Life Cycle Cost of A Civil Infrastructure

Bhumika Chandekar[1], Hitesh Kodwani[2]
[1, 2]Dept of Civil Engineering
[1, 2] SAMCET Bhopal

Abstract- *A well-maintained infrastructure is a fundamental necessity for a modern society that provides great value, but ensuring that it meets all the requirements sustainably and cost-effectively is challenging. Concrete as a construction material is in use for several decades. Conventionally civil structures are designed considering only the initial construction cost and target compressive strength. Regular maintenance of concrete structures is significant to maintain the performance of structures. Hence, methodologies are required to find out the expected maintenance required for a structure.*

Keywords- Concrete; Estimate; Service Life; Life Cycle; Cost.

I. INTRODUCTION

Structural design of concrete structures traditionally considered compressive strength and focuses over the initial cost of structural design and construction. However with time, material and structures degrades gradually and causes reduction in the integrity and reliability of a structure. Hence, maintenance of deteriorating concrete structures is required to upgrade the reliability and structural performance of concrete structures. The present work proposed methodologies to determine the expected life, required maintenance and methods for estimating life-cycle cost of structures. Life-Cycle cost for a building includes maintenance and repair costs other than construction cost.

Life-cycle Cost is the cost of an asset, or its parts, throughout its life cycle while it fulfills its performance requirements. As per ISO15686-5 (2008) [1]. Life-cycle costing is sometime called life-cycle cost analysis (LCCA). LCCA is appropriately applied to compare alternatives that would yield the same level of service and benefits to the project user (USDTFHAO, 2002)[2].

II. LIFE CYCLE COST

Life cycle cost (LCC) can be defined as the total cost for a customer of a machine or apparatus, including procuring costs and operating costs (which includes preservation, repair, and energy costs). Future operating costs are discounted to the time of purchase, and summed over the lifetime of the appliance or equipment.

The life-cycle cost of a structure includes the sum of the present value of all expected costs concerning the construction plus all the expenses related to maintenance and management of the structure during its life. Life-cycle cost usually refers to the deterioration due to mechanisms such as corrosion and risk related to natural hazards, such as wind or earthquake.

Total life cycle cost can be estimated by considering construction cost (Pc), inspection cost (Pi), maintenance cost (Pm), and renewing/ replacing cost (Pr), so the formula is

$$\text{Total cost} = Pc + Pi + Pm + Pr + \text{miscellaneous costs}$$

III. LITERATURE REVIEW

The life cycle cost of a structure is the sum of all funds expended from its construction to the end of its useful life. Several researchers performed studies to evaluate life cycle cost of concrete structures. Narasimhan (2006) [3] discussed that, the durability design of concrete structures is based on the requirements for minimum concrete cover, maximum water/cement ratio, and minimum cement content and so on. With such rules, it is not possible to provide an explicit relationship between performance and life of the structure. It is hence necessary to adopt a suitable design approach which provides a clear and consistent basis for the performance evaluation of the structure throughout its lifetime.

Kong and Frangopol (2003)[4] presented a method to evaluate the expected probability of maintenance at a certain time or age of a deteriorating structure and the expected life-cycle maintenance cost. Proposed method is suitable for application to both new and existing civil infrastructures under various maintenance strategies. This study also analyzed an existing reinforced concrete bridge for illustrating this proposed methodology.

Li and Guo (2012)[5] presented a case study on four buildings of Taiwan University for analyzing life cycle cost analysis. Utilized, historical maintenance and repair data of past 42 years, to develop life cycle cost prediction model.

Kim and Frangopol (2011) [6] presented a way to predict the structural perfornance of structures through structural health monitoring (SHM). The purposes of SHM have been identified as assessing structural performance, predicting remaining service life and providing a decision tool for optimum maintenance planning.

