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# Life Cycle Cost Analysis of Precast Concrete Bridge Projects

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**Conflicts of Interest**
There are no conflicts to declare.

## ABSTRACT

The aim of this research is to analyze the replacement of concrete bridges with precast concrete bridges, which could potentially lead to faster construction, thinner slabs and a more durable life. Precast concrete bridges also provide longer construction seasons throughout the year and reduce the duration of construction while maintaining roads or rebuilding bridge. Life Cycle Cost Analysis (LCCA) of precast concrete bridges with the traditional method by comparing the initial cost of precast concrete bridges with the traditional casting method, construction methodology, materials used, environmental impacts, recurring costs, maintenance costs, life-time assessment and life expectancy is discussed. Moreover, the traditional method is essentially to carry out all on-site activities, i.e. casting bridges on-site, curing bridges and then opening them up for traffic use. All these traditional methods can be eliminated if precast concrete bridges are used. The results expected from this study will identify how feasible it is to replace traditional bridge casting with precast concrete bridges in terms of cost, time and life expectancy

**Keywords:** LIFE CYCLE COST ANALYSIS, BRIDGE PROJECTS, USER COST

## Introduction

Traditionally, three of the top priorities for construction projects are quality, cost aspects and time. In construction projects, the owner, together with the manager, shall use the minimum available time at the minimum possible cost to obtain the maximum output. Construction projects today consume a lot of time and money to complete the task. Infrastructure projects that are reconstructed using the traditional casting method cause inconvenience to the public during construction.

Applying the idea of a precast concrete bridge over a cast-in-place bridge will help to minimize time and costs. As design enters a new period of growth, the study focuses on the construction of a precast concrete bridge for the construction of a new bridge and the retrofitting of existing bridges on the bridge. Precast concrete bridge will reduce construction time and duration. In addition, if the precast concrete bridge is pre-stressed, maintenance for its lifetime would be minimal. Precast concrete bridge panels are manufactured off-site, transported to the site and assembled on the prepared sub-base. They are also used for the reconstruction of bridges, bridge maintenance, and building of new bridges, urban street restoration, isolated repairs, intersections and rehabilitation of ramps. As the conditions of the site can differ, many precast bridge structures can be used for construction purposes. These systems include precast bridge systems, super slab, Kwik slab system, Roman road system, con-slab system, full depth slab and joint repair. The main objective of this study will be the LCCA of the precast concrete bridge over the bridge, which will promote the construction of the current infrastructure.

## 2. Methodology

### 2.1 Construction of Precast Concrete Bridges

For the construction of precast concrete bridges, the complete replacement of the panels or the maintenance and construction of the new bridge can be carried out on heavily cracked panels, punched out panels, damaged joints and prepared subcases. In addition, the detailed construction methodology for the construction of unpaved roads and the maintenance of a paved road has been mentioned below. Repairs and repairs are typically carried out in full lane width. The materials used in the base should be of good quality and should be easily positioned, graded and compacted within the time limit. The materials to be used in the foundation are thick, granular or lean concrete. In this technique, the settled base can be used and, if any unsettled base is found, it will be leveled to its previous level using compactors. If the current foundation does not serve the needs of the precast concrete bridge, another base will be built. A small layer of finely screened granular material or sand can be used to give a level surface to the floor. A granular sub base can be reworked, compacted and graded. If required, additional bedding materials will be supplied to hold the chamber up.

Bedding should be kept as thin as possible for both the maintenance and building of bridges, since thicker bedding causes less support. Help conditions for precast concrete bridges should be much higher than on-site casting bridges. When the foundation has been properly prepared, graded and compacted, precast concrete bridge panels can be assembled together at the site. The initial cleaning of the exposed base and the drying of the base shall be carried out by air cleaning or by gas flames. The dowel bar slots are air cleaned and sandblasted. The placement and leveling of the panels is carried out with the help of equipment such as cranes and labor. The location of the precast panel is adjusted with the adjacent cavity panel prior to the opening of the traffic. Various important measures to be taken before opening are temporary post-tensioning, filling or covering the stress pockets and ensuring a smooth transition from the end of the mounted panel to the current bridge. After the precast bridges have been assembled, post-tensioning of the bridge is carried out.

Our proposed study concerns the LCCA of precast concrete bridges and the design of precast concrete bridges. The study focuses on finding ways to incorporate and improve road infrastructure with precast concrete bridges, taking into account the time of construction, design, cost and life expectancy of this technique.

