"Life cycle cost and extending service life of Structures"

By Hemant Vadalkar

1. Introduction :

Most of our civil engineering projects are planned and sanctioned based on the initial cost of construction alone. Different design alternatives and corresponding cost estimates are worked out by the planners and design team. Generally, the option having low initial cost of construction is selected by the owner. This may not necessarily be the best and economical option if the life cycle cost is considered.

2. Life cycle cost analysis (LCCA) technique is very useful tool to decide most economical option among various alternatives. LCCA is a process of evaluating the economic performance of a building over its entire life It considers total cost during the asset's economical life span. For civil engineering projects, it can be used to select the best alternative. The total life cycle cost consists of cost of design and planning, initial cost of construction, cost of operation, replacement cost of some components, cost of maintenance, cost of repairs or upgrades during the service life and cost of disposal. It can be applied to Roads, bridges, infrastructure projects, buildings or any civil engineering structure. Therefore, life cycle cost analysis must be considered to select the most appropriate and economical option at the planning stage itself. **Life-Cycle Cost Analysis (LCCA)** can be described as "An economic evaluation method for determining the most cost- effective option out of competing alternative."

Ample technical literature is available on the subject. Figure 1 and Fig 2 indicates the cost components in life cycle cost analysis.

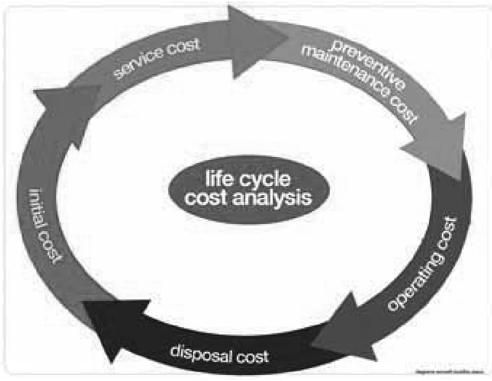

Fig. 1: Life cycle cost components

LCCA is based upon the assumptions that multiple building design options can meet programmatic needs and achieve acceptable performance, and that these options have differing initial costs, operating costs, maintenance costs, and possibly different life cycles. For a given design, LCCA estimates the total cost of the resulting building, from initial construction through operation and maintenance, for some portion of the life of the building (generally referred to as the LCCA "study life"). By comparing the life cycle costs of various design configurations, LCCA can explore trade-offs between low initial costs and long-term cost savings, identify the most cost-effective system for a given use, and determine how long it will take for a specific system to "pay back" its incremental cost. Because creating an exhaustive life cycle cost estimate for every potential design element of a building would not be practical, the Guidelines for LCCA focus on features and systems most likely to impact long-term costs.

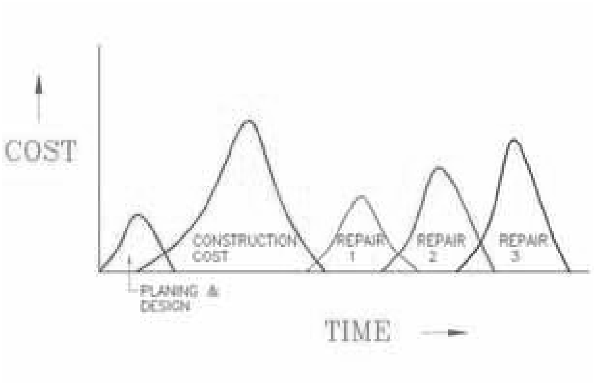

Fig. 2 : Costs to be added to get the life cycle cost.

Figure 3 shows saving potentioal in life cylce cost if the projects are scientifically planned and executed. It also shows change potential with time during the life of the asset.

