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Life Cycle Cost Assessment and Life Cycle Analysis of Roller Compacted Concrete Pavement

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A B S T R A C T

The social and economic conditions of every country in the globe is significantly influenced by its transportation infrastructure. The choice of pavement maintenance should be made based on a sustainable idea that satisfies the requirements for sustainability and long-term performance. To assess the financial and environmental effects of construction materials and projects, two complimentary approaches are used: life cycle cost assessment (LCCA) and life cycle analysis (LCA). This abstract concentrates on its use with Roller-Compacted Concrete (RCC), a strong and environmentally friendly building material that is becoming more popular in a variety of infrastructure applications and the application of LCCA and LCA to Roller-Compacted Concrete involves a detailed assessment of the material's production, transportation, installation, and maintenance phases using Net Present Value method and Cradle to grave approach. Stakeholders can take informed decisions that strike a balance between environmental duties and economic concerns by measuring the economic costs and environmental impacts of RCC in comparison to Conventional concrete or other construction alternatives. In conclusion, a thorough framework for assessing the viability and sustainability of roller-compacted concrete in construction projects is provided by the combination of life cycle cost assessment and life cycle analysis. Through the use of an integrated strategy, more resource and environment-conscious infrastructure solutions can be created.

Keywords: Life Cycle Cost Assessment

Life Cycle Analysis

Roller Compacted Concrete Pavement

Cost-Benefit analysis

Maintenance Benefits

Vehicle operation Costs

1. Main text

Any country's economic and cultural development depends heavily on road projects. When making significant financial investments in road projects, taking into account life cycle cost analysis and greenhouse gas estimation utilizing life cycle approach, the choice of pavement is especially crucial. Today, it's crucial to choose a transportation project that will reduce greenhouse gas emissions, which are what causes the global warming effect, in addition to making the appropriate decision when choosing that project. The paradigm in the building sector is changing in favour of effective, efficient methods that take into account the economy and the environment. In this context, life cycle cost assessment (LCCA) and life cycle analysis (LCA) have become crucial instruments for assessing the sustainability and ecological impact of building materials and projects. Roller-Compacted Concrete (RCC) is one such material that has attracted a lot of interest, notably in applications for pavement. This introduction presents an overview of LCCA and LCA as they are used to RCC pavements, emphasizing their importance in assisting in the formation of well-informed decisions about the development of infrastructure.

1.1) Comparison of Roller Compacted Concrete Pavement & Conventional Pavement:

Roller-compacted concrete has the same basic ingredient as conventional concrete: cement, water, and aggregates, such as gravel or crushed stone. But unlike conventional concrete, it's a drier mix—stiff enough to be compacted by vibratory rollers. Typically, RCC is constructed without joints. It needs neither forms nor finishing, nor does it contain dowels or steel reinforcing. Roller-compacted concrete, or RCC, takes its name from the construction method used to build it. It's placed with conventional or high-density asphalt paving equipment then compacted with rollers. roller-compacted concrete simple, fast, and economical. These qualities have taken roller-compacted concrete from specialized applications to mainstream pavement. Today, RCC is used for any type of industrial or heavy-duty pavement. The reason is simple. RCC has the strength and performance of conventional concrete with the economy and simplicity of asphalt. Coupled with long service life and minimal maintenance, RCC's low initial cost adds up to economy and value. Roller-compacted concrete is also known as Rolled concrete is a special kind of concrete blend that has almost the same ingredients as conventional concrete but in different ratios, and increasingly with partial substitution of fly ash for Portland cement. RCC is more durable than Conventional pavement and requires less maintenance Conventional pavement is less expensive than RCC, but requires more maintenance in the long run. RCC is better suited for heavy traffic and industrial areas, while traditional pavements are better for residential areas.

Cost-Benefit analysis:

RCC has a lower initial cost than traditional pavement, but may require more maintenance over time. RCC is also more durable and can withstand heavier loads, reducing the need for frequent repairs and replacement. Traditional pavement may be more suitable for areas with high traffic volume and frequent freeze-thaw cycles, as it is more flexible and less prone to cracking.

