

LIFE CYCLE COST ANALYSIS OF PRECAST CONCRETE PAVEMENT

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ABSTRACT

The focus of this research is to analyze the replacement of concrete pavements with precast concrete pavements which will potentially result in faster construction, thinner slabs, and a more durable life. Precast concrete pavements also provide longer construction seasons throughout the year, and it reduces the duration of construction while carrying out the maintenance of roads or reconstruction of roads.

This research focuses on the study of the Life Cycle Cost Analysis (LCCA) of precast concrete roads with the traditional method (cast-in-place) by comparing the initial cost of precast concrete roads with traditional casting method, the methodology of construction, the material used, environmental impacts, recurring cost, maintenance cost, life assessment and life expectancy. Furthermore, the traditional method is basically carrying out all the activities on site i.e. casting of pavements on site, curing of pavement and then opening it for traffic use. All these procedures of the traditional method can be eliminated if precast concrete pavements are used. The results which are expected after this study will identify how feasible it is to replace traditional casting of pavements with precast concrete pavements with respect to cost, time and life expectancy.

INTRODUCTION

Historically, two top priorities of construction projects are time and cost considerations. In construction projects, the owner, together with a manager, utilize the minimum available time with the minimum possible cost to get maximum output. Today, the construction projects consume a lot of time and money to complete the task. The infrastructure projects which are reconstructed with the traditional casting method causes inconvenience to the public during construction. Applying the concept of precast concrete pavement over cast-in-place pavement will help to reduce the time and cost.

As construction enters a new age of development, the research focuses on the implementation of precast concrete pavement for the construction of new pavement and retrofitting of the existing pavements on the roads. Using precast concrete pavement will reduce the construction time and duration. Furthermore, if the precast concrete pavement is prestressed, maintenance will be low for its lifespan.

Precast concrete pavement panels are fabricated offsite, transported to the site, and installed on the prepared subbase. These are also used for retrofitting pavements,

maintenance of pavements, construction of new pavements, urban street rehabilitation, isolated repair, intersections and ramp rehabilitation. As site conditions, may vary, several precast pavement systems can be adopted for construction. These systems include jointed precast pavement systems, super slab, Kwik slab system, roman road system, con-slab system, full depth slab and joint replacement method.

The main objective of this study will be the LCCA of precast concrete pavement on roads which will facilitate the development of existing infrastructure.

CONSTRUCTION METHODOLOGY

For the construction of precast concrete pavements, full panel replacements or maintenance and construction of new pavement can be done on severely cracked panels, punched out panels, deteriorated joints and prepared sub-base. Furthermore, the detailed methodology of construction has been mentioned below for the construction of unpaved road and maintenance of the paved road. Repairs and maintenance are usually conducted in full lane width. The materials used in the base should be of good quality and should be easily placed, graded and compacted within the time limit. Materials which will be used in the base are dense-graded, granular base or lean concrete. In this technique, the settled base may be used and if any unsettled base is found it will be levelled to its past level utilizing compactors. Another base will be constructed if the current base does not serve the necessities of the precast concrete pavement. A slight layer of finely screened granular material or sand may be used to give a level surface to set the board. A granular subbase might be reworked, compacted and graded. Extra bedding materials will be given if necessary to keep up the camber. The bedding materials for the base, which will be utilized, are sand and cementitious grout.

For both maintenance and construction of pavements, bedding should be kept as thin as possible, because thicker bedding causes weaker support. Support conditions for the precast concrete pavements should be far better than onsite casting pavements. Once the base is prepared, graded and compacted properly, precast concrete pavement panels can be assembled together at the site. Initial cleaning of the exposed base and drying of the base are done by air cleaning or by using gas flames. The dowel bar slots are air cleaned and sandblasted. Placement and levelling of the panels are done with the help of equipment such as cranes and labor. The placement of the precast panel is adjusted with the adjacent panel camber with grouts before opening to the traffic. Various critical steps, which shall be performed prior to opening, are temporary post-tensioning, filling or covering the stressing pockets and providing a smooth transition from the end of the installed panel to the existing pavement. After assembling the precast pavements, post-tensioning of the pavement is carried out.

Our proposed research is about LCCA of precast concrete pavements and construction of pavements using precast concrete. The focus of the research is to find ways on how to implement and improve road infrastructure with precast concrete pavement considering the time of construction, design, cost and life expectancy of this technique.