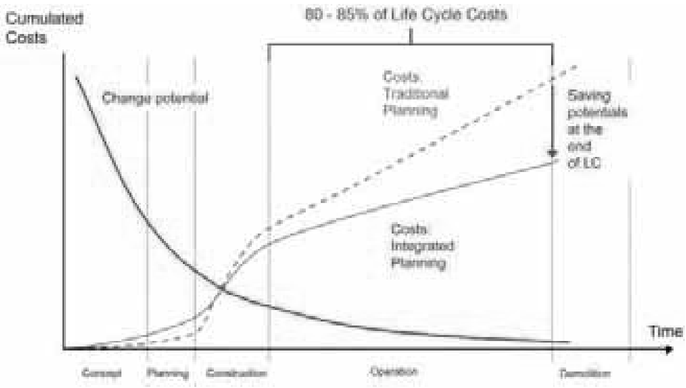

Fig .3 : Cost v/s time

The value of money today and money that will be spent in the future are not equal.

Project costs that occur at different points in the life of a building cannot be compared directly due to the varying time value of money. They must be discounted back to their present value through the appropriate equations. The discount rate is defined in terms of opportunity cost.

3. Basic terms used in the life cycle cost calculations

3.1 Discount rate

In order to be able to add and compare cash flows that are incurred at different times during the life cycle of a project, they have to be made time-equivalent. To make cash flows time-equivalent, the LCC method converts them to present values by discounting them to a common point in time, usually the base date. The interest rate used for discounting is a rate that reflects an investor's opportunity cost of money over time, meaning that an investor wants to achieve a return at least as high as that of her next best investment. Hence, the discount rate represents the investor's minimum acceptable rate of return.

To factor in the inflation effect, real discount rate can be worked out based on the nominal rate and inflation rate by the following formula

Real discount = {(1+nominal) /(1+inflation)} - 1

Thus, if the nominal rate is 10% and inflation rate is 4%, real discount rate will be

Real discount = (1+0.1)/(1+0.04) -1 = 0.0576 i.e. 5.76%

The basic discount equation is given as

PV = Fn /(1+D) ^n

Where PV = Present value

Fn = Future value at n year

D = Discount rate

n= number of years in future

Life-cycle cost analysis (LCCA) is a method for assessing the total cost of facility ownership. It takes into account all costs of acquiring, owning, and disposing of a building or building system. LCCA is especially useful when project alternatives that fulfill 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. For example, LCCA will help determine whether the incorporation of a high-performance HVAC or glazing system, which may increase initial cost but result in dramatically reduced operating and maintenance costs, is cost-effective or not

***3.2 Length of study period**:* The study period begins with the base date, the date to which all cash flows are discounted. The study period includes any planning/construction/implementation period and the service or occupancy period. **The study period has to be the same for all alternatives considered.**

3.3 Net present Value (**NPV**) can be calculated based on the equation

NPV = Initial cost + Sum (fn *Yn)
fn is present value factor = 1/ (1+d)^n

n is year of expenditure
Yn is expenditure in year n
d is the discount rate

3.4 Life cycle cost (LCC) : Basic equation of life cycle cost is

LCC = C1+ C2 -CR

Where

LCC : Life cycle cost of an asset

C1 = is the initial cost (design + construction cost) at year zero.

C2 = Present value (PV) of all recurring cost like running cost, repair cost, maintenance cost, component replacement cost, upgrade cost, interest on borrowed money etc

CR = Present value (PV) of the residual cost at the end of study life (Salvage value- demolition cost).

Future cost of an item can be calculated if present cost and escalation rate is known by the equation

$C_n = C_0 * (1 + e)^n$
Where C_n = future cost after n years
C_0 = present cost
e= escalation
n= number of years

3.5 Payback Calculation

For evaluating the cost-effectiveness of LCCA alter-natives, we can check their "payback" against the base case. The payback term is the time it takes an option to have the same life cycle cost as the base case.

4.0 Examples for Life cycle cost comparison

Consider two examples one for pavement and other for building.

