

CONCRETE PAVEMENT A SUSTAINABLE CHOICE

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ABSTRACT

Portland cement concrete pavement (PCCP) has long enjoyed the reputation as a longer lasting, durable pavement surface with low maintenance costs. Likewise, PCCP from a safety perspective has demonstrated a reduced potential for hydroplaning and better night time visibility. This paper will look at the sustainable performance characteristics of concrete pavement by examining and documenting some of its many social, economic and environmental advantages.

The paper will provide details on the various social benefits of concrete pavement including: reduced potential for hydroplaning; better night time visibility; improved stopping distance; and enhanced ride and comfort. Research on the environmental benefits such as reduced life cycle embodied energy for concrete compared to asphalt roadways, reduced “urban heat island” effect, and smog reduction are also identified. In addition, the paper will review the findings of several studies on truck fuel savings from traveling on rigid versus flexible pavement and show how these fuel savings translate into reduced greenhouse gas (GHG) and smug emissions. The reuse and recyclable nature of PCCP and use of supplementary cementing materials (SCM) will also be addressed. PCCP structures will be discussed to demonstrate the aggregate savings of when utilizing PCCP. Economic benefits such and life cycle cost and potential for reduced lighting requirements for PCCP are also being provided.

1. INTRODUCTION

Currently, DOT and municipal specifications do not require a new pavement to demonstrate sustainable performance characteristics. As the world’s non-renewable resources such as fossil fuels and roadway aggregates decrease in availability, it is important for all levels of government to begin considering paving structures on a sustainability basis rather than just a first cost basis. For government agencies to consider the sustainability of different types of pavement they will require documentation identifying the various attributes inherent in a pavement product. To help in this decision process it is essential for decision makers to know how a pavement structure measures up from the perspective of the three pillars of sustainability – environmental, social and economic benefits.

This paper provides an overview of the benefits Portland Cement Concrete Pavement (PCCP) structures provide related to the these key pillars of sustainability. Government agencies considering the sustainable benefits of the different pavement

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types will be better equipped to make informed decisions related to the impact new and rehabilitated roadways have on the general public.

2. ENVIRONMENTAL BENEFITS

Concrete pavement provides many environmental advantages compared to other pavement structures. This section of the report looks at the many environmental benefits including: reduced energy consumption, reduced carbon dioxide emissions from operating on PCCP, reusable and recyclable paving material, reduction in the use of granular materials, use of industrial by-products, heat island effect, smog reduction and use of pervious pavements.

2.1. *Reduced Energy Consumption*

The Athena Sustainable Materials Institute researched the Life Cycle Embodied Energy and Global Warming Emissions for Concrete and Asphalt Roadways. The study presents embodied energy and global warming potential (GWP) estimates for the construction and maintenance of equivalent PCCP and hot mixed asphalt (HMA) pavement structures for three different classes of roadway: Class 1 – secondary highway/local collectors; Class 2 – major highways/arterial roads; and Class 3 – major urban freeways. Athena (1998) The Athena study investigated 12 different pavement structures, each one lane kilometer over an assumed study period of 40 years. This takes into account activities from original construction through major rehabilitation for both roadway types. Two subgrade strengths were analyzed for each pavement class (i.e. California Bearing Ratios (CBR) of 3 and 8) to make the results broadly applicable across Canada. The study and analysis took into account material use and construction of the granular subbase, base and finished surface for both PCCP and HMA roadways, but eliminated items common to both (i.e. right-of-way clearing).

The report shows the PCCP pavement has lower total primary energy results for all roadway classes analyzed. The results ranged from a low of 2.4% less for the secondary highways / local collector roads (Class 1 CBR = 8) to as high 30% less for major highways / arterial urban roads (Class 2, CBR = 3). Figure 1 shows an example of the comparative total energy results for the urban freeway at 0% RAP. If feedstock energy (i.e. liquid asphalt in the asphalt pavement) is also considered in the analysis the total energy differences between the PCCP and HMA structures increases from a range of 245% to 349% (PCCP favour). Athena (1998)