LCCA METHODOLOGY

Life Cycle Cost Analysis provides an approach for computing the cost of a product or its serviceability. It is used to compare design alternatives over its life of each alternative, considering all parameters of cost and benefits. For infrastructure, major total cost over the lifetime of these assets is encountered after construction, i.e. during its serviceability life. The decision about the pavement design relates to the selection of pavement alternatives and recognizing the best alternative based on the present scenario, whilst achieving the project objective. Life cycle costs are usually associated with two types of costs, Agency cost and User costs. Agency costs are usually the cost that is paid by the department of transportation (DOT's) to contractors which includes initial construction cost, future maintenance and support cost of rehabilitation. User costs are usually the cost which is associated with the public motorists for added travel time and vehicle operation costs caused by construction-related traffic delays converted to the amount.

The different elements which we require to perform LCCA are as follows: Set up alternative design strategies, establish activity timings, evaluation of agency costs, estimation of user costs and determine the life-cycle cost (Scheving, A. G., 2011). The first step is to define realistic design alternatives (Scheving, A. G., 2011). For every design options, identify the initial construction or rehabilitation activities, as well as future rehabilitation and maintenance activities for individual actions. Therefore, each design option should have a plan of activities. After design alternative is defined, the next step is to outline all costs. It is recommended to consider both agency and user cost for an enhanced image of the construction or maintenance output. The next step is to calculate the total life cycle costs for each competing alternative. It uses the discount rate to convert the future cost to present values so that different alternatives could be compared directly. Figure 1, signifies costs that could be involved in calculations and LCCA process. Figure 2, signifies the selection of pavement alternative.

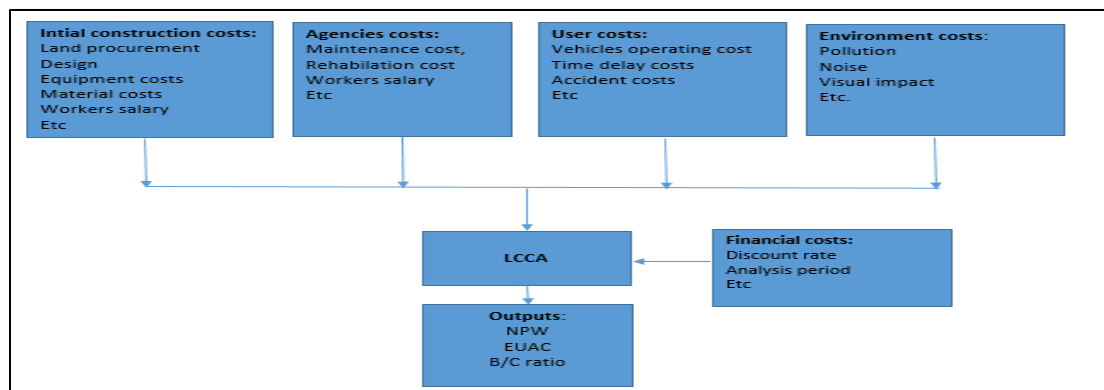


Figure 1. A flowchart describing LCCA process for pavement selection
Scheving, A. G. (2011).

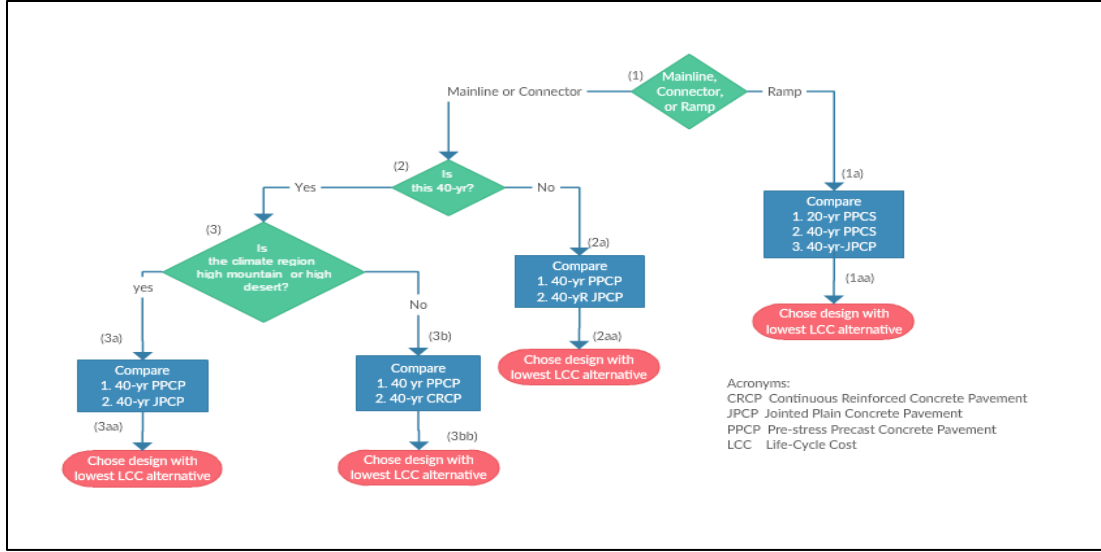


Figure 2. A flowchart describing selection of Pavement Alternative.

