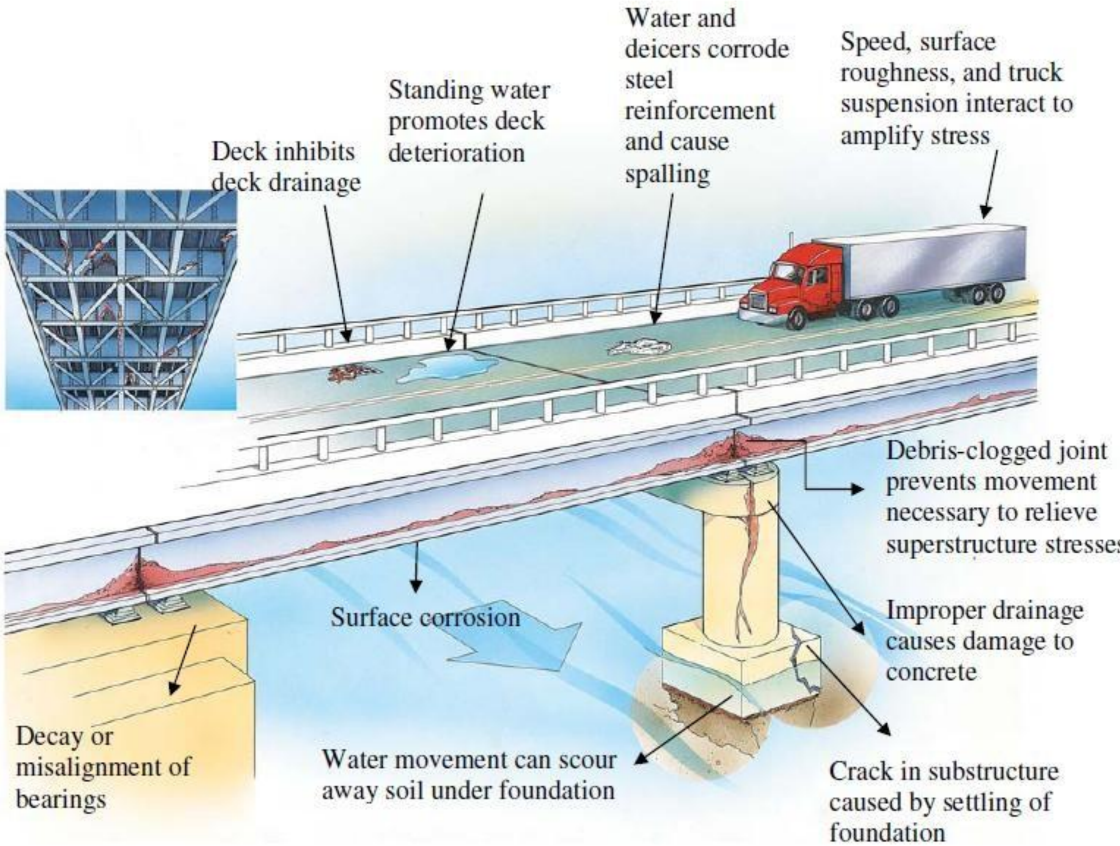

Figure 1: Corrosion Causes

This is a material which is gaining popularity amongst Civil Engineers which is both non-corrosive and lighter than traditional reinforcing steel allowing it to be constructed in less time, and last longer without maintenance. This material is known as fiber-reinforced polymer, or FRP. This is not something that has been recently discovered. In fact it was used in the aerospace industry to help create the stealth aircraft [8]. The reason why it has been such a success is because of its ideal characteristics; it generally has high strength, high fatigue resistance, and is most importantly corrosion resistant.

FRP composites are composed of two parts as shown in Figure 2. The fibers are made of anything from polyethylene, carbon fiber or kevlar and the matrix is generally made from a thermoset such as an epoxy resin, for example. The fibers provide the composite with its stiffness and strength while the matrix provides the composite with rigidity and protection from environmental factors [9]. Overall, FRP composites are generally light weight, have high tensile strength, high strength-to-weight ratios and corrosion resistant, making them very useful for harsh bridge deck environments.