Durability Benefits:

Roller compacted concrete (RCC) is a highly durable pavement solution that is ideal for heavy-duty applications. It is made of a mix of aggregates, cement, and, and is compacted with a roller to create a strong and dense surface water. RCC has a compressive strength of up to 10,000 psi, making it much stronger than traditional pavement. RCC as a lower water-cement ratio than traditional pavement, which means it is less susceptible to cracking and other forms of damage.

Maintenance Benefits:

RCC requires less maintenance than traditional pavement, which can save time and money in the long run. It is also more resistant to damage from freeze-thaw cycles and other weather-related factors. RCC requires less sealing and crack filling than traditional pavement, which can save time and money on maintenance costs. RCC is less susceptible to damage from freeze-thaw cycles and other weather-related factors, which means it requires less repair work over time.

Climatic Conditions:

RCC can be used in a variety of climates, but there are some considerations to keep in mind when choosing this pavement solution. In colder climates, RCC may require additional additives to prevent cracking and damage from freeze-thaw cycles. In hotter climates, RCC may require additional curing time to prevent cracking and other forms of damage.

1.2) Life Cycle Cost Assessment:

A construction project's total cost over its entire life, including initial construction, operation, maintenance, and final disposal or decommissioning, is evaluated using the life-cycle cost analysis (LCCA). Various cost factors, including the initial investment, maintenance and repair expenses, energy use, and possible revenue streams, are analysed. Decision-makers can use LCCA to select the alternative that will be the most economical. With regard to RCC, LCCA aids in determining whether its initial construction cost, which could be greater than that of conventional concrete, is justified by lower long-term maintenance and repair costs, as well as possible energy savings and increased service life. The goal of LCCA is to identify the most cost-effective options among the different alternatives.

Initial construction operation:

Initial construction costs in highway construction relate to the expenditures incurred during the planning, design, construction, or expansion and improvement of a new highway. These expenses cover all of the tasks and materials needed to accomplish the highway building project from start to finish. To guarantee that the project stays within budget and is successfully finished, accurate estimation and management of the initial construction expenses are crucial. The following are the main elements of the upfront construction costs for highway building:

Design and Engineering: Costs associated with the creation of precise plans and specifications as well as the planning, design, and engineering costs for the highway project. fees charged by design specialists like civil engineers and planners of transportation.

Land acquisition: The costs involved in procuring the property required for the highway's development, which may include paying for properties, easements, or right-of-way access.

Materials and supplies: Expenses for supplies used in construction, such as paint, asphalt, concrete, aggregates, steel, signs, and lights.

Labour Costs:

payments made to those who helped build the route, including laborers, contractors, and subcontractors. Wages, benefits, and overtime charges can all be included in labour costs.

Equipment and Machinery:

Costs for renting, buying, and maintaining the machinery and equipment required to build the highway, including bulldozers, pavers, graders, and compactors.

Utilities and temporary services:

The cost of providing temporary utilities during construction, such as electricity, water, and sewerage. Traffic control, site security, and portable restrooms are a few examples of temporary services.

Project management and Supervision:

Project management and supervision expenses, such as project managers' and site supervisors' wages and construction management services.

Maintenance Costs:

The expenses incurred to keep the pavement in excellent condition and increase its service life after the initial construction are referred to as maintenance costs in the building of roller-compacted concrete (RCC) pavement. Although RCC pavement is a long-lasting and economical substitute for conventional asphalt or concrete pavement, it still needs regular maintenance to maintain its functioning and safety. The following are some significant maintenance expenses for the creation of roller-compacted concrete pavement:

Regular Inspection and Evaluation:

To spot early indications of wear or damage, routine inspections are crucial. The state of the pavement is evaluated by maintenance staff members who search for cracks, potholes, surface degradation, and drainage problems.

Sweeping and Cleaning:

For both safety and aesthetics, keeping the pavement clean is essential. Sweeping eliminates accumulated trash, leaves, and other things that may reduce surface friction.

Repairing joints and sealing cracks:

Like any concrete pavement, RCC pavement may eventually develop cracks. Rapid crack sealing and restoration stop water intrusion and additional damage.

Surface alterations:

Repairs are required when portions of the pavement experience damage like potholes or spalling. Damaged areas may need to be patched, resurfaced, or replaced.

