Comparison of Sea Bridge and Under Water Tunnel using Life Cycle Cost Analysis (LCCA)

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Abstract- *Initial investment of money for a project plays a vital role in the success of any infrastructure project, higher the investment higher the risks and hence decision making in pre-investment phase is critical. The investment decision on an infrastructure project is complex and it should consider not only the initial service of the project that makes the public good but also its service required throughout its life span to make the investment available to the public. Investment decision should also consider the analysis of various alternate designs or methods to select a method which is more beneficial and efficient to complete the project successfully. Life Cycle Cost Analysis (LCCA) model is often used to compare two or more alternatives to decide which alternate is economical and beneficial to be chosen. LCCA is a tool which provides a detailed account of total costs in a project including every short –term costs and long term costs the project is associated with such as procurement of materials, construction, management, installation, operation, maintenance, repair, rehabilitation and replacement, demolition and landscaping of the same. Either banks of a waterbody can be connected by two alternatives, by bridge or by immersed tube tunnel. The ability of a project to provide service over time can be predicted by its maintenance. LCCA has proven to create savings in projects by helping the decision makers to identify the most beneficial and cost effective project between alternates. In this paper LCCA is done for Pamban bridge which is an existing sea bridge at Rameshwaram, Tamil Nadu with a proposal of construction of Immersed Tube Tunnel (ITT) as an alternate for the Pamban Sea Bridge.*

Keywords- LCCA, Bridge, Immersed Tube Tunnel, Short-term costs, Long-term costs.

I. INTRODUCTION

A bridge is constructed to carry roadway, railway etc. which is nothing but a manmade structure built specially to span physical obstacles present in the pathway which may be of waterbody, valley or a roadway to provide passage over the obstacle. A tunnel is a covered passage which is built to cut through mountains, dive deep into mines. Transportation tunnels are necessary to pass through natural or manmade obstacle such as mountain, underwater, across a congested city. An immersed tube tunnel is a kind of underwater tunnel which is of segments, pre-casted and floated to the place in which it should be sunken and then they are linked together. They are most commonly used for roadways and railways crossing rivers, sea or harbors. Immersed tube tunnels are constructed with combination of other type of tunnels such as cut and cover or bored tunnel which is required near the water's edge to connect with the land surface as entrance on both sides. Pamban bridge is a two lane structure connecting Mandapam and Rameshwaram in Tamil Nadu at a distance of 2345m having 79 piers in total, in which 64 piers are in waterbody having the depth of water at navigation span as 6.1m.

II. LIFE CYCLE COST ANALYSIS (LCCA)

Life Cycle Cost (LCC) is a technique that enables comparison of cost assessments which was made over a specified period of time having the account of all relevant economic factors including initial investment costs and future operational and maintenance cost flows over a specific period considered for analysis. Life Cycle Cost Analysis (LCCA)[6] is a tool that provides the total costs of a project over its expected life span or a specific period of time under consideration in detail manner. During decision making process under constrained budget, it is usual that the decision makers make conclusions based on short term costs that is cost associated with design and construction without considering the costs incurred with the project in the future which may be of maintenance, operation, repair and retiring of the project. Analysis of life time cost has to be done thoroughly which includes cost incurred in the project from procurement of raw materials till destruction of the project when its life ends technically. This analysis is done to give the total life cycle cost of the project including every cost the project is associated with such as planning cost, construction cost, maintenance cost, management cost and disposal cost as on Figure 1 [7].

Figure 1. Life cycle of a construction project

LCCA has been proven to create savings in many projects by helping the decision makers and policy makers to identify the most beneficial and cost effective project alternates comparing many alternates of a project than to get the true cost of the project.

Life cycle cost analysis initiation can be done in any of these stages of construction of projectbut most often initiated in design phase which helps in comparing different deign alternates finding the most effective solution. This phase is the key phase of savings since the cost required for any changes increases rapidly once the design has been chosen. During the project in service, LCC can be used to choose the repair alternate helping the decision maker to take decision such as whether to repair or replace. Finally, it can also be used to choose the optimal demolition strategy at the end of its life in cost perspective.

III. LCCA OF PAMBAN BRIDGE

Life cycle cost of bridges include agency costs, user costs and society costs with further subdivisions as on Figure 2. Most of the costs occur at different times during the life cycle of the project. Comparing of past, present and future costs on a common basis is usually done with Net Present Value (NPV) method[1], which is based on the principal that having money at hand today more valuable than to have at future. NPV method transfer all future and present costs to today's value.