## 2.2 Life Cycle cost Analysis

Life Cycle Cost Analysis provides an approach to computing the cost or serviceability of a commodity. It is used to compare design alternatives over the life of each alternative, taking into account both cost and benefit parameters. Infrastructure is subject to significant overall costs over the lifespan of these assets after completion, i.e. during its service life. The bridge design decision concerns the selection of bridge alternatives and the acceptance of the best alternative based on the current scenario, thus achieving the objective of the project. Life cycle costs are typically correlated with two forms of costs, Organization costs and Consumer costs. The cost of the Agency is typically the cost charged by the transport department to contractors, which includes initial construction costs, potential maintenance costs and rehabilitation assistance. User costs are typically those associated with public motorists for extra travel time and vehicle operating costs due to construction-related traffic delays translated to that number.

The various elements which we require to perform LCCA are as follows: Established alternative design methods, establish activity timings, evaluation of agency costs, and estimation of user costs and determine the life-cycle cost [1]. The first step is to define realistic design alternatives [1]. Identify initial construction or rehabilitation tasks for all design choices, as well as potential rehabilitation and maintenance activities for individual actions. Therefore, each design choice should have a business plan. Following the concept of an alternative design, the next step is to detail all costs. It is recommended that both the Organization and the customer expense be taken into account for an improved image of the construction or maintenance performance. The next step is to measure the cumulative cost of the life cycle for each competing alternative. It uses the discount rate to convert future costs to present values so that different alternatives can be directly compared. Figure1.1 shows the costs that could be involved in the calculations and the LCCA process.

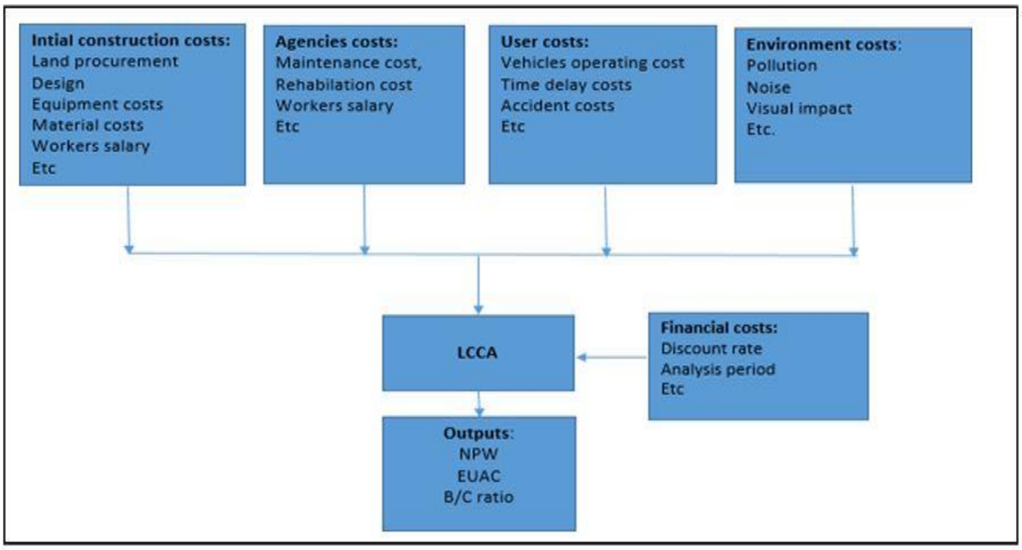


Figure 1.1 LCCA Process

## 3. Components for analysis & cost factors

### 3.1 Evaluation of Cost Factors

Various economic analysis techniques can be utilized to assess types of bridge options. Some of the most popular are the Net Present worth method, The Internal Rate of Return method, Benefit-Cost Ratio and Equivalent Uniform Annual Cost. The best method to adopt depends on the content and level of analysis which must be performed. This research will utilize NPW as it is the most widely used method for LCCA.

Net Present Worth is also called Net Present Value. The output of the NPW method is a lump sum of initial and future costs in present value. For the first year of the analysis period, the NPW cost is the same as the actual cost, as there will not be any correction for inflation and interest. For future maintenance and rehabilitation activities, the NPW cost is less than the actual cost since total costs are discounted [3]. It gives an indication of how a bridge alternative will cost over the analysis period and can be used to compare various alternatives to find the minimum cost. The equation for NPW of an alternative is:

### 3.2 Discount rate

The discount rate in LCCA is considered because the time value of the money must be measured to calculate the cost of future activities. The discount rate is also the interest rate by which the future costs will be converted to present value [5]. The FHWA suggests using discounts rates in the range of 3% to 5% [4]. Traditionally, these values have ranged from 2-5% around the world. This paper uses a discount rate of 4% in LCCA of bridge structures.

