Determination of Life Cycle Cost of Reinforced Concrete Structures

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

Abstract— 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.

Key words: Concrete; Structures; Service Life; Cost; Durability

I. INTRODUCTION

Life-Cycle cost for a building includes maintenance and repair costs other than construction cost. Durability and service life of concrete has been a major area of research for last three decades. Usually, the durability based design of concrete structures is based on certain rules for satisfying basic requirement of materials, material components and structural dimensions. Examples of such rules are the need for at-least concrete cover, maximum water/cement ratio and minimum cement content. With such system, it is not possible to develop a relationship between condition, performance and life of the structure. Therefore, it is needed to develop and implement a proper design methodology to provide a reliable basis for the performance evaluation of the structure throughout its service life.

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]. The agency that uses LCCA has already decided to undertake a project or improvement and is seeking to determine the most cost-efficient means to accomplish the project's objectives. Several researchers worldwide are working in this field, Kong and Frangopol (2003)[4] Proposed method suitable for application to both new and existing civil infrastructures under various maintenance strategies. Li and Guo (2012)[5] 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 performance of structures through structural health monitoring (SHM).

II. LIFE CYCLE COST OF A CONCRETE STRUCTURES

Let's us now consider a RC structure, situated in Bhopal. After collecting various information regarding plan, compressive strength, concrete cover and structural design, an estimate has been prepared, as shown in following tables – 1.

Estimated Cost Of The Project: 353000.00/-						
SOR :- PWD from 04 .06.2009						
S.NO	Pg/ Item	Unit	Particular of item	Qty.	Rate Rs.	AmountRs.
1	04/2.7.1	Cum	Earth work Earth work in excavation by mechanical means (Hydraulic excavator) / manual means over areas (exceeding 30cm in depth. 1.5m in width as well as 10 sqm on plan) including disposal of excavated earth, lead upto 50m and lift upto 1.5m, disposed earth to be levelled and neatly dressed.	12	171	2052.00
2	15/4.2.1.2	Cum	PCC Work Providing and laying cement concrete in retaining walls, return walls, walls (any thickness) including attached pilasters, columns, pillars, posts, struts, buttresses, string or lacing courses, parapets, coping, bed blocks, anchor blocks, plain window sills, fillets etc. up to floor two level, excluding the cost of centering, shuttering and finishing : With 20mm nominal size graded stone aggregate PCC In Foundation M-20	11.23	4039	
3	20/5.2/5.2.1	Cum	RCC Work Reinforced cement concrete work in walls (any thickness), including attached pilasters, buttresses, plinth and string courses, fillets, columns, pillars, posts and struts su spended floor roof slab, beams, etc. up to floor two level excluding cost of centering, shuttering, finishing and rcement : M 20 Nomial mix (with 20mm nominal size graded stone aggregate)	14.80	4221	62470.80

4	22/15.16.5	Kg	Steel Work Reinforcement for R.C.C. work including straightening, cutting, bending, placing in position and binding including cost of binding wire up to floor two level including all wastage etc. complete. (@ 162.25x 1% x7850 =12736.63 kg)	1395.00	52	72540.00
5	21/5.9/5.9.3	Sqm.	Centering Work Centering and shuttering including strutting, propping etc. and removal of form for: Suspended floors, roofs, landings, balconies and access platform. Shelves Cast in situ) Lintels, beams, beams, girders, bressumers and cantilevers, Columns, Pillars, Posts and Struts Walls in super structure.	159.00	199	31641.00
6	27/6.4/6.4.1	Cum	Brick work Brick work with M.S. bricks of class designation 40 in superstructure above plinth level up to floor II level in all shapes and sizes in : Cement mortar 1:4 (1 cement : 4 sand)	10.35	3780	39123.00
7	99/13.1	Sqm	plaster Work 12 mm cement plaster of mix :1:4 (1 cement: 4 sand)	166.00	90	14940.00
8	83/11.24	Sqm	Flooring Work Kota /cuddapahstone slabs 25 mm thick in risers of steps, skirting, dado and pillars laid on 12 mm (average) thick cement mortar 1:3 (1 cement 3 sand) and jointed with grey cement slurry mixed with pigment to match the shade of the slabs, including rubbing and polishing comple	42.00	701	29442.00
9	101/13.30	Sqm	White Wash Distempering with oil bound washable distemper of approved brand and anufacture to give an even shade13.30.1 New work (two or more coats) over and ncluding priming coat with cement primer.	166.00	45	7470.00
10	184/21.8	sqm	Aluminium work Providing and fixing double glazed hermetically sealed glazingin aluminium windows, ventilators and partition etc. with 6 mmthick clear float glass both side having 12 mm air gap including providing EPDM gasket, perforated aluminium spacers, desiccants, sealant (Both primary and secondary sealant) etc.as per pecifications, drawings and direction of Engineer-in charge complete.	12.00	3002	36024.00
			Total			295702.80
			Add for Internal & External Electrification 10%			29570.28
			Add for water Supply & Sanitation 10%			29570.28
			Grand Total			354843.36
(RUPEE THREE LAC TWENTY THOUSAND NINE HUNDREAD ONLY)						352997,00

