Life Cycle Cost Analysis Considerations in Pavement Type Selection in Red Deer and Construction Challenges

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ABSTRACT

In 2016 The City of Red Deer issued a Request for Proposals (RFP) to complete intersection/roadway improvements and upgrading of the 67 Street and Johnstone Drive intersection and the 66 Street and Orr Drive intersection. The RFP contained alternative bid options for asphalt concrete and Portland cement concrete (PCC). Pavement type selection is one of the most challenging decisions for municipalities. Life Cycle Cost Analysis (LCCA) as a part of the alternative bid process allows for a better understanding of the true costs of a roadway as opposed to considering only an initial cost of the pavement. The equivalent pavement structures were compared in terms of their Net Present Value. This LCCA approach provided the initial construction costs for each pavement structure and the costs of future maintenance and rehabilitation. Based on the LCCA, the concrete option was selected; the initial construction costs were comparable for both options but the preservation costs over the life cycle were significantly lower for the PCC. The selection process is described in detail and the challenges of traffic accommodation and construction at the busy intersection are discussed.

BACKGROUND INFORMATION

67 Street is a major transportation corridor in Red Deer, integral in servicing the nearby industrial and commercial developments in addition to providing access to the city from the west via Highway 11. The peak traffic volumes in both the morning and afternoon rush hours have been identified as having unacceptable levels of service. With the continued adjacent developments, this level of service is expected to deteriorate further. The City intended to complete intersection/roadway improvements to upgrade the 67 Street and Johnstone Drive intersection and the 66 Street and Orr Drive intersection. The project included the upgrade of two intersections to roundabouts, including their approaches. The roadwork comprised removals, deep utility construction, granular and subgrade preparation, both asphalt and concrete surfacing, sidewalk, curb and gutter placement, and asphalt mill and inlay.

The City of Red Deer RFP included two options for the proposed methodology:

- Option A – Asphalt Roadway Structure
- Option B – Portland Cement Concrete Pavement

Under Option B, proponents were requested to provide any other alternate methodologies, construction techniques, construction materials, or other solutions to address the project objectives.

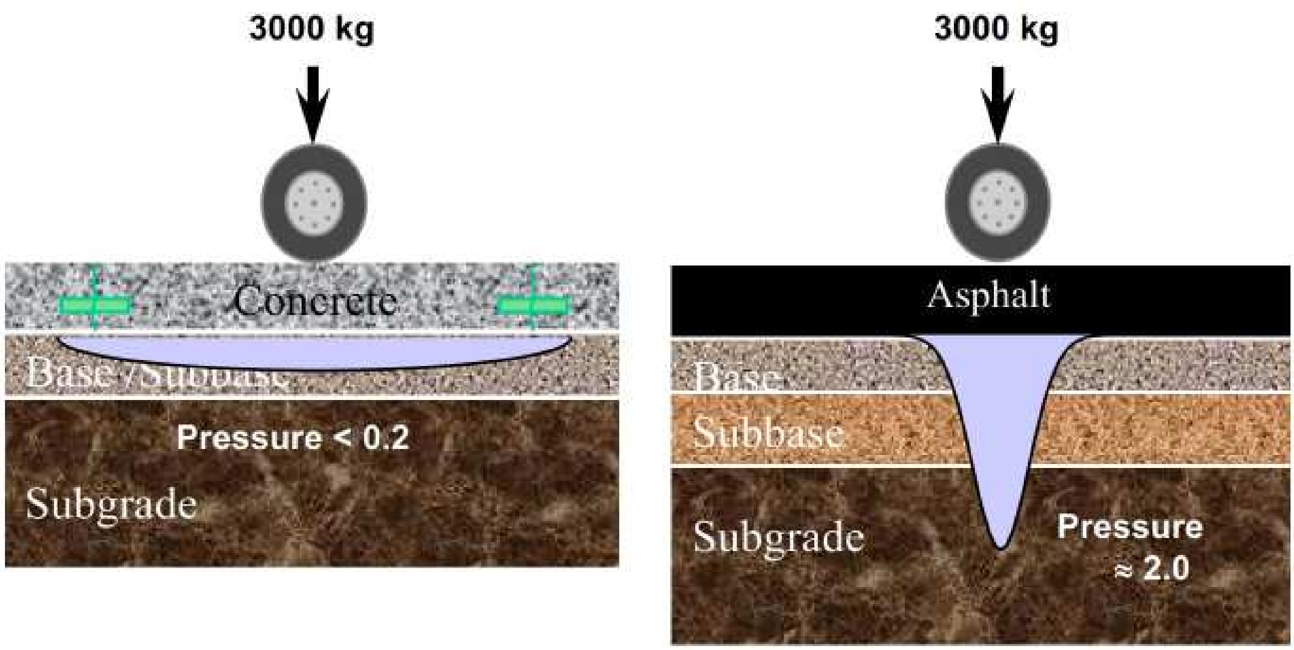
The design for the Asphalt Roadway Structure (Option A) was provided in the RFP document. Option B required a detailed methodology and included a Portland Cement Concrete Pavement (PCCP) design and construction plan.