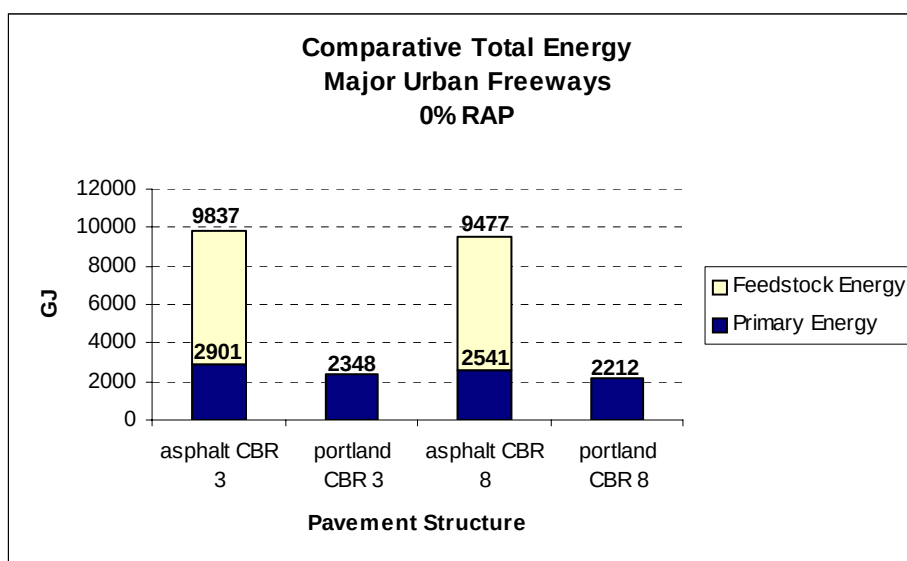


Figure 1: Comparative Total Energy HMA versus PCCP
- Major Urban Freeways – 0% RAP

Source: Athena Sustainable Materials Institute, Life Cycle of Embodied Energy and Global Warming Emissions for Concrete and Asphalt Roadways

Other findings from the report Include:

- For all 12-pavement structures investigated, the asphalt concrete alternatives require significantly more energy from a life cycle assessment perspective.
- The inclusion of 20% RAP in the HMA mix for roadways in areas where it is likely to be permitted (i.e. excluding urban freeways) reduces the total energy estimates for the asphalt but the remaining differences are still significant.
- Increases in transportation hauling distances for granular materials tend to increase the advantage of PCCP construction. This is due to the need for substantially more granular material being required under most HMA pavement compared to PCCP. Athena (1998)

Since the study deals with embodied energy and greenhouse gas (GHG) emissions for initial road construction and major maintenance or rehabilitation, it primarily reflects the effects of producing and transporting materials and components. The scope did not include operational considerations such as truck fuel savings by operating on different pavement types and energy savings due to the different light reflectance properties of the pavement types. The report does, however, recommend these types of issues be taken into account in any

decisions predicated on life cycle environmental effects. The report also noted that throughout the study Athena took:

“A conservative stance from the perspective of the Portland cement alternatives to avoid any perception of bias in the client’s favour. In fact, if anything we may have biased results in the other direction. For example, the following was identified in the report’s covering letter:

- *Excluding sub-grade construction from the scope ignores benefits that may result from narrower sub-grades for Portland cement roads, depending on the circumstances;*
- *Using 10% fly ash in the concrete specification leans toward the low end of the permitted range of fly ash use in some jurisdictions;*
- *The Portland cement designs may be conservative in terms of the amount of base and sub-base granular material, again depending on the circumstances;*
- *We have treated recycled asphalt pavement (RAP) as free of any environmental burdens, including feedstock values and energy costs incurred in its acquisition and transportation; and*
- *No benefit has been allowed for the life remaining in a Portland cement road beyond the 40-year study period.*
- *Individually, none of these factors is likely to involve significant distortion of the relative effects of the two types of construction, but together they may have a more significant bearing on the results and should at least be acknowledged.” Athena (1998)*