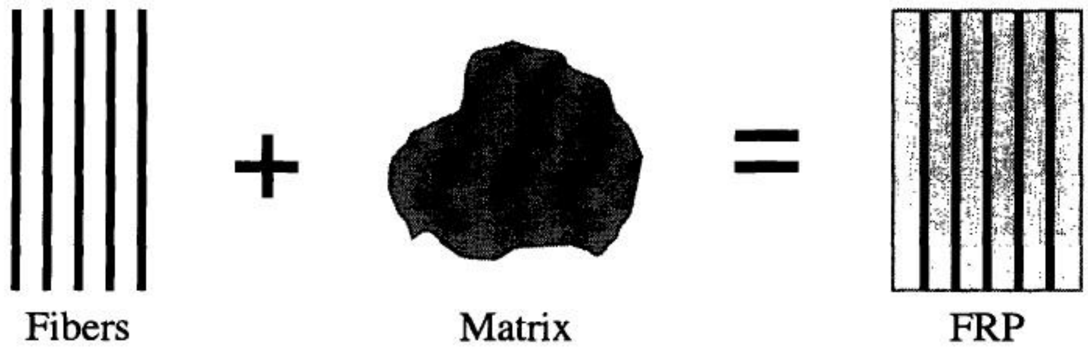

Figure 2: Fiber-Reinforced Polymer Breakdown

The use for FRP bridge decks as a replacement to SRC bridge decks in theory is the logical choice for engineers; however, there is one major deterrent—the initial cost. Fiber-reinforced polymer composites have a significantly higher initial material cost than steel-reinforced concrete. This may seem like a reason to shoot the idea down, however by looking at the costs in the long run it should become clear that FRP bridge decks are indeed economically feasible.

DISCUSSION

In order to do this effectively, a Life Cycle Cost (LCC) analysis must be performed. It is the best economic evaluation process for this construction material because it takes into consideration all costs from construction, maintenance, replacement and associated user impacts over the service life of all alternatives [7]. An additional reason that the LCC analysis is being used is because it not only shows the sum of the total expenses, but it shows the progression of expenses with respect to maintenance frequency, costs and inflation. In this study there will be two geometrically identical bridge decks being compared—one made from conventional steel-reinforced concrete and one made from fiber-reinforced polymer composites. The former will serve as a control for this experiment, and the latter will serve as the independent variable being tested. The LCC method that is being employed follows the outline of software developed by the National Institute of Standards and Technology (NIST) called BridgeLCC. Its methodology is based on both the American Society for Testing and Materials standard E-917 and a cost classification developed at NIST [2].

The first step in performing a LCC analysis with BridgeLCC is shown in Figure 3. For this we called the base case the steel-reinforced concrete deck, and the alternative to be considered the fiber-reinforced polymer deck. It is assumed the length of the study is 70 years, and the base year is 2011; the inflation rate is 1.80% and the real discount rate is 3.20%.

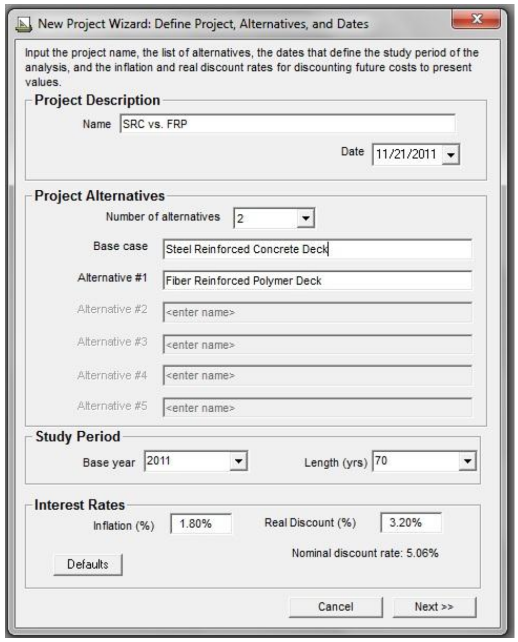

Figure 3: BridgeLCC Program (Step 1)

The second step in this LCC analysis simply identifies the dimensions for the area of the deck and the length of the bridge which are in feet^2, and feet respectively.

The third step assumes that there are two lanes on and under the bridge. It is also assumed that the bridges considered are of medium length and therefore have a length of 100 feet, and a deck area of 4500 feet^2. Since two geometrically similar bridges are being compared, the physical dimensions are kept the same to aid in a more accurate comparison. Here, the base case, or the SRC deck, is our control and the alternate case, or the FRP deck, is the independent variable while the dependent variable is the long term cost.

The fourth and final step allows us to input the various costs of Construction, Operation, Maintenance and Repair (OM&R), and Disposal costs. Table 1 shows a summary of these various costs in terms of dollars/foot^2.