PROJECT DESIGN CONSIDERATIONS

Traffic data was provided in the geotechnical evaluation included in the RFP document. The traffic information provided included the total Annual Average Daily Traffic (AADT) for 67 Street. The governing load for the roundabout was assumed to be the traffic fed into the intersection by southbound Johnstone Drive. The highest AADT value utilized in the design was 36,620, and the average daily trucks were 5.5%. An additional 20 trips per day of public transportation were also assumed. A California bearing ratio (CBR) of 2.0 was utilized in the concrete pavement design. The calculated Resilient Modulus of the Subgrade was 21.5 MPa. Based on the designed 200 mm of 25 mm base course, a composite Modulus of Subgrade Reaction of 57.8 MPa/m was obtained.

OPTION B – ALTERNATE FULL DEPTH CONCRETE ROADWAY STRUCTURE

The principle behind the proposed Alternate (Option B) is the difference in the structural performance of rigid PCCP and flexible asphalt concrete pavement (ACP). The flexible pavement structure relies on the asphalt, base, and sub-base layers to transfer the applied load from heavy vehicles through each layer of the pavement structure. Therefore, each layer of the asphalt structure is important to the structural integrity of the pavement. Rigid pavements do not require the base and the sub-base layers for structural support and subgrade strength is not a critical element in thickness design. Subgrade strength has a minor impact on the overall thickness of a concrete pavement structure but uniform support is the key to good performance. The load distribution concept is illustrated below (from Cement Association Canada, An Overview of Concrete Pavements in Canada, 2000).



Based on the load distribution in PCCP, the volume of the excavation of the existing granular material was reduced to accommodate the concrete and the 200 mm designed thickness of the granular material. The remaining granular material from the ACP structure was intended to serve as the subgrade for the PCCP structure.

Based on the design period of 40 years, traffic loading, subgrade support and composite modulus of subgrade reaction, and the remaining input parameters, the designed pavement structure is presented in Table 1.

Table 1: PCCP Design		
PCCP (mm)	**25 mm Crushed Granular Base (mm)**	**Existing Granular Sub-Base**
240	200	Not required – shall match adjacent structure where applicable

Concrete properties assumed in the design were to comply with the Canadian Standards Association (CSA) A23.1-14, Table 1, Table 2, and Table 4 requirements for class of exposure C-2, a minimum flexural strength of 4.2 Mpa at 28 days, and synthetic macrofibre reinforcement at 2 kg/m^3.

The total thickness of the PCCP structure is 440 mm. For comparison, the total thickness of the ACP flexible pavement structure is 800 mm, the structure consists of 200 mm ACP, 200 mm GBS, and 400 mm GSBC, and the design life is 20 years.