Surface treatments and seal coatings:

The longevity of the RCC pavement can be increased by applying seal coatings or other surface treatments that shield it from the elements.

Keeping up with drainage:

For RCC pavement to remain in good condition, proper drainage is essential. Drains may need to be cleaned, culverts may need to be repaired, and the pavement may need to have its ability to shed water properly checked.

Vehicle operation Costs:

The expenditures related to owning and operating a motor vehicle are collectively referred to as vehicle operation costs, operating expenses, or cost of ownership. These expenses include recurring charges that car owners must take into account, in addition to the initial purchase price or monthly lease payments. Budgeting and wise vehicle ownership decisions depend on having a clear understanding of these expenses. Here are some significant elements of vehicle operating expenses:

Fuel prices:

The cost of fuel makes up a sizable amount of the cost of operating a car. The cost of fuel is determined by the fuel economy (in miles per gallon or kilometres per litre) of the vehicle and the local fuel price at the time. In general, the cost of fuel is higher for larger, less fuel-efficient automobiles.

Upkeep and Repairs:

To keep a car running smoothly and avoid future expensive repairs, routine maintenance is crucial. Oil changes, tire rotations, brake pad replacements, and other standard repairs are all included in maintenance fees. Unexpected repairs for problems like gearbox failures or engine issues can be expensive and unpredictable.

Insurance:

For most drivers, car insurance is a necessary expense. The type of coverage you choose, where you live, and the make and model of the car all affect insurance rates. Generally speaking, comprehensive coverage is more expensive than liability-only coverage.

Depreciation:

Depreciation is the gradual decline in an object's value. It is frequently regarded as an invisible cost because there are no cash outlays involved, yet it has an impact on the car's resale value. In the first few years, the value of new autos often decreases quickly.

Finance Charges:

You will pay interest if you borrow money to finance your car. The interest rate, length of the loan, and cost of the car all go towards the total cost of financing. Monthly payments that are associated with leasing might be viewed as a cost of ownership.

Fees and Taxes:

Depending on where you live, you could have to pay sales tax, registration fees, and possibly other taxes or fees when you buy a car. These prices can differ greatly between different regions.

Tolls and Parking:

Parking taxes and tolls can mount up, particularly if you park a lot in cities or use toll highways or bridges to get to work every day.

Dependent Costs:

The price of commuting, parking permits, or specific equipment (like winter tires), which are tied to your driving habits and conditions, might also be included in the cost of ownership.

Life Cycle Analysis:

LCA is a thorough method for assessing how a material, process, or product will affect the environment over the course of its full life cycle. It entails evaluating a number of phases, such as the extraction of raw materials, manufacture, transportation, consumption, and end-of-life disposal. Resource depletion, greenhouse gas emissions, air and water pollution, and energy usage are all aspects taken into account by LCA. When used on RCC, LCA can shed light on the environmental advantages and disadvantages of employing this substance as opposed to traditional concrete or other substitutes. It aids in locating locations where RCC usage and production can be streamlined to have a smaller negative environmental impact.

Tables

Initial Construction Cost:

Sl. No:	**ITEM**	**TOTAL QUANTITY(m^3)**	**UNIT RATE/(m^3) in $**	**UNIT RATE IN Rs.**	**TOTAL COST**	**DENSITY OF OVERALL LAYER (kg/m^3)**
1	GSB	1050	6.83	₹ 564.02	₹ 5,92,222.47	1602
2	DLC	1050	7.51	₹ 620.18	₹ 6,51,184.59	2697.693
3	RCC	1890	12.38	₹ 1,022.34	₹ 19,32,223.36	2431
				TOTAL COST	₹ 31,75,630.42	

Maintenance Cost:

Let's examine maintenance costs, which are a crucial part of RCC pavements. Despite the fact that RCC pavements are famed for their longevity, maintenance is still necessary. The regular maintenance is one of the key elements. Despite the durability of RCC pavements, routine inspections and upkeep are necessary to solve small concerns before they develop into more serious ones. This covers procedures including surface treatments, joint repairs, and crack sealing. Seasonal upkeep might be important, particularly in places with extreme weather. Costs associated with winter maintenance, such as snow removal and ice control, may increase. Similar to this, precautions may be required in hot climates to stop heat-related harm. Furthermore, drainage is essential for the durability of RCC pavement. In order to prevent water from penetrating the pavement structure and causing erosion and degradation, proper drainage systems must be maintained. Although RCC pavements are sturdy, maintenance is still required. To keep maintenance expenses under control and guarantee the pavement's long-term performance, routine inspections, preventative maintenance, fixing damage, and managing drainage and joints are all essential. The purpose of maintenance expenses is to protect the infrastructure's dependability and safety, not only to spend money.