Example 1 : Lifecycle cost comparison of different type of pavements

Consider an example of alternative pavement options with varying initial cost and life cycle cost. A flexible (bituminous) pavement has less initial cost say Rs. 1500/sq.m compared to higher cost for rigid (concrete) pavement say Rs2200/sqm.

One more alternative of ultra thin white topping over the bituminous road has been considered which has reduced maintenance cost.

From the figure 4 it can be seen that payback period is at the intersection of both lines. Life cycle cost of pavement consists of initial cost, maintenance and repair cost, resurfacing cost, user cost etc. for a study period of 30 years. The life cycle cost of rigid pavement is lower than flexible pavement.

Fig. 4 : Life cycle cost for three pavement alternatives for 30 years

Performance of the pavement starts degrading with time. One has to see that the performance should be above the prescribed minimum acceptable level. After some time, rehabilitation is required to upgrade the performance. This is a cyclic process which continues during the life time. This can be seen from figure 5.

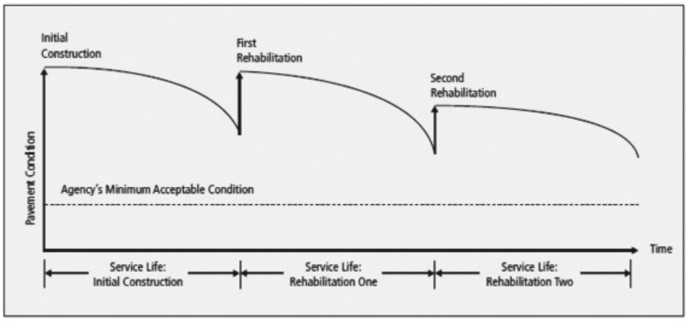

Fig.5: Performance v/s time for any one design alternative

Example 2 : Consider a building example for life cycle cost calculations.

Consider initial cost of construction is Rs. 3000/- per sq. ft at present date in 2018. Approximate cost break up is as given in Fig 7 below.

Real Discount rate is assumed as 6% . Study period considered is 60 years.

Total life cycle cost is worked out for three alternatives.

Case1 : Ordinary construction by saving on design, material and workmanship cost and cutting corners in quality of construction. Initial cost of construction reduced to Rs.2500 per sq. ft. But cost of repairs is very heavy during subsequent years.

In one case the building is not at all repaired by the occupants after construction. The building deteriorated and finally collapsed at the age of 25 years.

Case 2 : Building constructed with proper design, good material and quality control. Cost of construction is Rs.3000/ sq. ft. Subsequent repair cost is relatively less in subsequent years.

Case 3 : Extremely good design. Durability parameters introduced in design and construction stage. Corrosion inhibitor used in concrete to protect the steel, anti-carbonation paint used to coat concrete surface. Increase in cost due to these materials is up to 5 %. Stainless steel rebars are provided in place of carbon steel which resulted in cost increase by around 15%. (Reinforcement item rate considered is Rs.75 per kg for carbon steel and Rs 150 per kg for SS). Overall cost increase is about 20% compared to Case2. Cost of repair will be minimum over the span of 60 years. Building is functional beyond 60 years and objective life span is 100 years.

Building performance v/s time can be plotted for all the three alternatives. This is shown in fig.6. Building cost distribution is indicated in Fig 7a and 7b as % of total cost. Figure 8 shows the typical life cycle cost distribution in a building.