2.2. Reduced Carbon Dioxide (CO₂) Emissions from Operating on PCCP

Differences in fuel consumption as a function of pavement structure are an important consideration for users and government agencies. Heavy vehicles cause greater deflection on flexible pavements than on rigid pavements. This increased deflection of the pavement absorbs part of the vehicles rolling energy that would otherwise be available to propel the vehicle. Thus, the hypothesis can be made that more energy and therefore more fuel is required to drive on flexible pavements. Zaniewski (1989)

Several studies have been completed that support these findings. The first study was part of a larger 1989 study to update vehicle operating costing tables by the Federal Highway Administration (FHWA) for the World Bank. In this study, the FHWA found that the savings in fuel consumption for heavy vehicles traveling on concrete versus asphalt pavements was up to 20%. Zaniewski (1989)

Considering the results of the FHWA work, the Cement Association of Canada (CAC) initiated its own series of studies to investigate the potential truck fuel savings when operating on concrete pavement compared to asphalt pavement. In the fall of 1998 a small-scale study was undertaken to verify the findings of the FHWA work. Based on the results of this preliminary study a second more detailed study was funded by CAC for a year round analysis to examine the difference in fuel consumption of heavy trucks travelling on HMA, PCCP and composite pavements (PCCP with HMA surface) over the range of temperatures experienced during Canada's four distinct seasons (spring, summer, fall and winter). This study took place during 1999 and 2000. The study was completed by National Research Council of Canada (NRC) utilizing state-of-the-art real time computerized data collection equipment and current truck configurations / equipment and weights driven on Canadian highways. A regression analysis was performed on the raw fuel data collected during numerous runs made by the test vehicle when driving over asphalt, concrete and composite pavement structures. Using this model, the study concluded driving on a concrete highway provides potentially statistically significant truck fuel savings of up to 11%. NRC (2000)

To confirm the statistical significances of the Phase II fuel study data a multivariate analysis (MVA) of the 1999 - 2000 truck fuel data was completed. The databases collected (i.e. vehicle data, IRI, GPS) over all seasons were successfully transformed so that the test data and road physical data were merged into a single file with a common time and distance reference with over 64,000 records. The unified data files were then analyzed with a statistical analysis package (Minitab) to determine validity of a number of multiple regression models. Based on the analysis the following variables were found to have the highest statistical significance in predicting the fuel consumption of the vehicle - pavement structural type (concrete, asphalt, composite), vehicle load (mass), pavement temperature, road roughness as measured as IRI, road grade, and vehicle speed. These variables explained between 60% and 55% of the variation in fuel consumption on roads with IRI up to 2.2, which is quite satisfactory given the large size of the data set. The model developed indicated that concrete pavements had statistically significant lower fuel consumption than asphalt and composite pavements throughout the temperature range for full loaded trucks operating on smooth pavements. The report states the average change in fuel consumption from concrete pavement for IRI of 1.0 at 100 km/h ranges from 4.1 to 4.9 percent for asphalt and 2.7 to 3.2 percent for the composite pavement. At 60 km/h, the ranges are 5.4 to 6.9 percent for asphalt and 3.6 to 4.6 percent for the composite pavement. Taylor et al (2002)

The Cement Association of Canada undertook a third fuel study to verify the Phase II study results in partnership with the Federal government (Natural Resources Canada), the Ministry of Transportation of Ontario (MTO), and Ministère des Transport du Québec (MTQ). Like the Phase II study this was a year long study comparing fuel consumption data for HMA, PCCP and

composite pavements but would also include collecting data on pavement strength and car fuel consumption. Results from this study should be available in June 2005.

To show the potential effects of these fuel savings based on a tractor - trailer with a diesel engine travelling 160 000 km / year and averaging 2.48 km/litre, the CO₂ savings for each motor unit would be the following:

At 1% fuel economy over one year the CO₂ savings would be 1.785 metric tons or 0.0111572 kg of CO₂ / km

At 2% fuel economy over one year the CO₂ savings would be 3.57 metric tons or 0.0223144 kg of CO₂ / km

At 4 % fuel economy over one year the CO₂ savings would be 7.14 metric tons or 0.0446287 kg of CO₂ / km

At 7% fuel economy over one year the CO₂ savings would be 12.50 metric tons or

0.0781 kg of CO₂ / km

Based on the evidence identified above it is conservative to say that there are significant GHG savings when operating tractor-trailers on PCCP versus HMA, which also means less pollutants being emitted into the environment. Furthermore, the reduced fuel consumption decreases trucking firms' operating costs, thereby, possibly reducing cost of goods to consumers.