Year	Activity	Unit price in $	Unit price rupees	Quantity	Total area (m2)	Total cost
0	Initial Construction Cost					
3	Routine Maintenance	0.28	23.1224	50%	3500	₹ 80,928.40
6	Routine Maintenance	0.28	23.1224	50%	3500	₹ 80,928.40
9	Routine Maintenance	0.28	23.1224	50%	3500	₹ 80,928.40
10	Periodic Maintenance	8.58	708.5364	15%	1050	₹ 7,43,963.22
12	Routine Maintenance	0.28	23.1224	50%	3500	₹ 80,928.40
15	Routine Maintenance	0.28	23.1224	50%	3500	₹ 80,928.40
18	Routine Maintenance	0.28	23.1224	50%	3500	₹ 80,928.40
20	Rehabilitation	8.58	708.5364	10%	700	₹ 4,95,975.48
21	Routine Maintenance	0.28	23.1224	50%	3500	₹ 80,928.40
24	Routine Maintenance	0.28	23.1224	50%	3500	₹ 80,928.40
27	Routine Maintenance	0.28	23.1224	50%	3500	₹ 80,928.40
30	Periodic Maintenance	8.58	708.5364	15%	1050	₹ 7,43,963.22

Activity	Activity period	Quantity	Damage Type and Repair Method	unit price($/m2)
Routine Maintenance	once in 3years	50	Crack Filling (Bitumen or Epoxy Resinous) Non-structural Iow and medium cracks Partial damages in joints	0.28
Periodic Maintenance	once in 10years	15	Local Repair with Fresh Concrete Blowups in joints Pumping effect in joints Pothole Polished aggregate	8.58

			Popouts Scaling Spalling Longitudinal and transverse cracks greater than IO mm Corner cracks	
Rehabilitation	once in 20years	10	Full-depth New Surface Coating Sitting or separating blocks Durability (D) cracks Crocodile cracks Horizontal or vertical erosion	8.58

sl. No	Year	Stage	Maintenance Cost in Rs.	In US Dollars	Inflation cost in Rs. Rate of 8%			Discounted Cost in Rs.@12 %	Discounted cost in US Dollars		Inflation cost in Rs.@ rate of 8%	Discounted Cost in Rs.@ 12%
1	Initial Construction Cost							3175630.42	264307719.9			
					Overlay	Strengthening						
2	1st Year		50000	4161500	54000	803480.2776				10696	11551.68	10314
3	2nd Year		55000	4577650	58320	867758.6998				10956.5	11833.02	10565.19643
4	3rd Year		80928.4	6735670.732	62985.6	937179.3958				10961.5	11838.42	10570.01786
5	4th Year		50000	4161500	68024.45	1012153.747				11596.5	12524.22	11182.33929
6	5th Year	1st Overlay	50000	4161500	73466.4	1093126.047	73466.4	41686.80835	3469593.059	10696	11551.68	10314
7	6th Year		80928.4	6735670.732	79343.72	1180576.131				10696	11551.68	10314
8	7th Year		50000	4161500	85691.21	1275022.222				10956.5	11833.02	10565.19643
9	8th Year		50000	4161500	92546.51	1377023.999				10961.5	11838.42	10570.01786
10	9th Year		80928.4	6735670.732	99950.23	1487185.919				11596.5	12524.22	11182.33929
11	10th Year	1st Strengthening	743963.22	61920058.8	107946.2	1606160.793	1606161	517140.789	43041627.87	10696	11551.68	10314
12	11th Year		50000	4161500	116581.9	1734653.656				10696	11551.68	10314
13	12th Year		80928.4	6735670.732	125908.5	1873425.949				10956.5	11833.02	10565.19643
14	13th Year		50000	4161500	135981.2	2023300.025				10961.5	11838.42	10570.01786