Economic analysis components

The following are the various components for economic analysis that must be considered.

1. Evaluation methods

Various economic analysis techniques can be utilized to assess types of pavement options. Some of the most popular are the Net Present Worth (NPW) method, The Internal Rate of Return method (IRR), Benefit-Cost Ratio (B/C) and Equivalent Uniform Annual Cost (EUAC). 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 (NPV). 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 (VDOT,2002). It gives an indication on how a pavement 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:

$$NPW = C_0 + \sum_{n=1}^N \frac{M_n + O_n + U_n}{(1+i)^n} - \frac{S}{(1+i)^N} \quad (1)$$

Where, C_0 = Initial construction cost; n = specific year of expenditure; i = discount rate; M_n = maintenance cost in year n ; O_n = operating cost in year n ; U_n = user cost in year n ; S = Salvage value; N = Total analysis period (Scheving, A. G., 2011).

2. Analysis period

As per the Federal Highway Administration (FHWA) technical bulletin, LCCA period should be long enough to observe differences associated with maintenance strategies.

In general, the analysis period should be longer than the design period and long enough to include at least one complete rehabilitation activity (VDOT, 2002). The FHWA recommends a period of at least 35 years for all pavement projects, including new or total reconstruction projects and rehabilitation, restoration and resurfacing projects (Walls and Smith, 1998). However, most of the DOT's are using an analysis period of 40 to 50 years. As pavement condition and pavement life are dependent on each other, appropriate strategies of maintenance and rehabilitation should be implemented in a timely manner. Figure 3 demonstrates the relationship between the pavement condition and pavement life.

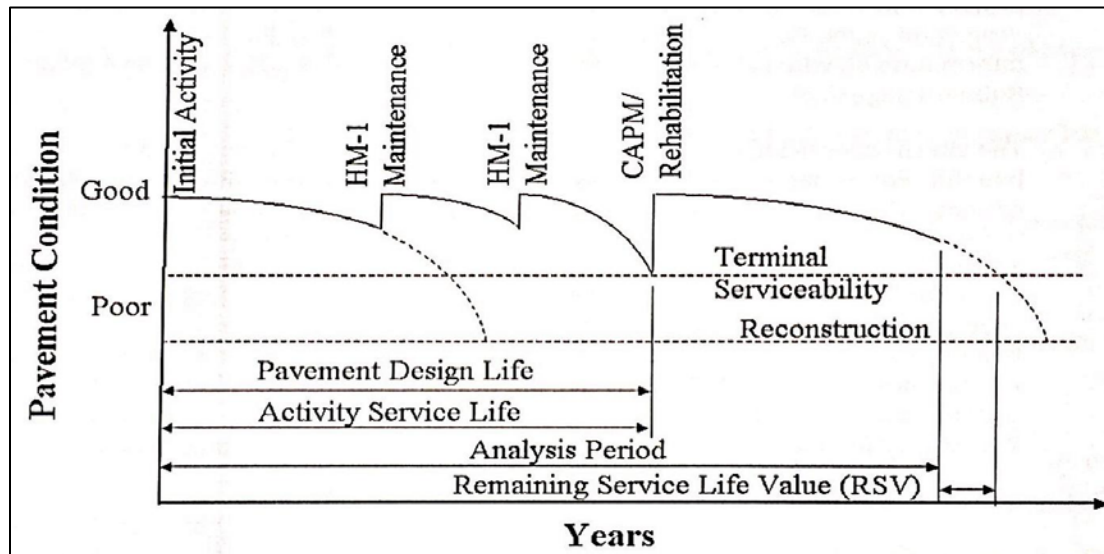


Figure 3. Pavement Condition vs. Years (Caltrans 2013).

3. 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 (Caltrans 2011). The FHWA suggests using discounts rates in the range of 3% to 5% (Walls & Smith, 1998). Traditionally, these values have ranged from 2-5% in United States of America (USA). Caltrans currently uses a discount rate of 4% in LCCA of pavement structures.

4. Sensitivity analysis

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 pavement 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 (Buncher, 2004).

Cost Factors

Agency Costs

It consists of the following two major costs: initial construction cost, maintenance and rehabilitation cost.