2.3. *Reusable and Recyclable Paving Materials*

Concrete pavement is a versatile product which can be reused by performing concrete pavement restoration techniques. Repair techniques such as full depth / partial depth repairs and load transfer restoration combined with diamond grinding will restore the pavement to an almost new state. Pavements in an advanced state of deterioration may be able to be left in tack and used as a base for a new PCCP. In these cases a thin layer of asphalt of 25 to 50 mm is placed over the old PCCP and then overlaid by a new PCCP.

Another possible reuse option for PCCP is a bonded overlay. When traffic patterns change and a roadway is receiving substantially more traffic than originally designed for a bonded overlay can be used to increase the PCCP thickness. As long as the underlying pavement is in good condition a new layer of concrete pavement can be placed over the existing PCCP, with matching joints, which effectively increases the amount of traffic the pavement structure can handle and increases the pavements expected life.

Concrete pavement is also a 100 percent recyclable material and provides government agencies an attractive option at reconstruction time. If subgrade or

pavement condition does not allow the older PCCP to be reused in its existing state it can be rubblized and used as granular fill, base course for new pavement and / or as an aggregate for new concrete pavement. In addition, the steel in the PCCP such as dowels and tie bars can be recycled. ACPA (1993) In fact, a company in the United States is developing a machine called Paradigm which is an in-place recycling system for concrete pavements. This machine breaks and crushes the concrete into the desired aggregate sizes and collects the reinforcing steel.

Reusing the concrete pavement minimizes the amount of non-renewable resources required for a new pavement structure and eliminates potential material going to landfill sites. In addition, the short hauling distance for the aggregate reduces the cost of providing aggregates to the job.

2.4. **Utilize Less Granular Material**

The essential difference between flexible and rigid pavements is the manner in which they distribute the load over the subgrade. Figure 2 below depicts how PCCP and HMA pavements carry heavy vehicles loads. Because of concrete's rigidity and stiffness, the slab itself supplies the major portion of a rigid pavement's structural capacity and distributes the heavy vehicle loads over a relatively wide area of subgrade. The flexible pavement, built with weaker and less stiff material, does not spread loads as well as concrete. Therefore, flexible pavements usually require more layers and greater thickness for optimally transmitting load to the subgrade. ACPA (2004)

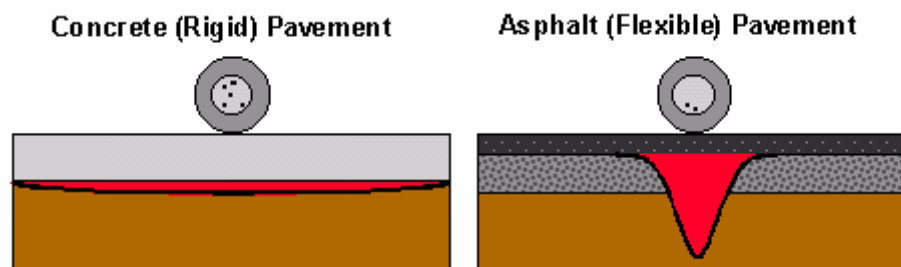


Figure 2: Illustration of How Concrete and Asphalt Pavement Structures Carry Vehicle Loads

*Concrete acts more like a bridge over the subgrade.
cm for cm much less pressure is placed on materials below
concrete than on asphalt pavements*

Source: American Concrete Pavement Association website

Applied Research Associates, Inc. ERES Consultants Division prepared an analysis on equivalent pavement designs for flexible and rigid pavements. In this paper ERES identifies the amount of granular material required in the base,

subbase and shoulders for the PCCP and HMA structures. For arterial roads on low strength subgrade the report recommends the following pavement structures: PCCP (200 mm, 150 mm base and 150 mm subbase) and HMA (175 mm HMA, 150 mm base and 585 mm subbase). ERES (2003) Based on these structures there is approximately twice as much granular material used in the asphalt structure. The environmental effect of this increased usage of granular material is magnified as the hauling distance to job sites increases due to depletion of suitable aggregate sources, thereby, increasing the fuel consumed by the gravel haul trucks and the CO₂ emitted from them. Therefore, a concrete pavement structure provides a more sustainable pavement when considering aggregate use.

