DETERMINATION OF LIFE CYCLE COST FOR REINFORCED CONCRETE STRUCTURES

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ABSTRACT: 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. Structures are assumed to be serviceable for whole life. However, the experience of last decades had proved that concrete structures deteriorates with time, there is a gradual declination in structure characteristics and properties and this results in the degradation of durability and performance. 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.

A procedure to determine the whole life cycle cost of a reinforced concrete structure has been presented in this research. This work attempts to integrate issues of structural performance and durability together with economic cost. Structural performance and durability of structure is determined through the service life concept of reinforced concrete structure.

Keywords: - life cycle cost, durability, deteriorates, performance

1. 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. It is now, required to make the optimum use of limited financial resources during inspection and maintenance. 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.

1.1 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

Total cost = Pc + Pi + Pm + Pr + miscellaneous costs

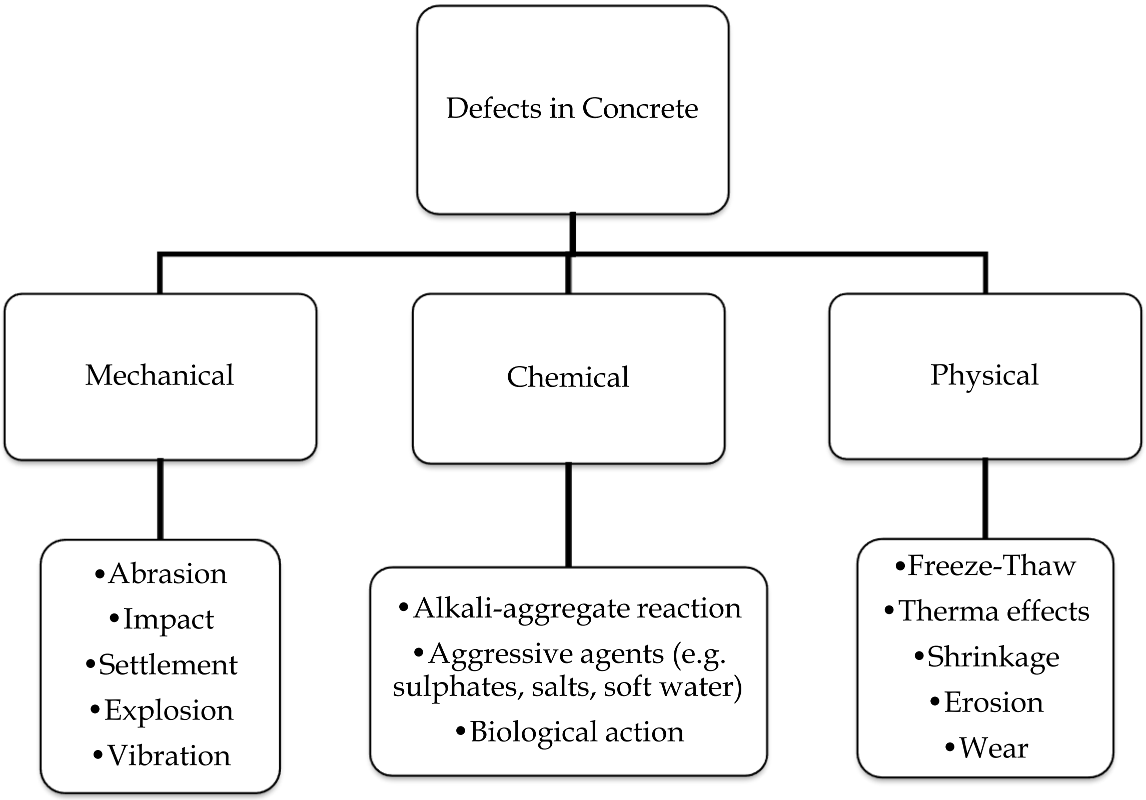
2. METHODOLOGY

1. Collect information regarding designated life of structures.
2. Design the structure to determine dimensions of structure and required reinforcement as per code
3. Estimate the construction cost using current S.O.R.
4. Estimate the corrosion initiation time based on carbonation through Fick's first law of diffusion
5. Find life cycle cost by adjusting initial construction cost and repair costs required over the entire designated life of structure to a common time period by converting to present rate
6. Determine the cost of repair to be carried out at the end of the service life
7. Compare the condition index with the target condition or reliability index. The highest time point at which the reliability index is equal to or just above the target reliability index is the service life

Deterioration of concrete structures

Deterioration of concrete structures before it have served its expected life is a global phenomenon and the situation is particularly severe in hot and arid regions of the world where high temperature, humidity and salinity exist.