Passer et al. (2007)[7] presented the results of a pre-feasibility study to identify future calls for actions for the construction industry towards sustainability: Three office buildings with load bearings systems made of reinforced concrete, steel and timber were compared. For the assessment a life cycle assessment (LCA) was undertaken. It is investigated how benefits of sustainable construction regarding different construction techniques can already be assessed. The main result is that the three construction techniques are very close to each other and no construction technique is preferable only on the basis of the life cycle assessment. It is necessary to extend the one-dimensional environmental assessment by adding the two other pillars of sustainability to be in the line with holistic considerations to full-fill the three dimensions of sustainability. It follows that in the context of buildings requirements such as safety and fitness for use must also be considered in a new dimension called structural sustainability.

Humphreys et al. (2005)[8] presented a concept map for assisting decision makers to appropriately choose the best treatment for bridge rehabilitation affected by premature deterioration through exposure to aggressive environments in Australia. The decision analysis is referred to a whole of life cycle cost analysis by considering appropriate elements of bridge rehabilitation costs. In addition, the results of bridges inspections in Queensland are presented.

Bowyer (2013)[9] presented a report to clarify the differences between Life Cycle Cost Analysis (LCCA) and Life Cycle Assessment (LCA), summarize what is known about the life cycle costs of non-residential wood construction, compare the life cycle costs of wood structures to those of other materials, and review processes for conducting life cycle cost analyses on structural systems or whole buildings. Summaries of LCCA resources are also provided.

Wen and Kang (2000)[10] conducted a sensitivity analysis for comparing the optimal design to the important but controversial parameters, such as design life, death and injury cost, structural capacity uncertainty, and discount rate. The method is applied to design under earthquakes, winds, and both hazards at Los Angeles, Seattle, and Charleston, South Carolina, and compared with current design. The optimal design is "dominated" by seismic load in Seattle and wind load in Charleston. These hazards, however, do not "control" or "govern" the design, for the lesser hazard still contributes significantly.

Lagaros and Magoula (2013)[11] proposed a performance-based seismic design procedure, formulated as a structural design optimization problem, for designing steel and steel–reinforced concrete composite buildings subject to interstorey drift limitations. For this purpose, eight test examples are considered, in particular four steel and four steel–reinforced concrete composite buildings are optimally designed with minimum initial cost. Life-cycle cost analysis (LCCA) is considered as a reliable tool for measuring the damage cost due to future earthquakes that will occur during the design life of a structure. In this study, LCCA is employed for assessing the optimum designs obtained for steel and steel–reinforced concrete composite design practices.

Gencturk et al. (2014)[12] presented an analysis to first identify the components in LCC evaluation that directly affect the outcomes, and propose strategies to improve the reliability of the analysis. The shortcomings of existing studies on LCC optimization of structures are identified. These shortcomings include simplified analysis techniques to determine the structural capacity and earthquake demand, use of generalized definitions for structural limit states, and inadequacies in treating uncertainty. In the following, the problem formulation and a brief review of existing literature on LCC optimization of structures are provided. A LCC model is presented, and techniques are proposed to improve the above mentioned shortcomings. Finally, LCC analysis of an example reinforced concrete (RC) structure is employed to illustrate the methodology.

IV. DETERMINATION OF LIFE CYCLE COST

Life-cycle cost analysis (LCCA) is a tool to determine the most cost-effective option among different competing alternatives to purchase, own, operate, maintain and, finally, dispose of an object or process, when each is equally appropriate to be implemented on technical grounds.

Whole-life cost, or Life-cycle cost (LCC), refers to the total cost of ownership over the life of an asset. Costs considered include the financial cost which is relatively simple to calculate and also the environmental and social costs which are more difficult to quantify and assign numerical values. Typical areas of expenditure which are included in calculating the whole-life cost include, planning, design, construction and acquisition, operations, maintenance, renewal and rehabilitation, depreciation and cost of finance and replacement or disposal..

Life cycle cost analysis as applied to civil structures, sometimes also referred to as value engineering or life cycle costing, involves accounting for all costs related to construction, operation, maintenance, and disposal at the end of the useful life of a structure. The purpose is to provide a basis for selection of the most cost-effective design alternative over a particular time frame, taking into account anticipated future costs as well as initial costs of construction. LCCA is particularly suitable for the evaluation of building design alternatives that satisfy a required level of building performance, especially when investment, operating, maintenance, and repair costs differ, and/or when alternative designs may have different expected service lives.