LIFE CYCLE COST ANALYSIS

Pavement type selection is one of the most challenging decisions for municipalities. Several engineering factors such as materials and structural performance are considered in conjunction with the initial and life cycle costs as well as sustainable benefits. Concrete roundabouts are long lasting and easy to maintain as concrete does not push, shove, or rut under the turning motion of heavy vehicles around the intersection. Concrete provides a long term solution (design life of concrete pavement 40 years versus 20 years for flexible pavements) and is well-suited to areas where future disruption to traffic must be kept to a minimum. Additional sustainable benefits are listed as follows.

- Long-term durability of PCC as compared to asphalt concrete that requires periodic rehabilitation such as overlays every five to ten years.
- Drainage characteristics are preserved over time when rutting, shoving, and potholes are not a factor.
- More efficient construction as concrete is placed in one pass of the paver instead of multiple lifts and mats needed in ACP construction.
- Decreased potential for hydroplaning provided by texturing, which assures good friction and better performance under wet conditions.
- Superior night time visibility as concrete pavement reflects light in a diffuse manner and light hitting concrete pavement is reflected at all angles, therefore illuminating a greater area of the roadway compared to asphalt pavements.
- Roadside noise levels can be modified with the surface texture characteristics.
- Environmental benefits such as the lower total energy, reduced carbon dioxide emissions from vehicles operating on concrete pavements, reduction of urban heat island effect, and use of recyclable materials and industrial by-products.
- Reduced impact to the public as the frequency of repair and rehabilitation work is lower.

COST ANALYSIS

The equivalent pavement structures were compared using a Life Cycle Cost Analysis (LCCA) in terms of their Net Present Value (NPV). This LCCA approach calculates the initial construction costs for each pavement structure and predicts future maintenance and rehabilitation costs. It should be noted that the financial contribution of the greenhouse gas emissions (GHGs) reduction for PCCP was not accounted for. However, recent studies indicate that significant GHG emission reductions are possible resulting in up to 10% reductions when compared to unimproved baseline (ACP) designs.

Typical pavement preservation plans used for the LCCA for the Major Arterial for ACP and PCCP are presented in Table 2 and Table 3. In order to evaluate the LCCA, one section of roadway 1,000 metres in length and six lanes wide was assessed. This is approximately 23 metres wide, for a total assessed pavement area of 23,000 square metres.

Table 2: ACP Preservation Plan

Expected Year	Activity	Estimated Quantity
8	Rout and seal	300 m
8	Spot repairs (mill 40 mm/patch 40 mm)	5%
13	Rout and seal	1150 m
13	Spot repairs (mill 40 mm/patch 40 mm)	15%
18	Mill hot mix asphalt (HMA)	50 mm
18	Full depth asphalt base repairs	10%
18	Resurface with new surface asphalt	50 mm
23	Rout and seal	750 m
28	Rout and seal	1500 m
28	Spot repairs (mill 40 mm/patch 40 mm)	10%
32	Mill HMA	90 mm
32	Resurface with new base asphalt	50 mm
32	Resurface with new surface asphalt	40 mm
37	Rout and seal	2250 m
40	Spot repairs (mill 40 mm/patch 40 mm)	10%
45	Mill HMA	50 mm
45	Full depth asphalt base repairs	10%
45	Resurface with new surface asphalt	50 mm
48	Rout and seal	2250 m

Table 3: PCCP Preservation Plan		
Expected Year	**Activity**	**Estimated Quantity**
12	Reseal joints	25%
12	Partial depth PCC repairs	2%
25	Partial depth PCC repairs	5%
25	Full depth PCC repairs	10%
25	Reseal joints	50%
25	Texturize surface	25%
40	Partial depth PCC repairs	5%
40	Full depth PCC repairs	15%
40	Reseal joints	50%
40	Texturize surface	50%

Based on the available information, the LCCA was completed to compare the overall cost that could be expected for ACP and PCCP over a 50 year analysis period. The LCCA for comparing equivalent pavement structures was completed using a discount rate of four percent (4%), as recommended in the Alberta Transportation (AT) Pavement Manual. The initial construction costs and the future pavement preservation costs based on 30 MPa subgrade strength were estimated for ACP and PCCP and are presented in Table 4.