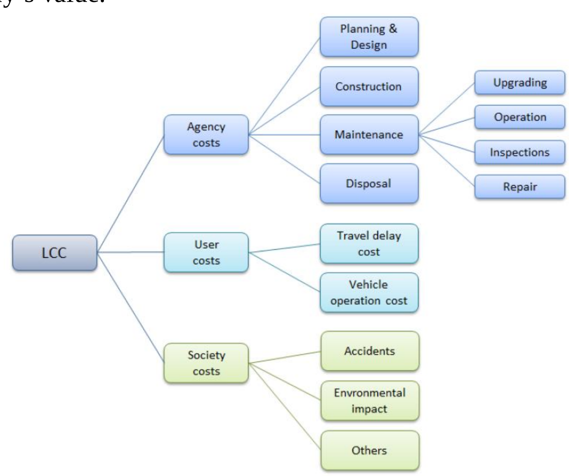

Figure 2. Life Cycle Cost of Bridges

Since the inflation is hard to predict, it is excluded in LCC calculations for the projects of long term investments. The value of discount rate depends on the purpose of analysis. Lower the discount rate, larger the consideration of future costs and maximum usage by public authorities. Larger the discount rate, larger the risks on investment and future cost not considered as important. Discount rate have a greater impact on LCC. LCC can be subdivided as shown in Figure 2. [1]

3.1 AGENCY COSTS

Agency costs [1] are direct expenses by the owner of the project which includes design cost, investment cost, insurance, utilities, servicing, remedial action costs and end of life management costs. Calculating agency cost with NPV method requires time and cost of every maintenance activity. Since these parameters are difficult to predict which is the greatest constraints for LCCA, assumptions are made for operation and maintenance cost based on historical data from actual bridge inspections and repairs. Agency costs may be subdivided as shown in Figure 3. The percentage divisions are based on European Telecommunication Standards Institute (ETSI) Standards[6]. The total of agency cost of the project is shown in Figure 4.

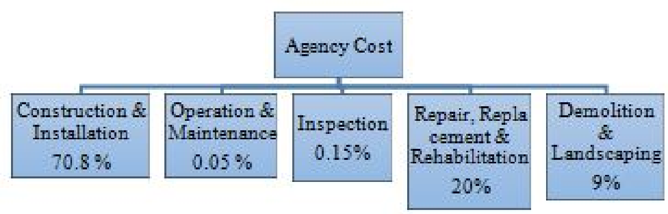

Figure 3. Agency Cost

3.1.1 INVESTMENT COST

Investment cost of a project which is expected to be productive for many years, is the costs that are incurred with procurement of materials that are required for the project, construction and installation of the project.

Cost of Construction of Bridge = Rs. 1998.32 Lakhs
in 1988 (Data Collected)

Future Value = Present Value x $(1+r)^n$

R	=	4%(For Bridges)*
n = (2016-1988)	=	27
Cost of Construction of Bridge in 2016	=	Rs. 57.62 Crores (70.8% of Agency Cost)

*Whole Life Cycle Cost Analysis in Bridge Rehabilitation by CRC Construction Innovation.

3.1.2 OPERATION AND MAINTENANCE COST

Maintenance is the preservation of a structure in its original condition and preventing deterioration which includes cleaning, painting, lubricating, applying protective systems and minor repairs. It has to be done every year throughout its lifespan.

0.05% of Agency Cost = Rs. 4.05 Lakhs
For Total Life Span of 100 years = 100 x 4.05 = Rs. 4.05 Crores

3.1.3 INSPECTION COST

Inspection is to ensure safety and traffic ability revealing the physical and functional condition of the bridge for efficient and economical management. The general inspection is to detect and access new damages. Every structural part of the bridge excluding the parts under water are to be visually inspected. Major inspection is done when the damages affect the traffic safety. It is done to detect any minor defect if not attended to can cause increased repair costs in a short period. Structural parts under water is also to be inspected with the help of qualified divers. Embankments, slopes, abutment ends are also to be inspected. Special inspection has to be done when the bridge requires sudden inspection due to unexpected happenings by nature or man-made leading to damages and repair. Inspection is done once for every 6 years.

0.15% of Agency Cost = Rs. 12.15 Lakhs
Interval = Every 6 years, which is 17 times during its total Life Span
For Total Life Span of 100 yrs = 100 x 4.05 = Rs. 4.05 Crores

3.1.4 REPAIR, REPLACEMENT AND REHABILITATION COST

Repair includes any activity intended to correct the affected material due to deterioration to its original condition so far in practice. The improvement of the structure to meet or to exceed the current design standards such as widening of bridge, strengthening of bridge to increase load carrying capacity, replacement or rehabilitation of deck, rehabilitation of superstructure, etc. These are done for every 10 years.