15	14th Year		50000	4161500	146859.7	2185164.026				11596.5	12524.22	11182.33929
16	15th Year	2nd overlay	80928.4	6735670.732	158608.5	2359977.149	158608.5	28977.17995	2411770.688	10696	11551.68	10314
17	16th Year		50000	4161500	171297.1	2548775.32				10696	11551.68	10314
18	17th Year		50000	4161500	185000.9	2752677.346				10956.5	11833.02	10565.19643
19	18th Year		80928.4	6735670.732	199801	2972891.534				10961.5	11838.42	10570.01786
20	19th Year		50000	4161500	215785.1	3210722.857				11596.5	12524.22	11182.33929
21	20th Year	2nd strengthening	495975.48	41280039.2	233047.9	3467580.685	3467581	359472.8723	29918927.16	10696	11551.68	10314
							Total NPV	41.2290807	343149638.6			2.117822143

2. Methodology

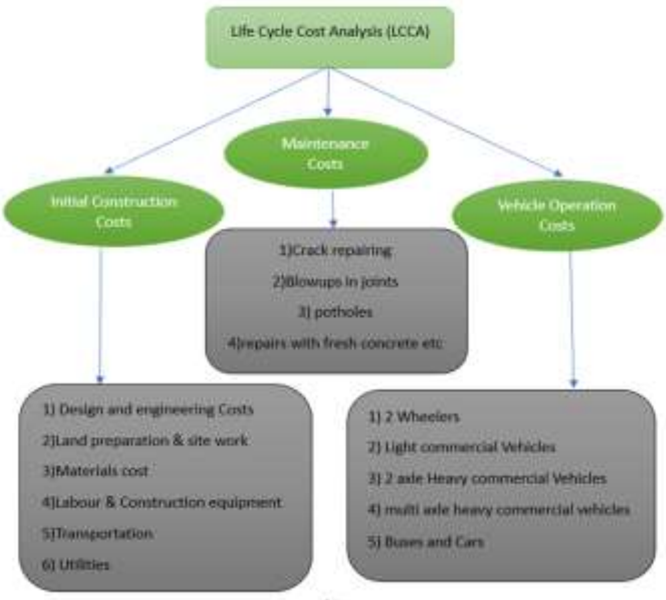
Life Cycle Cost Analysis (LCCA):

A Life Cycle Cost Analysis (LCCA) is a methodical procedure for assessing the total expenses connected with a project, a system, or a product over the course of their full life cycle. This covers expenses incurred for the purposes of planning, designing, building, operating, maintaining, and disposing. The following is a step-by-step procedure for carrying out an LCCA:

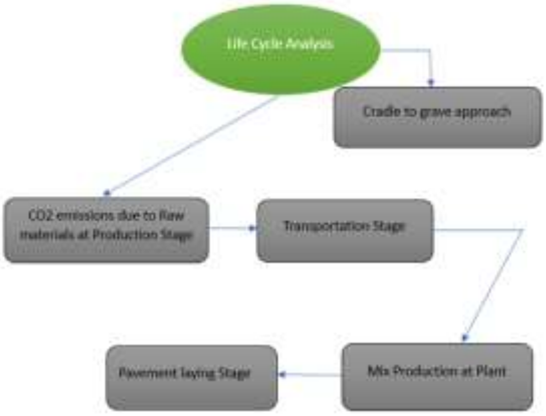
Defining the Scope and Objectives:

1) The boundaries of the system or project being considered, as well as the scope of your study, should be precisely defined.

2) Decide on the LCCA's goals, such as contrasting several solutions, pinpointing cost factors, or maximizing long-term cost-effectiveness.



Life Cycle Analysis (LCA):



Life cycle analysis (LCA), also referred to as life cycle assessment, is a methodical and thorough strategy used to evaluate the effects of a process, product, or service on the environment, society, and the economy throughout the course of its full life cycle. Making informed judgments about sustainability and resource management benefits from this analytical tool.