### 3.3 Sensitivity

As with any type of research, it is important to analyze which parameters are more sensitive and makes the largest contribution to the result. For LCCA, many parameters can affect the NPW value for a bridge alternative. For example, the unit price for materials is very important and can cause the alternative to go from very high NPW to low NPW. Other factors that can affect the LCCA results are the discount rate, analysis period and timing of activities [2].

## 4. Factors

### 4.1 Agency Cost

The agency cost includes two main factors described as below

1. **Initial construction cost**: The NPW has a major impact due to the initial construction cost. The initial costs are determined at the very beginning of the project at the year zero of the analysis period. Several activities are carried out during construction, reconstruction or major rehabilitation of a bridge, only specific activities which are related to bridge alternative should be considered with the initial cost. By concentrating on the specific bridge alternatives, estimators can focus on the quantities and costs related to these activities. It is difficult to estimate the exact initial costs, as there are unique situations and depends on many aspects: geological, economic, and environmental. Total construction costs can exceed the estimated cost or can also be lower than expected. Therefore, we need to add up an extra percentage of unseen costs.

2. **Maintenance Cost**: All bridge types need maintenance which can be routine during their service life, and after a certain point bridge must be renewed. Maintenance and rehabilitation include costs such as materials, equipment, staff salaries etc. The duration of these activities for maintenance and rehabilitation will vary from year to year. Cost data for preventive maintenance are very difficult to predict. A common type of maintenance which is required in the concrete bridge is crack sealing, diamond grinding and joint sealing. Crack sealing attempts to reduce the infiltration of moisture in the crack, to reduce the deterioration of cracks. Crack sealing is carried out with high -quality sealing materials. The diamond grinding removes a thin layer from the concrete bridge to repave it. Diamond grinding is usually carried out when there are signs of slab wrapping, wheel path rutting or crack faulting. Joint sealing is a treatment process where longitudinal and transversal joints are repaired.

### 4.2 User Cost

User cost helps to understand the impact of road work on road users. User cost may vary to different conditions i.e. it will be on the higher end when the maintenance work is carried out. Road work may cause delays and number of accidents too. User cost can be categorized as follows:

**Vehicle operation cost**: It mostly results in an increase of fuel usage, wear on tires and other vehicle parts, Vehicle operating cost increases during maintenance and rehabilitation. In service vehicle operating costs are a function of bridge serviceability level, which is often difficult to estimate [6].

**User delay cost:** It is cost which is related to road users' time. Usually saving time is the main factor considered in transportation projects. User delay cost are usually more during the maintenance and rehabilitation periods when traffic is completely closed or diverted to other lanes. Time delay cost is mostly due to changes in speed. Speed changes are the additional cost of slowing from one speed to another and returning to the original speed [4]. Time value depends on the vehicle type and the purpose of the trip [7]. Moreover, user delay cost is one of the most difficult and most controversial life cycle cost analysis parameters: they are extremely difficult to calculate because it is necessary to put a monetary value on individuals' delay time [8].

## 5. Method and model

### 5.1 Case Study

In this model, hypothetical dimensions of bridges are considered. All the bridge alternatives are assumed to be designed at an axial load of 80 KN. The quantity calculations are carried for the length of a one-mile road, and the comparison is done between different bridge alternative design models such as Precast Concrete Bridge (PCCB), Joint Plain Precast Concrete Bridge (JPPCB), Jointed Plain Concrete Bridge (JPCB) and Continuous Reinforced Concrete Bridge (CRCB). The standard specifications related to construction activities such as aggregate sub base and lean base concrete for the above hypothetical situation were adopted from the Department of Transportation, California. The dimensions for the prefabricated precast panel are 40ft x 8ft x 1ft. The components which were considered while estimating the initial construction costs are aggregate sub base, lean base concrete, polythene sheets, pre-tensioned and post-tensioned steel, dowel bars, equipment used and labor required. The model considered an overall discount rate of 4%. All the future costs were converted to present value with the help of the NPW equation. While calculating the maintenance and rehabilitation cost, joint sealing and diamond grinding costs were considered. Furthermore, User delay costs were calculated considering vehicle operating cost and user delay cost. The salvage value was not taken into consideration for this model. The calculation focuses on the variation obtained in initial construction cost with different design alternatives in calculating life cycle cost. The tables and graphical representations below show the calculation output and comparison carried out between the design alternative for Life Cycle Cost and Initial construction cost.