20% of Agency Cost = Rs. 16.2 Crores
Interval = Every 10 years, which is 9 times during its Total Life Span
For Total Life Span of 100 years = 9 x 16.2 = Rs. 145.8 Crores

3.1.5 END OF LIFE MANAGEMENT

This is the cost that involves demolition and landscaping of the project at the end of its life span that it cannot be used further in the future.

9% of Agency Cost = Rs. 7.29 Crores

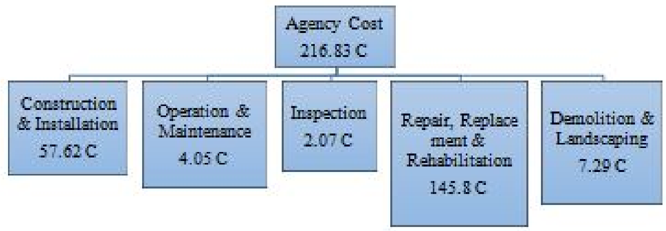

Figure 4. Total Agency Costs

3.2 USER COSTS

User costs [1]are indirect costs for drivers and vehicles. New construction causes traffic disruptions, increased vehicle trip time, discomfort, impact driver's personal time, etc. It also causes increased operating cost of vehicles sitting in traffic and increased risk as the passage of vehicles is diverted through any other alternate path for over a specific period till the work in regular path has been completed. The traffic censes report as on 2001 in Pamban bridge is give in Table 1.

Table 1. Traffic Censes as on 2001

Type of Vehicle	Numbers
Cars	3146
Trucks	1253
LCV	1547
Buses	2016
MultiAxle	1226
Tractor	1264
Total	10452

Average Delay Traffic (ADT_t) = Average Delay Traffic measured x $(1+1.1\%)^{year_{current}-year_{measured}}$

ADT_t = $10452\,(1 + 1.1\,\%)^{2016-2009}$

ADT_t = 11284

r_T = 0.0001 ADT + 8.40

= 0.0001 x 10452 + 8.40

r_T = 9.45%

User costs are divided as traffic delay cost and vehicle operating cost as in Figure 5[7].Traffic delay cost takes into account the additional time spent by the drivers in the traffic due to the construction work. Vehicle operating cost takes into account the additional time that the vehicle has to be operated in the traffic which causes additional usage of fuel, engine oi, maintenance, etc. The total user costs is shown in Figure 6.

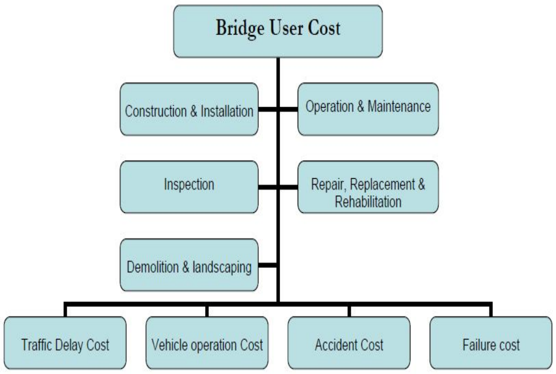

Figure 5. User Costs

3.2.1 TRAFFIC DELAY COST

Traffic Delay Cost (TDC) results from additional time requirement for the vehicles to cross the pathway due to reduction in speed in traffic, congestion delays and increased distance in alternate path than in regular path.

Traffic Delay Cost = $ADT_t \times [r_T w_T + (1 - r_T)w_p] \times [1-(1/(1+r))^n]/r$

= $11284 \times [9.45 \times 220 + (1-9.45)\ 110] \times 24.51$

For Total Life Span of 100 years = Rs. 31.79 Crores

Where assumptions are made as,

w_T = Hourly Time Value for 1 Truck = 220rs/hr

w_p = Hourly Time Value for 1 Passenger Car = 110rs/hr

3.2.2 VEHICLE OPERATING COST

Vehicle Operating Cost (VOC) is the additional cost incurred by the bridge user for operating the vehicle in additional time due to the traffic disturbances causing additional costs for fuel, engine oil, lubrication, maintenance and depreciation, etc.

Vehicle Operating Cost = $ADT_t \times [r_T O_T + (1 - r_T)O_p] \times [1-(1/(1+r))^n]/r$

= $11284 \times [(9.45 \times 170 + (1-9.45)\ 75] \times 24.51$

For Total Life Span of 100 years = Rs. 26.9 Crores

Where assumptions are made as,

O_T = Hourly Operating Cost for 1 Truck = 169.85rs/hr

O_p = Hourly Operating Cost for 1 Passenger Car = 75.05rs/hr

3.2.3 ACCIDENT COST

Accident cost is the cost due to increasing the risk of crashes, health-care and deaths caused by traffic disturbances because of the construction work carried out on the bridge. Though bridge related accidents are only 1.7% of all traffic accidents as per survey, the degree of severity is estimated to be 2 to 50 times than any other road accidents.