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 pavement, only specific activities which are related to pavement alternative should be considered with the initial cost. By concentrating on the specific pavement 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, 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 and rehabilitation cost

All pavement types need maintenance which can be routine during their service life, and after a certain point pavement 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 pavement 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 pavement 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.

User costs

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 categorised as follows:

1. Vehicle operating costs

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 pavement serviceability level, which is often difficult to estimate (Tapan, 2002).

2. User Delay costs

It is cost which are 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 (Walls & Smith, 1998). Time value depends on the vehicle type and the purpose of the trip (USDOT,1997). 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 (Walls & Smith, 1998).

3. Crash costs

Crash costs include damage to the users' and others' and public/private, as well as injuries (Tapan, 2002). Road accident cost is computed from accident rates and economic costs. This LCCA model is not considering crash costs due to lack of information. Additionally, Caltrans does not include the crash cost in LCCA model. (Caltrans 2013)

Salvage value

The FHWA, in its Interim Technical Bulletin in LCCA, recognises that a pavements functional life represents a more significant component of salvage value than does its residual value as recycled material (FHWA, 1998). As per the bulletin, the salvage value has very little impact on LCCA results when the value is discounted over 35 years or more (VDOT, 2002). Therefore, this LCCA model is not considering salvage value.

LCCA 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 pavement and traditional casting method will be carried out. Equation for LCCA is:

$$LCCA = (I + M\&N + U + O + S) \quad (2)$$

where:

I= Initial construction cost,

M&N= present value of maintenance and rehabilitation cost,

U= present value of user cost,

O= present value of operating cost,

S= present salvage value.

Case Study

In this model, hypothetical dimensions of pavements are considered. All the pavement 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 pavement alternative design models such as Precast Prestressed Concrete Pavement (PPCS), Joint Plain Precast Concrete Pavement (JPPCP), Jointed Plain Concrete Pavement (JPCP) and Continuous Reinforced Concrete Pavement (CRCP). 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 subbase, 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.

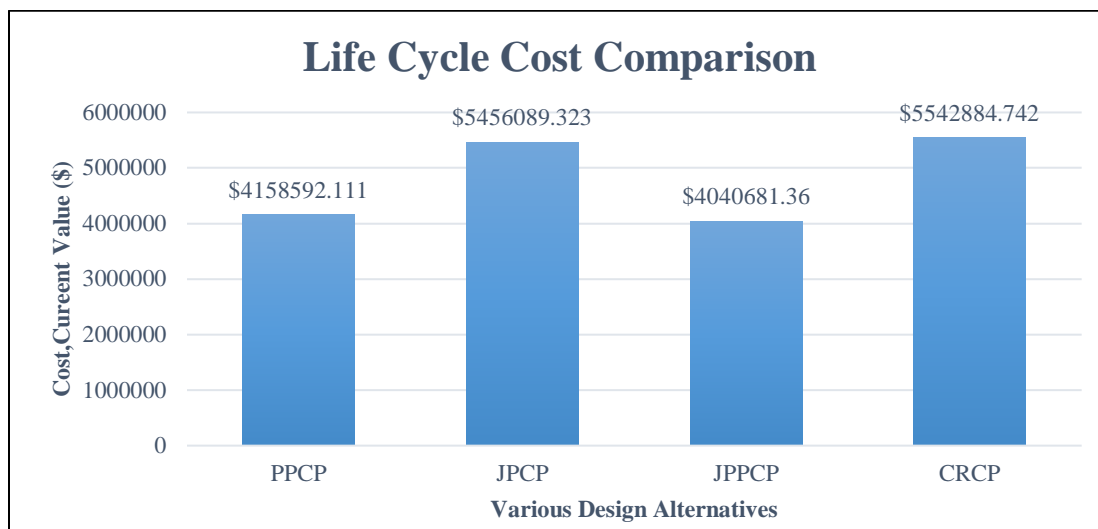
Result and Analysis:

