Life-Cycle Cost Analysis of Ultra High-Performance Concrete (UHPC) in Retrofitting Applications

Abid Hossain – Graduate Research Assistant, Florida International University, Department of Civil and Environmental Engineering, Miami, Florida, USA, Email: ahoss019@fiu.edu

Carlos M. Chang, Ph.D., P.E – Associate Professor; Florida International University; Department of Civil and Environmental Engineering; Miami, Florida, USA, Email: cachang@fiu.edu

Keywords: UHPC, Life Expectancy, Life Cycle Cost, Corrosion.

Abstract

Bridge components are affected by loads and environmental stressors, deteriorating faster or even collapse without effective maintenance and rehabilitation strategies. Furthermore, wet-dry cycling and higher concentrations of chlorides in coastal areas accelerates the deterioration process of bridges while increasing the frequency of maintenance and cost of the repairs. To address this problem, innovative materials like Ultra High-Performance Concrete (UHPC) should be considered in the development and implementation of maintenance and rehabilitation strategies. A comparison of conventional and UHPC applications for bridge repairs is presented in this study using Life Cycle Cost Analysis. A life expectancy model framework is proposed based on chloride corrosion model and Monte Carlo simulation. A case study is presented to demonstrate the applicability of the LCCA methodology, and it was found that the use of UHPC can result in a significant reduction in the total life cycle cost. The sensitivity analysis revealed that the life expectancy, Average Daily Traffic (ADT) and construction duration of the rehabilitation activity have the most significant effects on the life cycle cost. The life expectancy model predicts that 40% spalling damage is expected for conventional concrete after 30 years, and the same amount of spalling damage is projected for UHPC after 80 years. Products from this research aims to support funding allocation decisions at both network and project management level. The step-by-step LCCA methodology is developed in this study to identify cost-effective retrofitting techniques to preserve bridges in a "State of Good repair".

1. Introduction

Ultra-High-Performance Concrete (UHPC) is an innovative material with the potential to become a viable alternative for improving the sustainability of infrastructure components. To recognize the potential benefits of UHPC applications, it is essential to compare conventional retrofitting techniques to equivalent UHPC applications. Life-cycle cost analysis (LCCA) is one of the tools that can assist to compare treatment solutions for bridge maintenance strategies. UHPC is comparatively a recent invention in terms of concrete materials. The challenges for the wide use of these materials are generally due to the lack of quantitative tools to evaluate the structural performance over time and to compare the life cycle costs. This research study aims to apply life cycle cost analysis to compare UHPC applications with conventional bridge repair techniques.

2. Methodology

The research methodology was developed in two parts. The first part consists of developing a life expectancy model for UHPC. The model is developed based on Fick's second law of diffusion. Diffusion of chloride was considered as the deterioration factor for the concrete element. The bridge element was divided into a certain number of small elements with similar properties. But the small sections have separate probabilities for corrosion due to monte Carlo simulation. Since the small elements are independent, the cumulative damage is just the multiplication of the probabilities of the small sections. The process was simulated on python. The second part of the methodology involves calculation of life cycle cost analysis. The methodology adopted from a study from Federal Highway Administration (FHWA) developed by Walls & Smith (1998) for pavement design selection under a FHWA sponsored research project (Walls III and Smith). The methodology considers the concept of Net Present Value as the economic efficiency indicator. Both agency and user costs were calculated.

3. Results

The case study consisted of two alternatives: Alternative 1: Conventional cast in place concrete deck slab. Alternative 2: Precast deck slab with UHPC closure joints.

As shown in Figure 1, the life expectancy model predicts that 40% spalling damage is expected for conventional concrete after 30 years, and the same amount of spalling damage is projected for UHPC after 80 years.

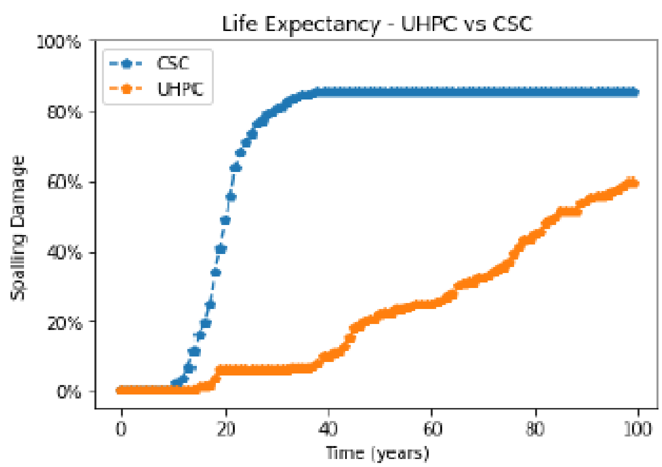

Figure 1. Life expectancy estimation for UHPC and Conventional Concrete.

