Life-Cycle Cost Analysis of Concrete Structures

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ABSTRACT:

Structural designs of concrete structures traditionally focus over the initial cost of structural design and construction. However with time, there is a gradual deterioration in material characteristics and properties and this translates into a decline in the performance and durability of a structure. Maintenance of deteriorating concrete structures is required at regular interval to maintain the performance of structures. However, it is required to make the best possible use of limited financial resources during maintenance. Hence, methodologies are required to determine the expected number of maintenance required for new and deteriorating structures. This paper reviews several methods proposed by researchers for the analysis of life-cycle cost of structures.

1. INTRODUCTION

Concrete has been used as a construction material for several years. However, the researches in the last few decades showed that concrete structures degrades with time and is therefore not maintenance free. Life-Cycle cost for a building includes maintenance and repair costs other than construction cost.

Traditional approach to structural design tends to focus primarily on the initial cost of structural design and construction. A major drawback of this approach is that there is no elaborate consideration given at the structural design stage to the actual future costs that would accumulate throughout the life of the structure [1]. Therefore, it required to-decide when and how to repair, rehabilitate and replace the deteriorating structures. Hence, effective methods are needed to assess expenditure for maintaining deteriorating structures during their service life [2].

Life cycle of a concrete structure is similar to human life affected by age, may suffer physical deterioration and obsolescence with age [3]. Generally life cycle cost analysis considers construction cost, inspection cost, maintenance cost and failure cost. Present article reviewed several studies performed by researchers for analyzing life cycle cost of concrete structures.

2. DETERIORATION MECHANISMS OF CONCRETE STRUCTURES

Major deterioration mechanisms of RC Structures identified are:

Corrosion induced cracking

Carbonation

Chloride attack

Sulfate attack

Freeze thaw attack

Alkali Silica Reactivity (ASR)

Corrosion induced cracking

Corrosion induced cracking has been recognized by many researchers as the major cause of deterioration of concrete structures. Main causes of corrosion are the ingress of chloride ion and carbonation.

Carbonation

In carbonation process atmospheric carbon dioxide penetrates the concrete and reacts with hydroxides to form carbonates. This reduces alkalinity (pH) of concrete and increases the risk of corrosion.

Chloride concentration

Concrete protects steel from corrosion through its highly alkaline nature by providing a passive film on steel. High ingress of chloride ions from seawater can destroy the protective film.

Sulfate Attack

Excessive amounts of sulfates in soil or water can attack and destroy a concrete, it attacks concrete by reacting with hydrated compounds in the hardened cement paste especially calcium aluminates hydrate. Sulfate attack is more severe at locations where concrete is exposed to wetting and drying cycle.

Freezing and Thawing attack

Durability of concrete gets affected by alternate freezing and thawing cycles. During freezing, water is displaced by ice formation, and makes concrete expand, this expansion caused disruption of concrete. Deterioration is caused by subsequent expansion of cement paste, the aggregate particles, or both.

Alkali Silica Reactivity (ASR)

Concrete deterioration occurs when the reactive silica react with the alkali hydroxides in the concrete. Alkali silica gel is expansive in nature, so causes serious cracking conditions.

3. LIFE-CYCLE ANALYSIS PERFORMED BY RESEARCHERS

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) [1] 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) [2] 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. Also n existing reinforced concrete bridge is analyzed for illustrating this proposed methodology.

Li and Guo (2012) [3] 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) [4] presented a way to predict the structural performance 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. (2009) [5] 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. [6] 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) [7] 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) 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) 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 etal. (2014) 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.

4. CONCLUSIONS

Premature deterioration such as corrosion of reinforced concrete structures due to aggressive environment condition affected the real life of structure services. The actual design life of the reinforced concrete can be reduced from designed life to very low and the level of deterioration depends on many factors including corrosion of reinforcing steel, condition of concrete and external environments. One of the critical issues causing reduced service life of the structures was a delay of conducting maintenance. Furthermore, delaying maintenance can result in increased cost due to repair and rehabilitation. The time to repairing and selecting protection system are the most critical decision-making step strategies and will usually have a major impact on the life cycle cost. Therefore, planning maintenance and analysis cost of repair is necessary at design stage

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