The useful service life of a concrete structure is typically a function of corrosion rate of the reinforcement. Before the corrosion to start, aggressive elements such as chlorides or carbon dioxide must penetrate the concrete in sufficiently high concentrations, to the depth of the embedded reinforcing steel. Corrosion of steel is an expansive process. The process fractures the surrounding concrete and weakens the steel as it rusts. Concrete can also deteriorate because of chemical reactions between and within the cement matrix, aggregate and moisture. Various deterioration mechanisms of concrete structures are shown in flow chart 3.1 and various factors affecting the condition of concrete structures are shown in flow chart 3.2.



Flow chart 1 – Various deterioration mechanisms

Mechanism and causes of concrete deterioration

Deterioration mechanism	**Deterioration factor**	**Deterioration phenomena**
Freeze-thaw action	Freezing and thawing	Freezing and thawing of water in concrete causes deterioration of concrete surface e.g., scaling, micro cracking and pop-outs.
Chemical attack	Acidic substances Sulphate ions	Hardened concrete in contact with acidic substances or sulphate ions is dissolved, or concrete deteriorates due to the expansion pressure due to the formation of chemical substances

Alkali-silica reaction	Reactive aggregates	Reactive silicate minerals contained in or carbonate rocks chemically combines with pore solution whose pH is high and it causes irregular expansion or cracking in concrete.
Chloride induced deterioration	Chloride ions	Corrosion of steel in concrete is induced by chloride ions and it causes the cracking or peeling of concrete or reducing the cross section of steel.

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.

Figure: 1- Corrosion induced cracking

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.

Figure: 2- Carbonation

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.

Figure: 3- Chloride concentration

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.

Figure: 4- Sulfate Attack

Application of LCC in Design of Concrete Structures

Degradation of reinforced concrete structures with increase in age is major concern for the researchers. It has been observed from literature that a concrete structure is not maintenance free. The most usual way to investigate the durability problems coupled with concrete is through assessing of service life or the period during which concrete performs all necessary requirements. The inclusion of the idea of service life into a design procedure involves consideration of its economic and social impacts. Life cycle costing provides a tool to compute the economic impact of service life, thus clearing the way for its insertion into existing design procedures. The implementation of life cycle costing in the design of structures hence enables a thorough understanding of the economic impacts of durability on the performance of the structure during its lifetime. Following are the major steps for performing LCC of any civil infrastructure –

1.Fix priorities

The first step in LCC analysis is to define requirements of the client or the owner and to fix priorities about the structure which it must achieve. Also, any unusual constraints must be recognized at this time.

2. Identify alternatives

A set of substitutes that satisfy the requirements and achieve the basic priorities are to be chosen. It is necessary to identify all practical design approaches for further analysis. This process of selecting alternatives for further study can be listed as follows:

- Identify different design methods, idea and structural element alternatives.
- Fix minimum performance requirements for each alternative.
- Filter different alternatives, by eliminating those which do not meet fixed minimum performance requirements and constraints.
- The remaining alternatives are considered for further study.

3.Select Life Cycle

This includes decision making about the planning or life cycle valid to all the alternatives. To finalize about any definite number of years for a life cycle set up the duration of time over which future costs (operating, maintenance etc.) are to be estimated.

4. Estimate Costs

All the costs and revenues which are directly relevant to the comparison of alternatives are identified. The initial costs for each alternative are computed first.

There are three types of recurring costs - normal operation and maintenance costs incurred on a daily, weekly or monthly basis, the annual costs for utilities and fuels and the recurring costs of repairs, alterations and replacement of structural elements or systems. Estimates of their occurrence and periodicity depend on the estimates of the live cycles derived in the previous step. Also adjustments are made for price escalation.

5. Compute Present Values or Annual Equivalents

As the various expenditures estimated above take place at different times during the life cycle of the structure, the costs are adjusted to a common time period by converting to present values or annual equivalents. This is done by multiplying these costs by the appropriate discount factors in order to take time value of money into account.

6.Test sensitivity of results

The results from present value or annual equivalent computations for each alternative establish their ranking. The lowest alternative is the preferred one based on a total life cycle cost approach. However, finally a sensitivity analysis is carried out to review the influence of the various input parameters on the life cycle cost. Once these sensitivity tests are completed, the resulting lowest life cycle cost alternative is recommended for implementation.

3. 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.

The estimation of structural performance and durability is made on the basis of determination of the service life of reinforced concrete structures. The service life is determined based on the concept of exceeding limit states that is commonly used in structural design.

Limit state is based on the initiation of corrosion induced by carbonation. The service life hence determined decides the amount and timing of the future costs to be incurred during the design life of the structure. The life cycle cost is then determined based on discounting of the initial construction cost and the future repair costs to present values to ensure a time- consistent comparison of costs.

Replacement cost after the failure for concrete structures, if no repair is provided, is almost 8-10 times the repair cost, if provided, at the time of corrosion initiation.

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