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PRINCIPLES OF USING LIFE-CYCLE ASSESSMENT IN BRIDGE ANALYSIS

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ABSTRACT

Bridges are an important component of the transportation infrastructure, but their environmental analysis is lacking critical mass of literature. Principles of applying environmental analysis to bridges are presented.

Keywords: environment, emissions, wastes, end of life.

1 INTRODUCTION

Of all the components of infrastructure, bridges are the least studied from an environmental perspective. Although they seem to attract less attention than transportation systems, bridge building is nevertheless a major activity, planning, design and construction take years, and they are not only expensive, but much emission and waste are generated by such a capital investment. In addition, bridges require constant maintenance and rehabilitation throughout their life, which tends to be long.

2 BACKGROUND

The literature is scant on environmental analysis of bridges. Three papers from ASCE's *Journal of Infrastructure Systems* tackled the material choices in bridge design. In chronological order, a paper by Horvath and Hendrickson [1] explored bridge material selection, a life-cycle inventory analysis of steel and steel-reinforced concrete bridge girders. They compared a steel design to a steel-reinforced concrete design through materials production, maintenance, and end of life, and found that for "equivalent designs for a particular location, a steel-reinforced concrete bridge has generally lower environmental effects than a steel bridge." However, they identified a number of data and methodology uncertainties which make the comparison difficult, and considered recycling to be an activity that may swing the analysis in the favor of steel bridges, depending on how it was organized.

Keoleian and co-authors [2], [3] studied engineered cementitious composites (ECC) as alternatives to conventional concrete. In reference [2], they reported on a comparison of two bridge deck systems (one using conventional steel expansion joints and the other an ECC link slab design). Over 60 years of service life, the ECC bridge deck system was found to have "significant advantages in environmental performance: 40% less life cycle energy consumption, 50% less solid waste generation, and 38% less raw material consumption. Construction related traffic congestion is the greatest contributor to most life cycle impact categories." In reference [3], "an integrated life-cycle assessment and life-cycle cost analysis model was developed and applied to... a conventional concrete bridge deck and an alternative engineered cementitious composite link slab design." Life-cycle cost analysis focused on agency, user, and environmental costs. "Despite higher initial costs and greater material-related environmental impacts on a per mass basis, the link slab design results in lower life-cycle costs and reduced environmental impacts when evaluated over the entire life cycle. Traffic delay caused by construction comprises 91% of total costs for both designs. Costs to the funding agency comprise less than 3% of total costs, and environmental costs are less than 0.5%. These results show life-cycle modeling is an important decision-making tool since initial costs and agency costs are not illustrative of total life-cycle costs. Additionally, accounting for construction-related traffic delay is vital to assessing the total economic cost and environmental impact of infrastructure design decisions."

The above three papers illustrate the challenges associated with environmental analysis of bridges. Following is a set of principles of environmental analysis of bridges.

3 PRINCIPLES OF ENVIRONMNETAL ANALYSIS OF BRIDGES

Questions need to be defined carefully. Like in all good analysis, the first and crucial step is to define carefully the questions we want answered. In the case of bridges, questions might deal with exploring alternative materials (steel, concrete, FRP) for bridge components (e.g., girders), comparing various bridge designs (e.g., if cable-stayed bridges are more environmentally friendly than suspension bridges), reducing the overall environmental burden of constructing a particular bridge or bridge type, or even larger, network-type questions, e.g., if we should tunnel or build a bridge or build a long road around a natural barrier (e.g., in the case of the San Francisco Bay, or mountains and valleys). One must not define the questions too narrowly. For example, drawing conclusions from studying individual bridge components (e.g., girders) is inherently difficult because components interact. Thus making a material change in one component may lead to material amount and design changes in other components. Indeed, substituting one material for another may necessitate the redesign of the entire bridge.

Full LCA is needed. LCA has become a great aid to decision makers, and it has to be applied according to defensible scientific principles and best practices in order to make comprehensive decisions. The environmental aspects of the entire life cycle of bridges need to be studied, including planning and design, material provision, construction, maintenance and rehabilitation, end of life, and transportation in all phases. Missing a life-cycle phase may result in suboptimal decisions.

Location of analysis is important. Many bridge designs are unique, and bridge construction has local characteristics with respect to what materials are used, where they are sourced from, what labor and technologies are available, what topographic conditions there are, and others. Transportation of materials alone is an important factor in the analysis, especially since a lot of material is moved in a bridge project.

Time horizon. Decisions about bridges need current information. Unfortunately, right now there are many data gaps about bridges wherever they are in the world, and the decision-maker would be happy to get any kind of information, even if the source is outdated. The situation is even more dire about using novel materials and the designs which could accommodate them in the future. Many times there is little experience with putting the alternative materials in place and monitoring their performance over time. LCA has had difficulties with predicting future performance. Maintenance schedules in the future may be very different from the original plans. End of life actions such as recycling the majority of the bridge may be infeasible by when that time actually comes in several decades.

All emissions and wastes need to be assessed. Greenhouse gases (GHG) get a lot of attention these days as the discussions about climate change mitigation intensify. But we must not forget that environmental assessment is not just about GHG. There are other air and water pollutants, and wastes of various kind that must be kept to a minimum, as well as critical inputs that need to be tracked and minimized, such as water, and renewable and non-renewable materials. A good LCA should quantify the widest range of environmental inputs and outputs, and perform impact analysis (global warming potential, human and ecological toxicity analysis, resource depletion assessment).

Recommendations to decision makers must be unambiguous and practical. It is important to generate relevant environmental results about bridges, but also to interpret the results and to the extent possible, translate them into action and policy. It is far from trivial to take results of LCA studies and turn them into recommendations that practitioners can implement, but it is a necessary step in order to make an impact.

4 SUMMARY

The case for studying bridges is rather strong, and more studies are needed, in every part of the world, about as many bridges as possible, and about various types of bridges, with various material options. Once a critical mass is available, conclusions and lesson learned should be translated into recommendations that practitioners could implement.

REFERENCES

[1] A. Horvath and C. T. Hendrickson: Steel vs. Steel-Reinforced Concrete Bridges: Environmental Assessment. Journal of Infrastructure Systems, ASCE, Vol. 4, No. 3, pp. 111-117 (1998)

[2] G. A. Keoleian, A. Kendall, J. E. Dettling, V. M. Smith, R. F. Chandler, M. D. Lepech and V. C. Li: Life Cycle Modeling of Concrete Bridge Design: Comparison of Engineered Cementitious Composite Link Slabs and Conventional Steel Expansion Joints. Journal of Infrastructure Systems, ASCE, Vol. 11, No. 1, pp. 51-60 (2005)

[3] A. Kendall, G. A. Keoleian and G. E. Helfand: Integrated Life-Cycle Assessment and Life-Cycle Cost Analysis Model for Concrete Bridge Deck Applications. Journal of Infrastructure Systems, ASCE, Vol. 14, No. 3, pp. 214-222 (2008)