Phases of a Product's Life Cycle:

LCA considers several stages in a product's life cycle, typically including:

a. Raw material extraction and acquisition

b. Manufacturing and production

c. Transportation and distribution

d. Use and maintenance & End-of-life disposal or recycling

3. Design procedure

In the following section, the test procedure of RCC pavements is given for a typical data parameters like soil subgrade (CBR) in %, modulus of sub base reaction(k) and flexural strengths

Step1: Assume a trial thickness, h=190mm

Step2: Assume joint spacing, L=3.75m

Step3: Edge stress due to wheel load (σ)

$$\sigma=\frac{0\cdot803p}{h^2}\left(4\log(L/a)+0.66(A/L)-00.0034\right)$$

Where a = radius of the equivalent circular area in mm and is given by

$a=\sqrt{p/(\pi * p)}$

$a=\sqrt{(50*1000N)/(\pi*0.8mpa)}$

a=141.06mm

L= radius of relative stiffness, mm and is given by

$l=\sqrt{(Eh)^3/(12(1-\mu)^2)K}$

Where E=3*10000, h=190, μ=0.15 for CBR= 5% and K= 42

So, after putting all the parameters l=726.16mm

σ=4.198 mpa at h=190mm

σ> Flexural Strength (3.67mpa)

Edge stress> Flexural Strength(F)

Hence design is Unsafe. Assume another trial thickness of 230 mm and repeat steps 2-3.

Similarly, for h= 230mm:

$\sigma = 3.28 mpa < 3.67 mpa$

Here, Edge stress $<$ Flexural Strength (So Safe)

Step 4: Calculate warping stress at edge region,

$\sigma(te) = E\alpha tC/2$

$\sigma(te) = ((3*10000*10*10^{(-6)} *18.66)/2) *0.73$

C= (L/l) =0.73 (Bradbury graph)

$\sigma(te) = 2.05 mpa <$ Flexural Strength (So Safe)

C= Coefficient depending upon the ratio of length and Radius of relative stiffness

L= length of joint, 3750mm

As per IRC: SP: 62-2014[1] Table 4.1 Recommended Temperature Differentials for Concrete Slab is, t=18.66

Step 5: Calculation of total stress σ(total):

Total stress σ(total)=Edge load stressσ(e)+ Warping stresses σ(te)

$=3.28+2.05$

$=5.33 mpa$

Total Stresses $\sigma(total)=5.33 > 3.67 mpa$ (not safe)

Similarly, repeat this process again we got h= thickness= 270mm.

4. Conclusions

1) Conducting both a Life Cycle Analysis (LCA) and a Life Cycle Cost Analysis (LCCA) of roller-compacted concrete (RCC) provides valuable insights into the environmental and economic aspects of using RCC in construction projects.

2) LCCA allows for a thorough cost comparison between RCC and other construction materials or methods. It considers not only initial construction costs but also long-term costs over the life of the structure.

3) LCCA can reveal the maintenance and repair costs associated with RCC structures over time. This can help assess the durability and long-term cost-effectiveness of RCC compared to alternatives.

4) LCCA can identify strategies to reduce the overall lifecycle costs of RCC construction, such as selecting high-quality materials or implementing maintenance programs that extend the service life of RCC structures.

5) The results of LCCA can inform financial decision-making for project planners and stakeholders. It can help them make informed choices regarding the selection of construction materials and methods based on cost-effectiveness.

6) As we know that LCA and LCCA is existed for the conventional pavements but, we found the LCCA and LCA of roller compacted concrete pavements using net present value method

7) Since we got the Positive NPV which suggests that the project will yield positive returns, meaning that it will provide a rate of return greater than the discount rate used in the analysis. This is often seen as a favourable outcome for investors seeking to grow their wealth.

8) The cradle-to-grave approach provides a holistic and comprehensive view of a product or system's life cycle, encompassing all stages from raw material extraction to end-of-life disposal or recycling. This perspective allows for a thorough assessment of all potential environmental, social, and economic impacts.

9) In cradle to grave approach, we have done four stages such as raw material production stage, Transportation of raw material to construction site, mix production at plant and pavement laying stage out of which we got the huge carbon emissions at the initial stage.

10) We also found the inflation and discounted rates for the maintenance and vehicle operation costs of the existing data

11) Here we also found the design of the different layers of the roller compacted pavement using flexural strength and k value

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