Table 1. Cost Category Breakdown

Cost Category	Base Case (Steel Reinforced Concrete) (dollars/foot^2)	Alternative Case (Fiber Reinforced Polymer) (dollars/foot^2)
Construction	40	70
OM and R (5 year)	80.5	43.5
Disposal	19.7	14.5
Total	140.2	128

Of these values, construction costs include the price of the physical concrete deck, mobilization costs and traffic control costs. For this study it was assumed that the average cost per square foot for FRP and SRC was 70 and 40 dollars/foot^2, respectively and that the area of the deck that would be used to calculate the total cost, as indicated in the third step would be 4500 feet^2. The operation maintenance and repair costs are derived from the Life-Cycle Civil Engineering text by Fabio Biondni, which outline a FRP versus SRC bridge deck 70 year LCC comparison. It states that the OM&R costs for FRP and SRC are 8.7 and 16.1 dollars/foot^2, respectively [2]. It must be pointed out that the FRP bridge deck needs less maintenance and repair activities, so as expected its costs are lower. To keep things consistent we assume that each bridge must be repaired every 5 years, and as such the FRP decks are cheaper to maintain. Accordingly, disposal costs are also outlined in the same report and are estimated at 19.7 and 14.5 dollars/foot^2 for SRC and FRC, respectively.

After inputting all these data, a cost summary is shown in the form of the two graphs below. The first does not factor in inflation to show the raw costs of things, and the second factors in inflation which we will see is a major proponent for FRP.

The total OM&R of the SRC deck is estimated at $390,005 and of the FRP deck is $185,048 in base-year dollars which exemplifies the notion that FRP bridge decks cost less to maintain than SRC bridge decks, which is also evident in Figure 4 where the blue corresponds to the SRC bridge deck, and the red corresponds to the FRP bridge deck. It's important to note that this estimate does not include inflation. Additionally, it turns out that the total overall price in base-year dollars for the FRP bridge deck is $79,957 dollars less, or 14.3% cheaper than the SRC bridge deck.

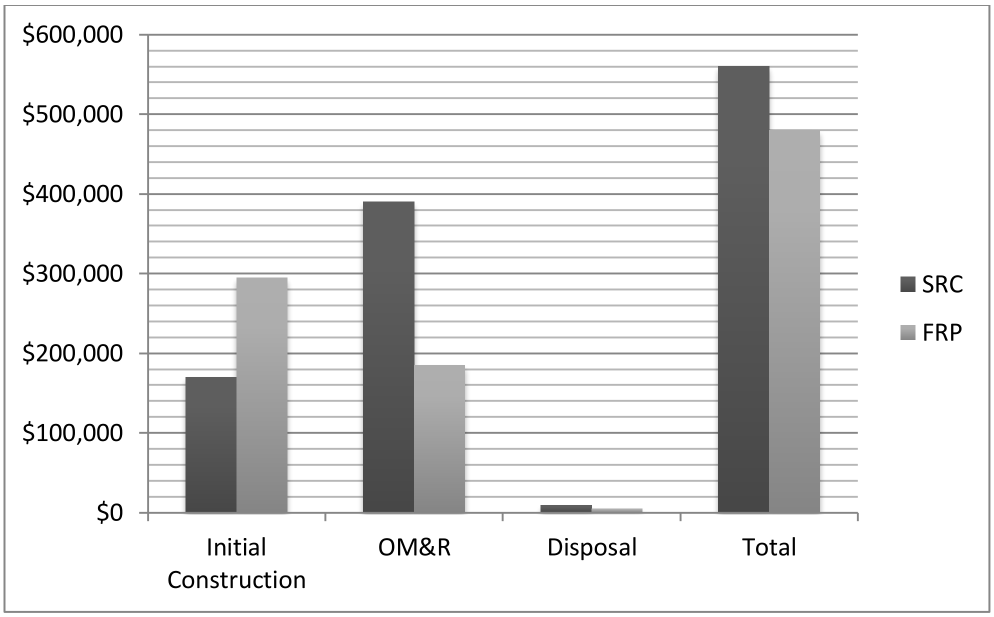

Figure 4: Life Cycle Cost Graph in Base-Year Dollars

After approximately 20 years, the FRP bridge deck becomes the less expensive option. Figure 5 shows the cumulative cost in current-year dollars of both bridge decks, and the intersection of the two is the break-even point. It must be noted however that this is a conservative estimate and includes inflation of 1.80%. When inflation is factored in it is important to note that FRP is 35% cheaper than SRC. This is a 20.7% increase, purely based on inflation.