2.5. *Use of Industrial by-products*

Concrete pavement is a mixture of fine and coarse aggregate, cement, water and admixtures. It is possible to replace a portion of cement with a variety of industry by-products often referred to as supplementary cementing materials or SCMs. These materials if used in the proper proportions will enhance the properties of the concrete mix as well as stabilize the by-product material in the pavement structure rather than dumping them at local landfill sites. The three most commonly used SCMs are fly ash (by-product of coal burning), blast furnace slag (by-product of steel manufacturing) and silica fume (by-product of manufacture of silicon or ferrosilicon alloy). Some of the enhanced properties of using SCMs include improved concrete pavement durability, permeability and strength. Fly ash and blast furnace slag also increase workability of the concrete mixtures. Fly ash, blast furnace slag and silica fume can also control alkali - silica reactivity also known as ASR (a chemical reaction that occurs when free alkalis in the concrete combine with certain siliceous aggregates to form an alkali-silica gel. As the gel forms, it absorbs water and expands, which cracks the surrounding concrete). Kozmatka et al (2002)

Another added benefit of utilizing SCMs in concrete pavement is the reduction of CO₂ emissions associated with the PCCP. The SCMs replace a portion of the cement in the concrete mixture and thereby decreases the total amount of CO₂ associated with the construction of PCCP structure. The amount of CO₂ reduction is related to the percentage of the SCM used in the mix design. Work is currently underway to determine what amount of fly ash, blast furnace slag and silica fume is permitted across Canada and the northern United States by the various levels of government agencies.

2.6. *Heat Island Effect*

Dark, heat – absorbing surfaces, such as flexible pavements and black roofs create phenomena called urban heat islands. According to the article, *Keeping Things Cooler*, the average U.S. urban temperatures have risen an estimated 1° to 2° C in the past 4 decades. Downtown areas register readings up to 5° C

warmer than suburban and rural surroundings, where natural vegetation cools the air through evapotranspiration. Granitto D. (2000) Furthering the problem is the cranking up of air conditioning in urban areas to counteract higher temperatures which not only increases energy costs but also increases emissions of GHG, accelerating pollution and ozone depletion. It is estimated that smog increases 3% for every degree of temperature. Granitto D. (2000)

Since concrete's light color reflects light, it heats up less and reduces the Heat Island Effect. The exact effect of pavements on heat retention and resulting air quality issues is complicated by several factors, including: shadows from vehicles, trees and nearby buildings; change in pavement colour over time and absorption of reflected solar radiation by nearby buildings. Regardless of such factors, recent research shows black surfaces in the sun can become up to 21°C hotter than the most reflective white surfaces. Roads and parking lots are frequently paved with black asphalt and other dark materials that absorb most of the sunlight that falls upon them. The energy of the sunlight falling on the surfaces is converted into thermal energy and the pavements get hot, heating the air around them contributing greatly to the heat island effect. As Figure 3 below shows, the reduction in heat retention and emittance can be significant. Figure 3 is a NASA infrared imagery of the Atlanta Airport from May 1997. This figure shows the black asphalt surfaces are in the light to dark orange area while the concrete runway is in the light green to yellow area and concrete parking deck is in the green to light green area. Based on this information it is easy to see concrete surfaces provide a cooler surface than asphalt pavements and a potential solution in combination with natural vegetation for reducing urban heat island affects.