Whole life cycle costing (WLCC) has been becoming a standard method for the long-term cost evaluation of building and civil infrastructure projects. In the context of civil engineering structures rehabilitation, the purpose of a Life Cycle Cost Analysis (LCCA) is to investigate the overall costs of curing methods and select the best one which confirms that constructed facility will provide the lowest overall cost with its quality and function. Nowadays owners are demanding a project that ensures value for money over the life of structures. WLCC has become a crucial device for those concerned in the design, construction, operation and risk investigation of construction projects. It takes into account all costs of acquiring, owning, and disposing of a system. The study is especially valuable when treatment alternatives that fulfils the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximizes net savings (Fuller et al. 2006) [14].

The life-cycle cost of a structure includes the sum of the present value of all expected costs concerning the construction plus all the expenses related to maintenance and management of the structure during its life. Life-cycle cost usually refers to the deterioration due to mechanisms such as corrosion and risk related to natural hazards, such as wind or earthquake. Figure 1, presents the life cycle cost of any equipment –

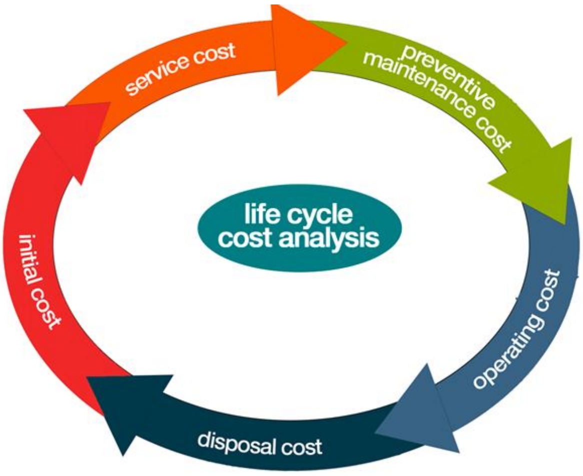

Fig. 1– Life cycle costs

Life cycle cost of any equipment

Life-cycle cost is the total customer cost over the life of a piece of equipment, including purchase cost and operating costs (which are comprised of energy costs, maintenance costs, and repair costs). Future operating costs are discounted to the time of purchase and summed over the lifetime of the equipment. Life-cycle cost is defined by the following equation:

$$LCC = IC + \sum_{t=1}^{N} OC_t / (1+r)^t \qquad \text{(eqn. 1)}$$

where -

LCC = life-cycle cost, IC = total installed cost, Σ = sum over the lifetime, from year 1 to year N, where N = lifetime of equipment (years), OC = operating cost, r = discount rate, t = year for which operating cost is being determined.

The discount rate (r) is the rate at which future expenditures are discounted to establish their present value. The cost of capital is commonly used to estimate the present value of cash flows to be derived from a typical company project or investment. Most companies use both debt and equity capital to fund investments, so their cost of capital is the weighted average of the cost to the company of equity and debt financing.

The total installed cost to the customer is defined by the following equation:

$$IC = EQP + INST \qquad \textbf{(eqn. 2)}$$

where -

EQP = equipment price for customer. *INST* = installation price or the customer price to install equipment (i.e., the cost for labor and materials). Operating cost can be evaluated by the following equation:

$$OC = EC + RC + MC \qquad \textbf{(eqn. 3)}$$

where -

OC = operating cost, *EC* = energy cost associated with operating the equipment, *RC* = repair cost associated with component failure, *MC* = service cost for maintaining equipment operation.

V. DISCUSSION AND CONCLUSIONS

A life cycle cost estimation process for reinforced concrete structures has been presented in this research. The method attempts to incorporate issues of structural service life and durability together with financial cost optimization into the structural design process. In-situ data have to be collected and used to validate different life cost models for concrete structures. Performance based design of concrete has been required to be implemented. New advanced procedures for assessment of Life Cycle cost of RC structures are required to be developed.

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