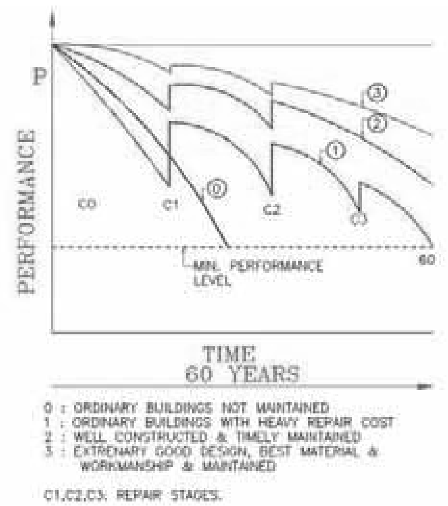

Fig. 6 : Performance of building v/s time for three alternatives

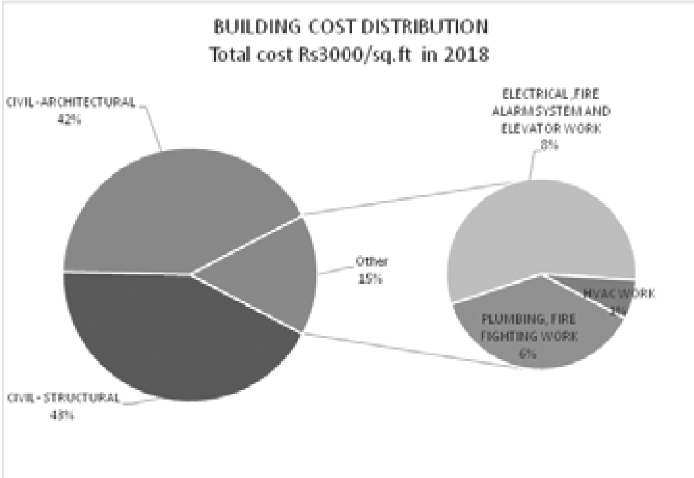

Fig.7a : Building cost distribution Structural – Architectural and other.

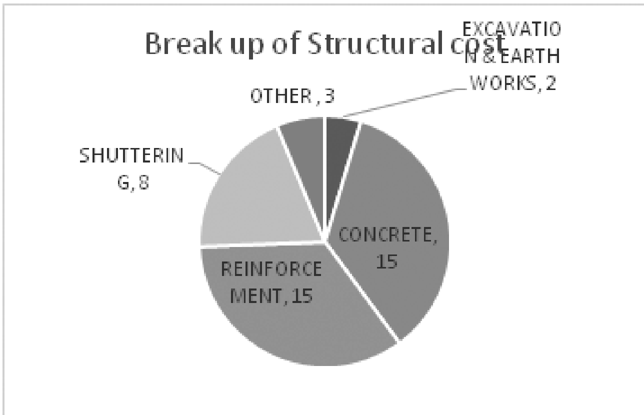

Fig. 7b : Cost break up for structural items.

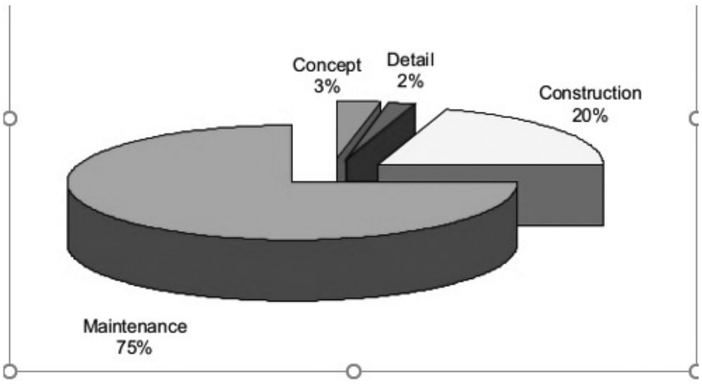

Fig. 8 : Distribution of life cycle costs for a building

Table 1 provides calculations of life cycle cost for three alternatives. It can be seen from the table 1 that life cycle cost saving of 22% can be achieved for Case2 and cost saving of 27% is achieved for Case3 compared to a base case

Life cycle cost calculations for three cases of buildings

Assumed discount rate d = 6.00%
Study period years = 60
Reduction factor = 1/(1+d)^n
Present value (PV) = Reduction factor * Cost incurred