2.7. *Smog (Ozone) Reduction*

An additional environmental result of temperature reductions through urban heat island mitigation practices is the reduction of harmful ozone. This is accomplished by the use of light coloured (high albedo) surfaces. Automobile exhaust and industrial emissions are responsible for the release of a family of NO_x (nitrogen oxide) gases and other VOC's (volatile organic compounds) as by-products of burning gasoline and coal. These NO_x and VOC's combine with oxygen to form ozone on sunny, high temperature days. According to the "Urban Heat Island Group" of the Lawrence Berkeley National Laboratories:

"The formation of smog (measured as ozone) is highly sensitive to temperatures; the higher the temperature, the higher the formation and concentration of smog. In many cases at temperatures below 21°C, the concentration of smog is typically below national standards. At temperatures around 35°C all days can be considered smoggy. Cooling a city by about 3°C can have a dramatic impact on smog concentration." In Los Angeles, for example, for every 0.6 degree centigrade the temperature rises above 21°C, the incidence of smog increases by 3%. LBL (2004)

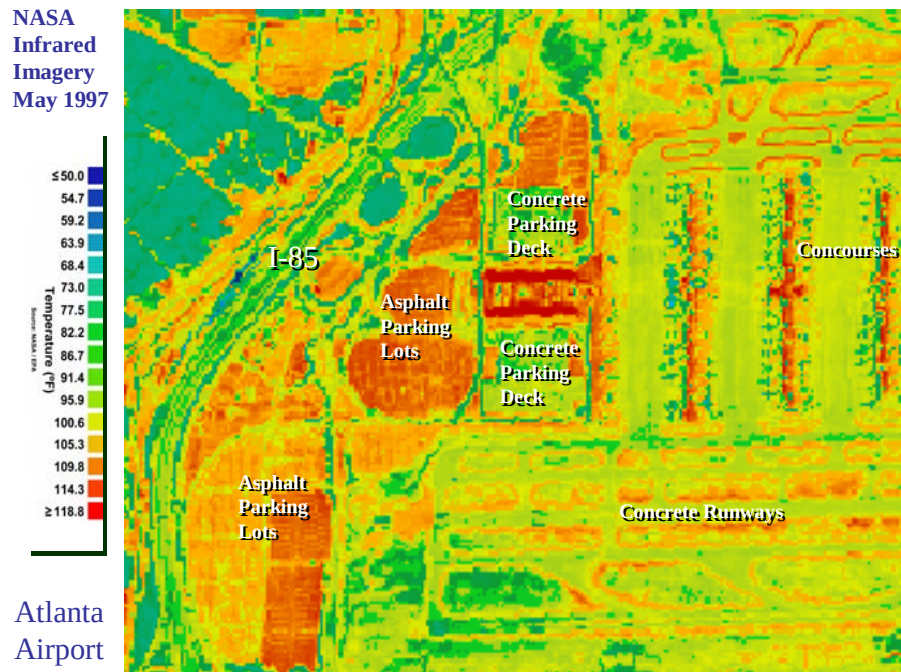


Figure 3: NASA Infrared Imagery Atlanta Airport May 1997

Source: NASA Infrared Imagery Atlanta Airport May 1997

Recent studies show surface heating differentials across the Atlanta, Georgia urban landscape using remotely sensed surface temperatures of between 21 and 55 degrees centigrade with daytime air temperatures in the high twenties. Extremes in high temperature readings included asphalt spots in excess of 66 degrees centigrade. LBL (2004)

While ozone pollution is formed primarily in urban and suburban areas, its effects and impact are being detected as far as 400 kilometres downwind of the urban/industrial areas in which it is generated. EPA (1998)

2.8. *Use of pervious pavements*

Pervious pavements have been around for some time and can be constructed of concrete or asphalt surfaces. The Green Building movement, however, has brought more of a focus on this technology as an environmentally friendly product.

Pervious concrete pavements also known as “no fines concrete” or “porous concrete” are comprised of specially graded coarse aggregates, cementitious materials, admixtures, water, possibly fibres and little or no fines. Mixing these products in a carefully controlled process creates a paste that forms a thick

coating around aggregate particles and creates a pavement with interconnected voids in the order of 12 to 35 percent. This provides a pavement that is highly permeable with drainage rates in the range of 100 to 750 litres per minute per square meter. Brown (2003) The most common uses of this pavement are parking lots, low traffic pavements, and pedestrian walkways. Figure 4 shows a picture of a pervious pavement integrated with the existing trees and grass areas.