The life cycle cost analysis results showed that for alternative 1 with conventional concrete, the agency cost is slightly lower than alternative 2 with UHPC. However, the lower frequency of preventive maintenance in alternative 2 due to the higher durability of UHPC is reflected in the results balancing the initial construction cost. At the end of the 60-year analysis period, the total agency cost of the alternatives is very close ($950,604 in alternative 1 versus $952,630 in alternative 2). The user cost is found to be lower for alternative 2 because the construction time is lower than alternative 1 (4 days versus 14 days). When user costs are included in the analysis, the total life-cycle cost of alternative 1 – including agency and user costs - is about three times the total life cost of alternative 2 ($ 5,270,161 versus $1,700,178). Therefore, alternative 2 with UHPC is recommended as the most cost-effective solution in the case study. The life expectancy of the precast deck slab with UHPC was almost twice than conventional cast in place concrete deck slack. and this difference is reflected in the LCCA results. Figure 2 shows the tornado diagram with the results of a life cycle cost sensitivity analysis for alternative 1. The construction unit cost, service life, average daily traffic, rehabilitation duration, and discount rate values were varied negative 50% and positive 50% in the sensitivity analysis. The results show that the Average Daily Traffic (ADT) has the most significant effect on the total life cycle cost. For a service life increase of 50%, the total life cycle cost would be less than half if it decreases by 50%. Increasing the duration of the rehabilitation activity by 50% has a similar impact on the total life cycle cost as the service life increase. Construction unit cost shows the lower impact on the total life cycle cost when compared to the other variables. On a similar plot for alternative 2 showed that the total life cycle cost for alternative 2 is less sensitive to ADT variations when compared to alternative 1. These results are influenced by the difference in construction days between alternatives 1 and 2 (14 days versus 4 days. It is also observed that that total life cycle cost is more sensitive to construction unit cost variations in alternative 2.

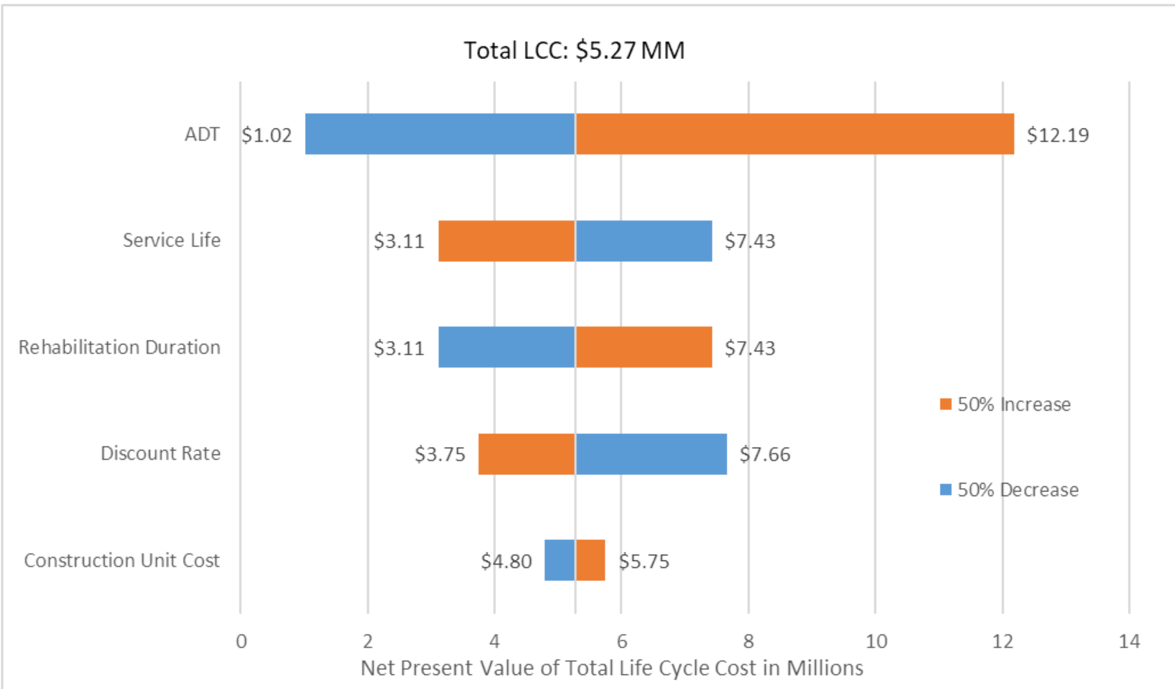

Figure 2. Tornedo diagram for sensitivity analysis of alternative 1.

Acknowledgements

The authors acknowledge the financial support provided by the Accelerated Bridge Construction-University Transportation Center (ABC-UTC) at Florida International University.

References

Walls III, J., and M. R. Smith. *LIFE-CYCLE COST ANALYSIS IN PAVEMENT DESIGN - INTERIM TECHNICAL BULLETIN*. FHWA-SA-98-079, Sept. 1998. *trid.trb.org*, https://trid.trb.org/view/497646.