Accident Cost = $ADT_t \times \text{Accident Rate} \times [(C_F P_F + C_I P_I)] \times [1-(1/(1+r))^n]/r$

Accident Rate = $[0.783 \times ADT^{0.073} * BL^{0.033}] - 1.33$

= $[0.783 \times 10452^{0.073} * 7691^{0.033}] - 1.33$

Accident Rate = 0.74

Accident Cost = $11284 \times 0.74 \times [(50000 \times 0.009) + (5000 \times 0.991)] * 24.51$

Accident Cost = Rs. 110.62 Crores

Where assumptions are made as,

P_F = Average number of Killed Persons in Bridge Related Accidents = 0.009

P_I = Average number of Injured Persons in Bridge Related Accidents = 0.991

C_F = Average cost of Killed Persons in Bridge Related Accidents = Rs. 50000

C_I = Average Cost of Injured Persons in Bridge Related Accidents = Rs. 5000

3.3 SOCIETY COSTS

Society costs [1] are costs incurred not with the owners or direct users of the bridge but with the environmental damage caused by the bridge such as damage caused due to emissions, resource consumption, etc. This cost is attained by multiplying the cost of the used material by a factor to account the energy from manufacturing and transportation.The factor varies according to the usage demand of the bridge in the specific path. Higher the factor for most usage of the bridge and lower the factor for less usage of bridge due to many nearby alternate paths available to reach the destination at the other side. Bridges are often seen as sculptures relating with the city for identification. So there must be a hidden value for its appearance and beauty of the bridge which must be considered in design process and in LCCA calculation. Since Pamban Bridge is demanding in the area, K_{AES}=0.114 based on ETSI standards[7].

Aesthetical Cultural Value Cost	=	K_{AES} x Agency Cost
	=	0.114 x 8097.54
Aesthetical Cultural Value Cost	=	Rs. 9.23 Crores
For Total Life Span of 100 years	=	Rs. 923 Crores

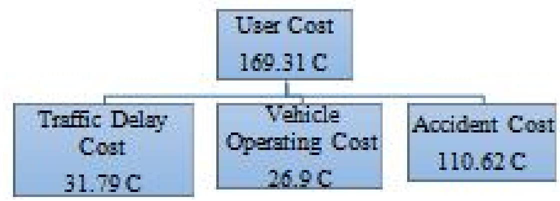

Figure 6. LCC of Pamban Bridge

IV. IMMERSED TUBE TUNNEL

Immersed Tube Tunnels (ITT) are elements prefabricated used for construction of pathway beneath the water bodies for roadways and railways. Cross section of an element is shown in Figure 7.

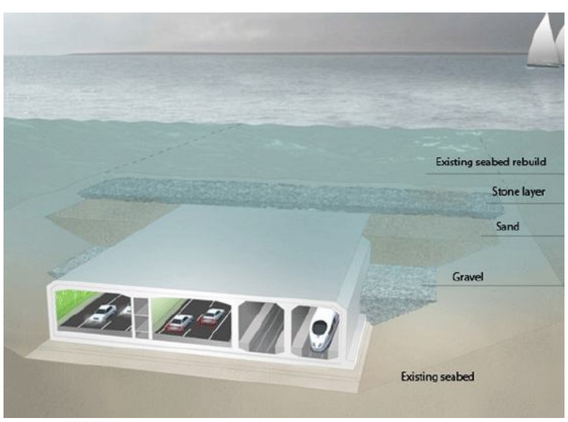

Figure 7. Cross section of Immersed Tube Tunnel

The main advantage of immersed tube tunnel over bridge is that the length of the area required for ITT is much lesser than the length required for the bridge as in Figure 8[4], increased aesthetical value of the structure giving out pleasant environment for the users passing through, increased tourism which in turn increases economic value of the structure.

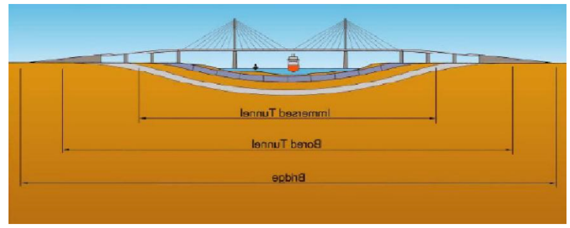
Figure 8. Various Length Requirements

The length of Pamban bridge is 2345m whereas the substitution of immersed tube tunnel requires 1950m. ITT is of precast elements in each element is of 150m and requires 13 elements to construct ITT in the place of Pamban bridge.