			Case 1 building		Case 2 Building		Case3 Building	
Description	Year	Reduction factor	Cost incurred	PV of cost	Cost incurred	PV of cost	Cost incurred	PV of cost
Initial cost Rs/sqft	0	1.000	2500	2500	3000	3000	3600	3,600
	5	0.747		0		0		0
Repair	10	0.558	2000	1117	1000	558	500	279
	15	0.417		0		0		0
Repair	20	0.312	3000	935	1500	468	750	234
	25	0.233		0		0		0
Repair	30	0.174	4000	696	2000	348	1000	174
	35	0.130		0		0		0
Repair	40	0.097	5000	486	2500	243	1250	122
	45	0.073		0		0		0
Repair	50	0.054	6000	326	3000	163	1500	81
	55	0.041		0		0		0
Repair	60	0.030	7000	212	3500	106	1750	53
Total NPV Life cycle cost				6273		4886		4543
Life cycle Cost saving				Base		22.10%		27.57%

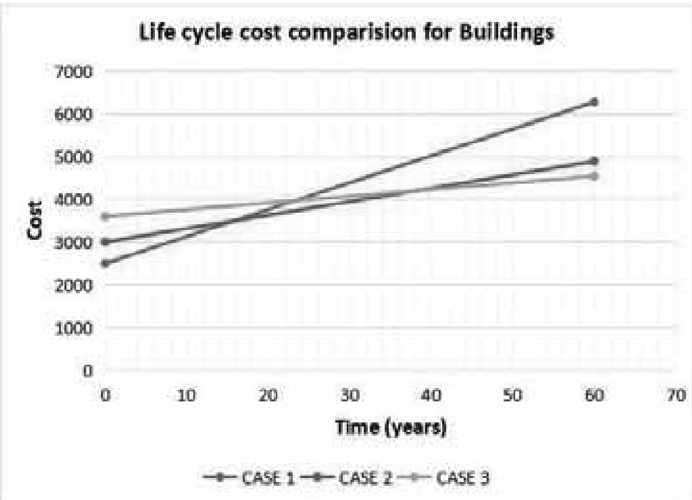

Fig. 9 Life cycle cost comparison for building

Though, the initial cost of construction for building in case3 is higher, the life cycle cost is lower for that building. This is evident from table 1 and Figure 9.

5.0 Predicting Service life of a building :

For predicting residual service life of a building, some mathematical models are available. **ACI-365** provides guidance on service life prediction based on various measured parameters. Different corrosion models are used to predict the residual life of structure which accounts for chloride concentration at concrete surface, chloride diffusion coefficient of concrete, Concrete cover thickness.

Durability & Service Life is defined in ACI 365

5.1 Durability is the ability of a *structure or its components* to maintain serviceability in a given environment over a specified time.

5.2 Service life is the period of time after installation during which all the properties exceed the minimum acceptable values when routinely maintained.

5.3 Technical service life is the time in service until a defined unacceptable state is reached, such as spalling of concrete, safety level below acceptable, or failure of elements.

5.4 Functional service life is the time in service until the structure no longer fulfils the functional requirements or becomes obsolete due to change in functional requirements, such as the needs for increased clearance, higher axle and wheel loads, or road widening.

5.5 Economic service life is the time in service until replacement of the structure (or part of it) is economically more advantageous than keeping it in service.

5.6 Some software tools are available to predict service life of structure. **Life-365** software developed by consortium of concrete corrosion inhibitor association, National ready mix concrete association, Slag cement association and Silica fume association USA is being used by various researchers to study the corrosion model based on various parameters.

6.0 Factors affecting Service life of a building –

Various factors right from design, materials, workmanship and maintenance practices will affect the service life of a structure.

Design considerations : Design parameters for strength, serviceability and durability

Material specifications : Appropriate selection of material based on type of structure, environmental conditions, intended design service life

Workmanship : Implementation of good engineering practices in all items of work and strict adherence to the specifications

Regular and timely maintenance : Constant monitoring, inspections, preventive maintenance, timely repair as and when required.