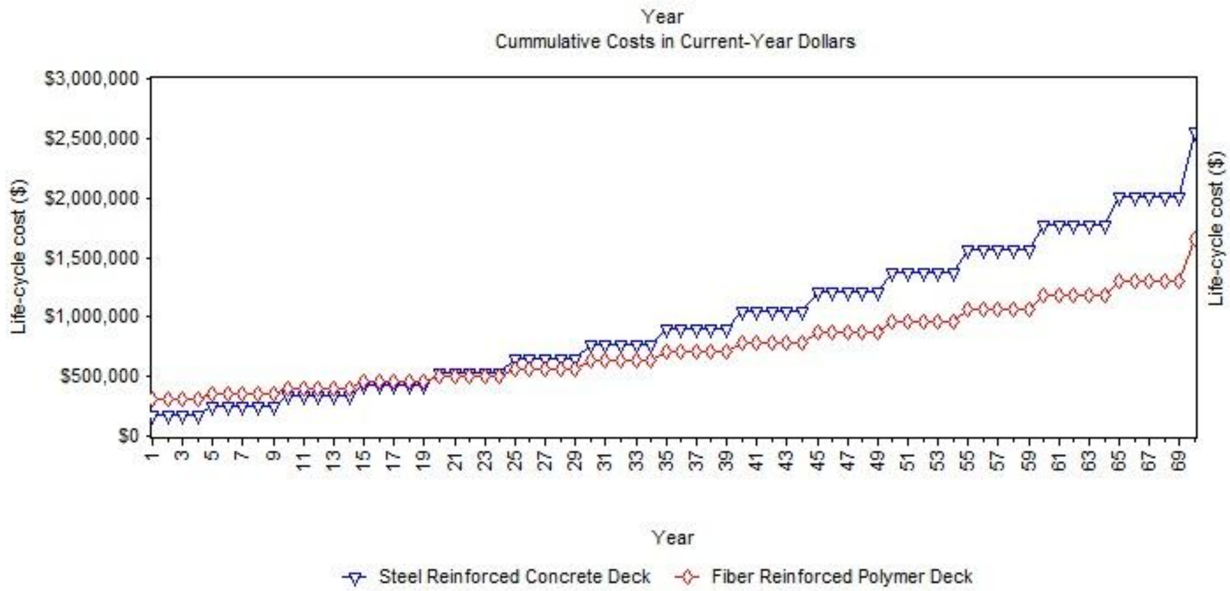

Figure 5: Cumulative Cost in Current-Year Dollars

Fiber-reinforced polymer composites are relatively primitive in their civil engineering application, especially in comparison to other more established bridge deck technologies. Based on the theory of the learning curve, the costs should decrease in an exponential manner as experience builds up [9]. Figure 6 displays this notion in graphical form. FRP composites are on the left portion of this graph because they are so new in their application.

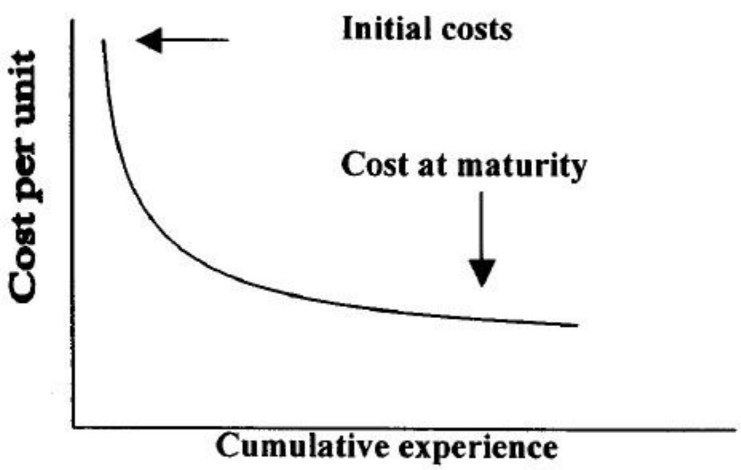

Figure 6: The Learning Curve

However, fiber-reinforced polymer composites are not limited to bridge decks. In fact, it has been shown that FRP composites can be used in the form of wraps to repair deteriorated concrete piers, pier caps and beams [8]. The Federal Highway Administration (FHWA) performed a study on carbon fiber sheets used to repair pre-stressed concrete girders. The results of the study were that the repaired girders were actually stronger than that of the original girders [8]. Currently, many states such a Florida, South Carolina, Georgia and Utah employ these FRP composite sheets to repair damaged or deteriorated beams because it is both an efficient and cost effective solution for repairs. Additionally, FRP decks are proven to reduce the weight of conventional construction by 70 to 80 percent, effectively curbing the problem of excessive dead load for longer bridges [8]. In addition to increasing savings in substructure costs, it enables the use of higher live load levels in the case of replacement decks, and brings forth the potential of longer unsupported spans [5].

CONCLUSION

This study proved that after 20 years, the cost of a fiber-reinforced polymer bridge deck is cheaper than a geometrically equivalent steel-reinforced concrete bridge deck, and that based on base-year dollars, there is a 14.3% savings. When inflation is factored in, this number jumps to 35%. The potential for FRP composites to improve the deteriorating infrastructure of the United States of America is highly apparent because of its ability to save engineers money and time with respect to maintenance frequency. As we move along the learning curve the initial hurdle of FRP composites will get smaller; however in order for this to happen, engineers must acknowledge the promise FRP composites hold its in Civil Engineering applications, develop additional standards, and then aid in its research to further its growth. If all three of these things happen then the market for FRP will flourish and it will become even more economically feasible in the future.

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