4.1 CONSTRUCTION COST OF ITT

The construction cost of each pre cast element is estimated based on RS means 2001 [5] and with the help of NPV method, the day to day construction cost is calculated in INR.

Initial Construction Cost estimated with RS means	=	Rs. 11.02 Crores
In INR = 11.02 x 55.61	=	Rs. 612.83 Crores (as on 2001)

Future Value = Present Value * $(1+r)^n$

r	=	4% (For ITT)*
n = (2016-2001)	=	15
Cost of Construction of Immersed Tube Tunnel in 2016	=	Rs. 1061.21 Crores

*Whole Life Cycle Cost Analysis in Bridge Rehabilitation by CRC Construction Innovation.

4.2 LCCA OF IMMERSED TUBE TUNNEL

The percentage variations for each activity of immersed tube tunnel for its total life span of 100 years is taken from review report by Cascadia Center, North America[2]. Table 2 shows the life cycle cost analysis of immerse tube tunnel proposed as a substitute for Pamban sea bridge.

Table 2. LCCA of Immersed Tube Tunnel

Costs Involved	% of CC	Cost (Rs.) (Crores)
Construction Cost (CC)		1061.21
Inspection and Construction Management Cost	3%	31.84

Operation and Maintenance Cost	15%	159.18
Repair and Rehabilitation Cost	7%	74.29
Decomposition and Deconstruction Cost	19%	201.63
Total Life Cycle Cost		1528.15

Life Cycle Cost of Immersed Tube Tunnel over a Life Span of 100 years	=	Rs. 1528.15 Crores

V. RESULTS AND DISCUSSION

Comparison of sea bride and immersed tube tunnel based on their initial cost of construction and life cycle cost is done.

Table 3. Comparison of Sea Bridge and Immersed Tube Tunnel

	Sea Bridge (Rs)	Immersed Tube Tunnel (Rs)	Variation
Initial Cost	57.62 C	1061.21 C	18.42times
Life Cycle Cost	1309.14 C	1528.15 C	1.17times

The graphical representation of comparison of sea bridge and immersed tube tunnel is shown in Figure 9.

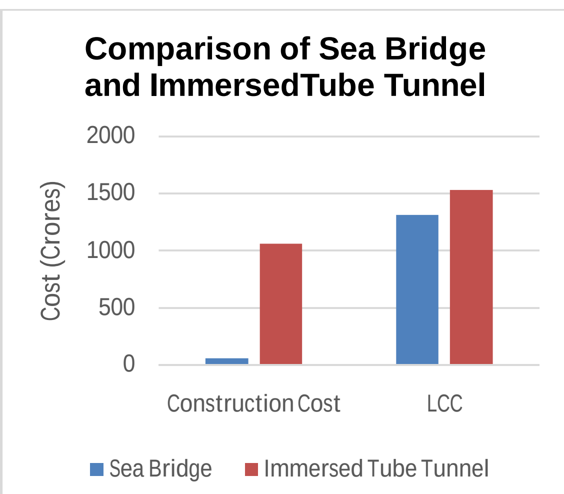

Figure 9. LCCA comparison of Sea bridge and ITT

Comparing initial construction of sea bridge and immersed tube tunnel, there is a vast difference in the construction cost, in which immersed tube tunnel is 18.42% higher than the sea bridge. Whereas comparing Life Cycle Cost of sea bridge and immersed tube tunnel there is no vast difference, in which immersed tube tunnel is just 1.17% higher than the sea Bridge as shown in Table 3.

VI. CONCLUSION

Most investment decisions are taken based on the initial cost of construction of a project. This may lead to short sighted decisions. Life Cycle Cost Analysis helps in decision making during pre-investment phase of the project. Mostly, sea bridge is constructed in most of the places to link either sides of a water body since the cost of construction of bridge is comparatively lesser than any other means to cross the waterbody. There is also an alternate, immersed tube tunnel to connect either sides of a waterbody. The initial cost of construction of immersed tube tunnel is very much higher than the bridge and so it is neglected in most of the places. But by calculating the life cycle cost of bridge and immersed tube tunnel for a specific period of time and comparing, it looks beneficial to construct immersed tube tunnel instead of a sea bridge because of the fact that sea bridge represents only roadways, while immersed tube tunnel represents both roadways and railways and also it gives pleasant environment and great experience to the travelers passing through it. It also does not cost much higher than the sea bridge calculating the life cycle cost of both and comparing.

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