Rules of 5's is very interesting to understand the importance of durability in the initial stages which states -

Rule of 5's: "$1 spent on durability in the design phase is equivalent to $5 in the execution phase, and to $25 in the service phase"
(DeSitter, 1980s)

A common question asked by people and which is bothering all civil engineers is "Why our present day structures constructed with latest technology and modern materials has a short life span compared to structures built by our ancestors which are standing for centuries?"
Every civil engineer has to think over this valid question and try to find answers. I could think about some of the reasons for this.

Some of the reasons for reduced service life of modern day structures could be –

1. Higher stress level due to competitive designs
2. Deficiencies in design, material specifications and quality control at site.
3. L1 criteria (minimum initial cost design)
4. Neglect of timely maintenance of the structure

5. Corrosion of steel - Single major factor affecting life of structure

7.0 Corrosion of steel : Corrosion of steel is a natural process which cannot be stopped but can be delayed. If we can increase initiation time for corrosion, we can increase service life. Process of corrosion is well documented and known. When the PH of concrete cover is more than 12, it protects the steel. Due to carbonation of cover concrete, PH drops below 7 which means, it cannot protect the steel any more. Chloride ion ingress and diffusion in concrete initiates corrosion of steel which is not protected by carbonated cover concrete. As the volume of corrosion products is much higher than original volume of steel, it exerts pressure on concrete cover. This results in cracking and spalling of cover concrete. If not attended in time, this may lead to collapse of structure. Popular corrosion curve is as shown in Fig10.

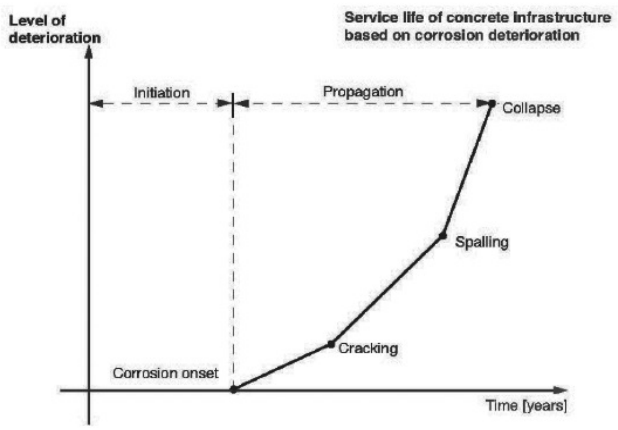

Fig. 10 : Corrosion deterioration of concrete structures with time

Once, the corrosion starts, its like a cancer to the structure. We should aim at delaying the initiation time for corrosion.

Some of the tenders specify design life of 100 years. How to obtain 100 year service life of our future structures and how to maintain our old structures is a big question ???? We need to understand the degradation mechanism. Correct use of materials, composition, production, protection, repair and restoration is the key to achieve this goal.

7.1 Corrosion protection techniques –

There are certain techniques that can be employed to mitigate the corrosion problem. Based on the project requirements, following options can be considered.

1.Use of TMT or CRS Steels
2.Use of Stainless steels for better corrosion resistance
3.Various Protective Coatings can be used like
Organic Coatings
Fusion Bond Epoxy coating
Galvanization
4.Admixtures in Concrete to enhance durability
5.Migrating Inhibitors can be used in concrete mixes
6.Cathodic Protection to steel

Out of the available options, use of stainless steel rebars seems to be a much promising option for extending life span of RCC structures with affordable incremental cost. Some of the Indian manufacturers have started producing SS bars. Bureau of Indian Standard had come out with code Stainless Steel Rebars IS16651:2017

Rate of corrosion for different type of steel can be seen from Table 2

Table 2 : Corrosion rate for different material

Corrosion Rate (in micro meter / year)

Period	10 Years		
Metal	RURAL (µm / yr)	MARINE (µm / yr)	SEVERE MARINE (µm / yr)
Mild Steel	4.32	37.1	219
430	< 0.0025	0.0406	0.1727
304	< 0.0025	0.0076	0.0406
316	< 0.0025	< 0.0025	0.0279
Stainless Steel Grade G (Ferritic)	< 0.0025	0.104	1.722

Pitting & Crevice corrosion Resistance Equivalent Number (PREN).