### 5.2 Mathematical Model

All the cost categories should be gathered into a single equation converted to present dollar value, which will help to develop an LCCA model. In this model, cost categories include initial construction cost, maintenance and rehabilitation cost, user cost and salvage value. Using this model, a comparison between precast concrete bridge and traditional casting method will be carried out. Equation for LCCA is:

$$LCCA = (I_C + M_V + U_C + O_C + S_V) \qquad 2$$

Defining:

$I_C$ = Initial cost

$M_V$ = Maintenance cost

$U_C$ = User cost

$O_C$ = Operations cost

$S_V$ = Salvage value

## 6. Results

Table 1.1: Cost Calculation

| | **PPCB** | **JPCB** | **JPPCB** | **CRCB** |
|---|---|---|---|---|
| **$I_C$** | 2842726 | 2032423 | 2724816 | 2119218 |
| **$M_C$** | 479595 | 972241 | 479595 | 972241 |
| **$U_C$** | 1147383 | 2762537 | 1147383 | 2762537 |
| **LCC** | 4469704 | 5767201 | 4351793 | 5853997 |

*All cost is in USD

Table 1.2: Construction time period

| | **Precast** | **On-location** |
|---|---|---|
| **LCB** | 10 | 20 |
| **Aggregate** | 13 | 13 |
| **CB** | 25 | 70 |
| **Total duration (days)** | 48 | 103 |