Table 4: LCCA Comparison				
Pavement Type	**Initial Construction Costs ($)**	**NPV Pavement Preservation Costs ($)**	**Life Cycle Costs ($)**	**Cost Difference (%) Compared to ACP**
ACP	3,597,200	1,348,227	4,945,427	
PCCP Option B	4,298,470	358,233	4,656,703	-5.83

It should be noted that a negative cost difference indicate that a rigid pavement has a lower life cycle cost than a flexible pavement.

The results of the LCCA indicate that PCCP Option B has a lower life cycle cost when compared with ACP. Since the principle of PCCP performance does not require any substantial granular thickness and the actual requirement for granular thickness is reflected in the estimates, PCCP Option B is more cost effective when compared with ACP. The pavement preservation costs are significantly lower for PCCP.

Of importance is the timing of repairs required for the flexible and rigid pavement options; the first repairs to ACP are required four years earlier than for the rigid pavement option, and ACP repairs are required on a much more frequent basis.

The life cycle presented in Table 4 is based exclusively on the real costs of construction and NPV of pavement preservation costs. However, the following items were not quantified in the LCCA model but would additionally decrease the life cycle cost of concrete options:

- GHG reduction for PCCP due to use of industrial materials and recycled materials and the improved fuel economy for driving on concrete surfaces.
- The cost of reduced accidents impact due to less hydroplaning and improved night visibility.
- The cost of traffic accommodations and traffic disruption for users when the pavement preservation items are less frequent than ACP.

TRAFFIC ACCOMMODATION STRATEGY

The Traffic Accommodation Strategy (TAS) for both the A and B options were identical to facilitate all work within the confines of the proposed project limits as outlined in the Terms of Reference (TOR). The purpose of the TAS is to effectively manage and mitigate all traffic expecting to enter and exit the work zone. The best strategy is one that ensures traffic is managed through the work zone without delay, has options, or has enough warning to choose an alternate path and avoid the area completely. The main concerns were as follows:

1. Maintain two lanes of traffic through the work zone in both directions, primarily at peak periods with the potential to drop to one lane in the westbound direction in off peak hours for short durations.
2. North and south movements on Johnston Drive and Orr Drive will be eliminated and will be limited to right turn movements only.
3. Provide an acceptable detour for transit through the work zone.
4. The TAS must ensure access to businesses to reduce potential disruptions.

The challenges of the TAS reports, which included control drawings showing stages, detour routing, and access management, were due to several changes in the geometrical design of the roundabout and additional construction activities within the intersection construction zone. Each of the changes triggered a new TAS report to ensure traffic through the work zone was managed without delay.

CONCLUSIONS

Based on long-term durability, life cycle costs, construction efficiency, and less frequent disruption to traffic due to future scheduled maintenance, The City of Red Deer selected a rigid pavement (PCCP) option for the upgrades to the 67 Street and Johnstone Drive intersection. The construction of PCCP was more efficient as some of the existing granular material remained in place and concrete was placed in one pass of the paver instead of multiple lifts and mats.

One of the benefits of the installation of a roundabout is the improvement in overall safety performance. The reasons for the increased safety level at roundabouts include fewer vehicular conflict points in comparison to conventional intersections, reduced potential for high severity conflicts such as right angle and left turn head-on crashes, low absolute speeds associated with roundabouts allowing drivers more time to react to potential conflicts, and reduction of crash severity. In addition, pedestrians need to cross only one direction of traffic at a time at each approach as they traverse roundabouts. Concrete roundabouts are long lasting and easy to maintain as concrete does not push, shove, or rut under the turning motion of heavy vehicles around the intersection and may become a preferred choice for future transportation projects.