Some of the Govt. Organizations like Railways have started using stainless steel in their structures by taking our circulars in that regard.

CRS100 Ferritic Stainless Steel cost comparison in 2017 is given by one of the manufacturers in India

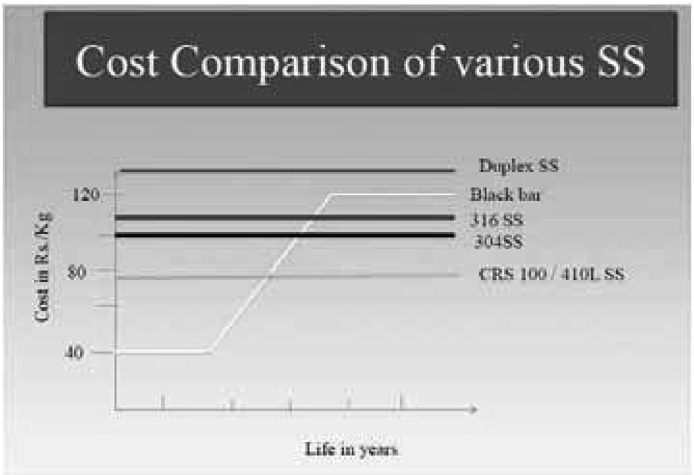

Fig.11 Cost comparison of various Stainless Steel options

Fig. 12 Ferritic Stainless Steel reinforcement bars

8.0 How can we increase service life of our RCC Structures ?

For healthy and durable concrete structures, we need to implement durability parameters in the project design process. Parameters listed below if implemented can enhance service life of RCC structures –

1.Minimum cement content for strength and durability

2.Use of Pozzolans (Fly ash, GGBS, Silica fume..)

3.Minimum w/c ratio by using suitable admixtures

4.Adopt best practices in concrete production, transportation, placement, compaction, protection and Curing

5.Reduced concrete permeability is the key : Specify desired level of permeability and check concrete by conducting permeability tests. Water permeability / Rapid Chloride Permeability Test (RCPT).

6.Concrete cover : correct concrete cover can be provided by use of best quality Factory made concrete cover blocks.

7.Limiting chloride and sulphate content in concrete

8.Limiting crack width to less than 0.1mm

9.Use of corrosion inhibitor in concrete.

10.Use of corrosion resistant steel like galvanized / stainless steel reinforcement

11.Protective coating on concrete surface (Anti-carbonation paints) for blocking entry of aggressive elements into concrete.

12.Periodic inspection , monitoring and timely repair

9.0 Conclusion :

1.Life cycle cost analysis must be carried out for choosing the best alternative. Minimum life cycle cost will be the best option though the initial cost is more.

2.Durability parameters must be implemented from planning to execution for achieving longer service life of our assets. This will help in achieving sustainable construction and minimum life cycle cost.

10.0 References :

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SAD DEMISE

We had lost eminent civil engineers during the last quarter. ISSE team pays tribute to the departed soul.

1. D. V. Karandikar (22 Sept 2018) – Senior Geotechnical Consultant, Mumbai. He was known for his deep knowledge on the subject and provided solutions to complex geotechnical problems.
2. Prof. D. S. Joshi (24 Nov 2018) – Senior Structural Consultant and ISSE President. His book on Design of Reinforced concrete Structures for Earthquake resistance will guide civil engineers.
3. M. D. Tambekar (15 Dec 2018) – Ex. Chairman of IEI Maharashtra centre and arbitrator in civil engineering projects. He chaired many sessions in the technical seminars and it was pleasure listening to his experience.