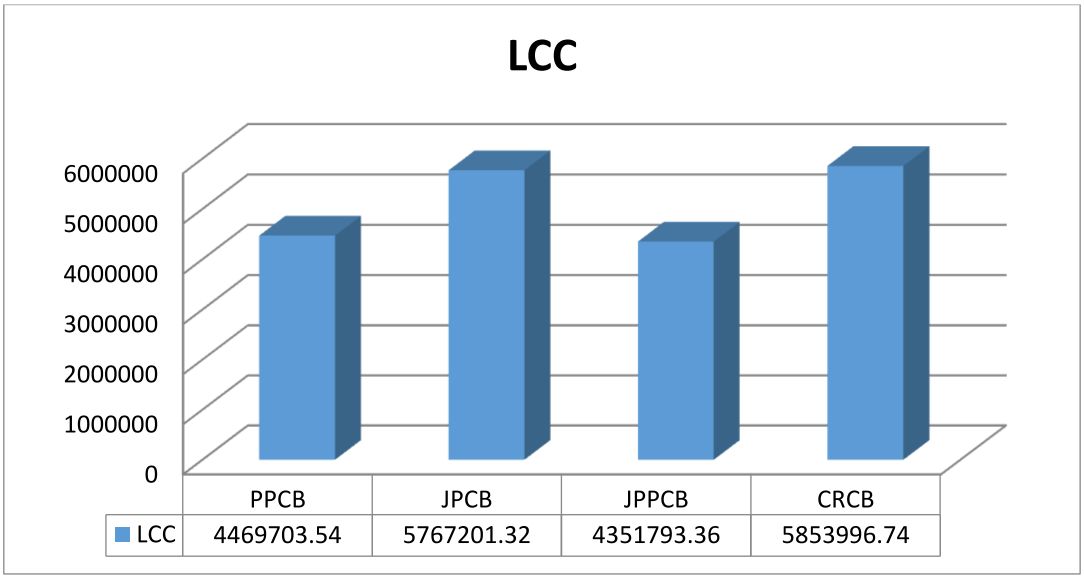


Figure 1.2: Life cycle cost comparison by design alternatives

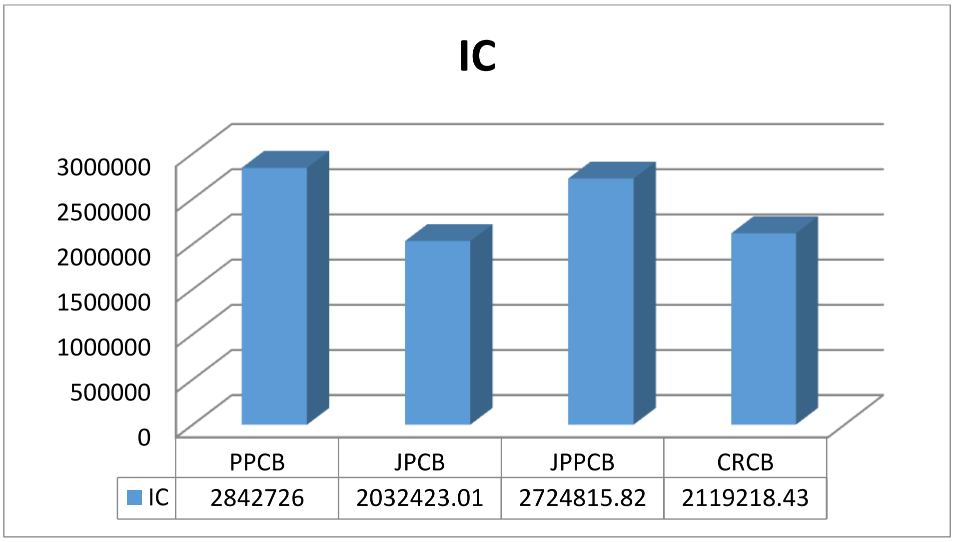


Figure 1.3: Initial cost by design alternatives

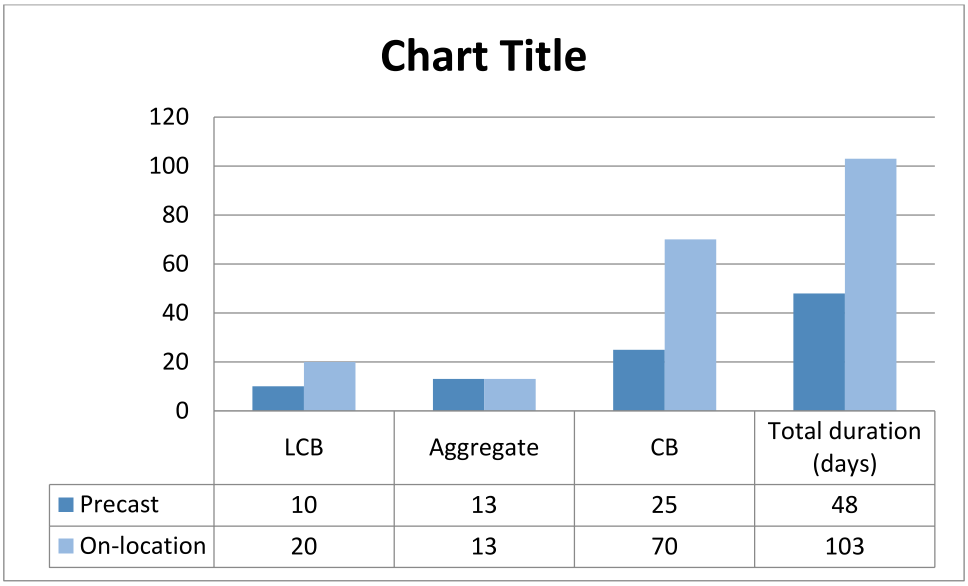


Figure 1.4: Duration comparison

## 7. Conclusion

From the above analyzes, it can be determined that the Life Cycle Cost of precast concrete bridge for both alternatives are less than the traditional method. The construction duration for onsite casting is 103 days which is way higher than the precast concrete which is 48 days.

The initial construction cost for PPCB ($2,842,726) and JPPCB ($2,724,816) is higher than the traditional method JPCB ($2,032,423) and CRCB ($2,119,218), because of the high cost associated of using cranes to place panels. It can be determined that maintenance cost for precast concrete bridges ($479,595) is less than the traditional onsite method ($972,241). Furthermore, the user cost for precast concrete bridge ($1,147,383) is less than the traditional onsite casting ($2,762,537). From the above graphs, it can be determined that JPPCB has the lowest Life Cycle Cost.

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**Habibullah Sharifi** is a top achieving Master’s graduate with more than 4 years’ experience in various civil engineering construction and environmental management’s functions. Drafted, examined and contributed responsibilities with many small-medium grants projects. Accomplished to redesign the engineering principles and improving organization's new product and system and developed it by 25%. Currently, working towards publishing research papers in peer-reviewed high indexed journals.