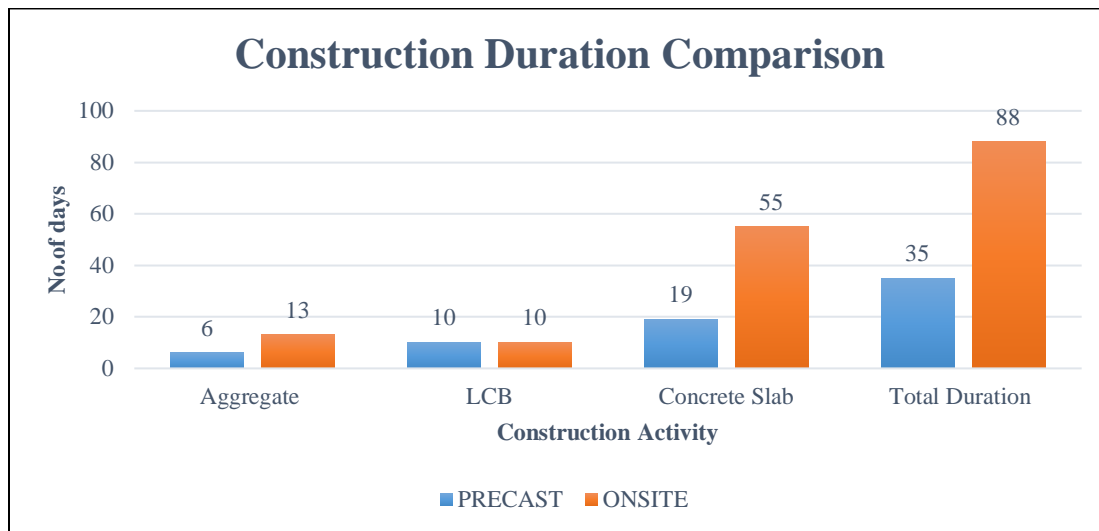
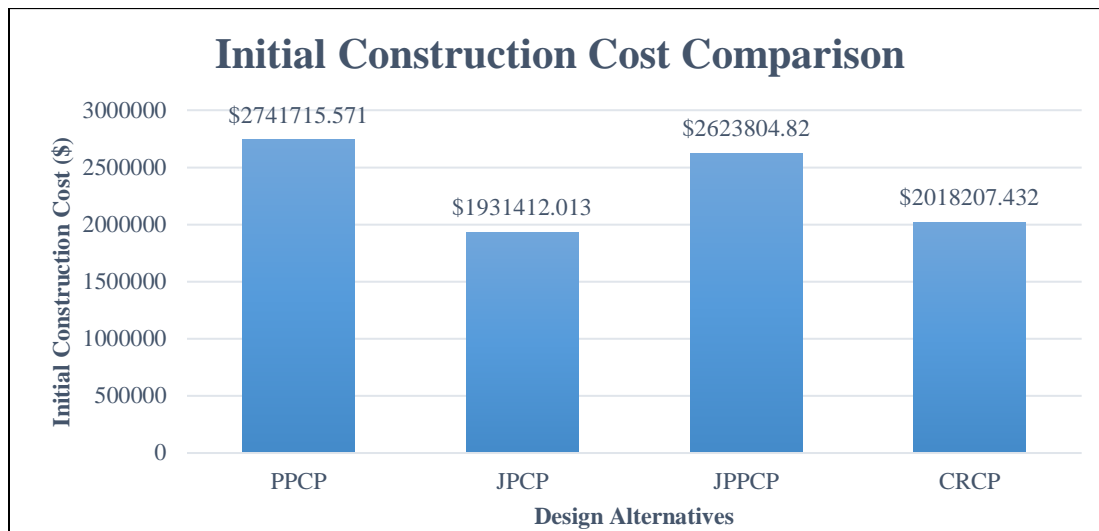
Cost calculation:

Activity	PPCP	JPCP	JPPCP	CRCP
Initial Construction Cost (\$)	2,741,715.57	1,931,412.01	2,623,804.82	2,018,207.43
Maintenance and Rehabilitation Cost (\$)	379,493.99	872,140.29	379,493.99	872,140.29
User costs (\$)	1,037,382.55	2,652,537.02	1,037,382.55	2,652,537.02
Life Cycle Cost (\$)	4,158,592.11	5,456,089.32	4,040,681.36	5,542,884.74

Construction duration calculation:

Activity	Precast (Days)	Onsite (Days)
Aggregate	6	13
LCB	10	10
Concrete Slab	19	55
Total Duration	35	88





From the above analyzes, it can be determined that the Life Cycle Cost of precast concrete pavement for both alternatives are less than the traditional method. The construction duration for onsite casting is 88 days which is way higher than the precast concrete which is 35 days.

The initial construction cost for PPCP (\$2,741,715.57) and JPPCP (\$2,623,804.82) is higher than the traditional method JPCP (\$1,931,412.01) and CRCP (\$2,018,207.43), because of the high cost associated of using cranes to place panels. It can be determined that maintenance cost for precast concrete pavement (\$379,493.99) is less than the traditional onsite method (\$872,140.29). Furthermore, the user cost for precast concrete pavement (\$1,037,382.55) is less than the traditional onsite casting (\$2,652,537.02). From the above graphs, it can be determined that JPPCP has the lowest Life Cycle Cost.

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