Table 1: Abstract of Estimated Cost

Following details has been collected about the beam. By performing field survey, compressive strength as evaluated using rebound hammer is 20MPa. Concrete cover measured using cover-meter is 30mm. Designated life of structure is 50years. Corrosion initiation time can be evaluated through carbonation model presented in eqn. 1. Corrosion initiation time calculated using carbonation model is → $t_i = (30/7)^2 = 18.37$ years

For the structure considered for study, here all the above costs are calculated as per methods provided by researchers. After estimating useful service life or the period when corrosion initiates, initial cost of the construction of beam and percentage of component required to be replaced at the end of service life these costs are evaluated below.

1) Pr = replacement cost;
2) m = percentage of component required to be replaced = 50%= 0.5, as only concrete surrounding rebars is required to be replaced;
3) i = annual inflation rate i.e. 4% = 0.04;
4) N = expected service life = 18.37 years ==18 years;
5) Pc = construction cost = 353000/-;

Renewing or replacement cost can be calculated by the relation shown below –

$$Pr = Pc \times m\,(1+i)^N \quad (1)$$

- So, $Pr = 353000 \times 0.5(1.04)^{18} = 357557$.
- This cost can be converted to its present value using
- Present cost = cost to be adjusted/ $(1+r)^t$
- Where, t is number of years between the date of investment and present time and r is the net discount rate of money. Considering r = 0.05
- So present value of Pr = 148572

However, if no repair is provided at the time of corrosion initiation, and repair or replacement of beam is performed at the 40 years of age, time of failure then it costs –

It is better to replace damaged concrete at regular interval of time to avoid early failure of structure. Here, in the present study for designated life of 50 years if repair or replacement of corrosion affected concrete is performed after interval of 18 years i.e. at age of 18, 36 and 54 years by replacing 50%, 60% and & 75% of concrete then total replacement cost is

Pr = Pr (18) + Pr (36) + Pr (54);

Pr (18) is already estimated as 148572

For estimating Pr (36) initial construction cost is obtained by adding Pr (18) and value of 353000 at the age of 18 years

Pr (36) = $(353000*(1.05)^{18} + 148572) * 0.6\ (1.04)^{18}$ = 1213190

So, present value of Pr (36)= 209467/-

Pr (54) = $(353000*(1.05)^{36}+148572*(1.05)^{18}+209467) * 0.75\ (1.04)^{18}$ = 3967867/-

So, present value of Pr (45)= 441610

Therefore, Pr = 148572+ 209467+ 441610 = 799649

In general, inspection is performed for detecting corrosion of rebars and formation of cracks, and thus requires modern non- destructive techniques (NDT), Inspection cost for first year can be considered as a fraction of initial construction cost i.e. 0.07 of construction cost (Frangopol et al.) [2], when no damage is detected.

Therefore, inspection cost for first year is

0.07 * 353000=24710

Further inspection costs for future years can be calculated using

$$Pi = Pin\ (1+r)^{D} \quad (2)$$

Pi = inspection cost for whole life of the structure i.e. designated life of structure.

Pin = inspection cost for first year of the life of structure = 24710.

D = designated life of structure = 50 years

S0, Pi = 283360

Preventive maintenance and repair cost Pm can be evaluated according to the frequency of inspection. According to Frangopol et al. (2011) [4]

$$C_{main,t} = C_{main} \times t; \quad (3)$$

Where Cmain = cost of preventive maintenance at year one; and t= age of concrete in years. For the present study if preventive maintenance is scheduled at the age of 15, 30 and 45 years so total cost for maintenance is

Pm = $C_{main,15}/(1+r)^{15} + C_{main,30}/(1+r)^{30} + C_{main,45}/(1+r)^{45}$ Considering Cmain as 0.05 fraction of initial construction cost = 17650

Pm = 127349+122514+88397 = 338260

Hence total life cycle cost for the beam is estimated as

Total cost = 353000 + 799649 + 283360+ 338260 = 17,74,269.

III. Conclusions & Discussion

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.

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