Figure 4: Pervious Concrete Pavement Integrated with Natural Vegetation

Pervious concrete pavements reduce storm runoff and minimize the amount of pollutants (car oil, anti-freeze and other automobile fluids) contained in storm water that is captured. By allowing the rainfall to percolate into the ground, soil chemistry and biology are allowed to naturally “treat” the polluted water. Brown (2003) This allows for reduction in storm water retention areas. These pavements also recharge groundwater thereby, reducing the need to water trees and shrubs in the paved areas. The light coloured pavement surface is also a solution to the heat island effect discussed in section 2.7.

Pervious concrete pavements have been used mainly in areas with minimal freeze-thaw issues. Currently, only a few installations exist in extreme wet freeze-thaw regions. However, studies are underway to investigate this issue to address any possible problems or concerns in this area.

Clogging of pervious pavements can occur and in many cases is due to design issues. For example, where natural areas with grass or exposed soils is allowed to drain stormwater across the pervious pavement surface a fine material may be deposited in localized areas of the pavement. Routine sweeping or vacuuming of the pavement surface will remove this material or any vegetation

matter that may collect on the pavement. In addition, pressure washing will restore the porosity of clogged pervious concrete to nearly new conditions.

3. SOCIAL BENEFITS

Concrete pavement provides many social benefits compared to other types of paving surfaces. This section of the report looks at the many social benefits of concrete pavement and how they assist society including the following: decreased potential for hydroplaning, better night time visibility, improved stopping distance, improved fuel savings and reduced pollution, improved health and micro-climate through smog reduction, smooth ride for long period, and quiet ride.

3.1. *Decreased Potential for Hydroplaning*

Hydroplaning is tire separation from the pavement surface by a layer of water, which causes loss of vehicle steering and braking control. Several factors may contribute to hydroplaning potential such as tire wear, driver speed / experience and pavement surface characteristics. The following discussion focuses only on the pavement surface characteristics as government agencies have little control over tire wear or driver experience and behaviour. Governments do, however, decide on the type of pavement chosen for roadways.

All types of pavement have the potential for hydroplaning when it is raining or water is present on the surface. However, concrete pavement's macrotexture, grooves put in the plastic concrete, provide water a channel to escape from beneath the vehicle's tires thereby reducing the hydroplaning potential. In addition, concrete's rigid structure prevents heavy vehicles from causing deformations in the pavement surface such as rutting and washboarding where water can accumulate and create increased hydroplaning potential. If studded tires are permitted to be used on provincial roadways high strength concrete pavement can be used to virtually eliminate potential wear ruts in the vehicle wheel paths.

3.2. *Better Night time visibility*

Concrete pavement's light reflective surface not only provides a pavement surface that minimizes heat island effect in urban areas but also provides better night time visibility. As noted in the earlier write-up on heat island in section 2.6 effect the albedos (reflectance) of pavement surface is better for concrete pavement (0.35 – 0.40 new PCCP and 0.20 – 0.30 weathered concrete) than asphalt (0.05 -1.0 new HMA and 0.10 – 0.15 weathered HMA).

A case can be easily made for additional cost and energy saving associated with having to specify fewer high-output lighting fixtures and standards associated with the specification and construction of street, road and parking lots/structures

built with highly reflective concrete surfaces. The case of improved visibility and safety for drivers and pedestrians alike can also be made as demonstrated in Figures 5 and 6.

“While high-albedo (reflective) pavements can cool temperatures during the day, reflective pavements can improve visibility at night. Consider a pedestrian near a street lamp crossing the street at night. The pedestrian is obviously illuminated by light from the street lamp. However, the pedestrian is additionally illuminated by light from the street lamp that is *reflected* off the pavement. The geometry is drawn in the figure following.” LBL (2004)

“We estimate, for a subject S (of area A_s), that the ratio of light from the street lamp that reflects off a pavement ("Reflected light") to that light directly from the street lamp ("Direct light") is approximately equal to the pavement's reflectivity in the visible spectrum ("Visible reflectivity"). In other words, if the reflectivity is 10% and 10% additional light will illuminate the pedestrian from the street lamp after reflecting from the pavement. If the reflectivity is high, the amount of street lighting could be reduced to achieve the same illumination thus saving energy.” LBL (2004)

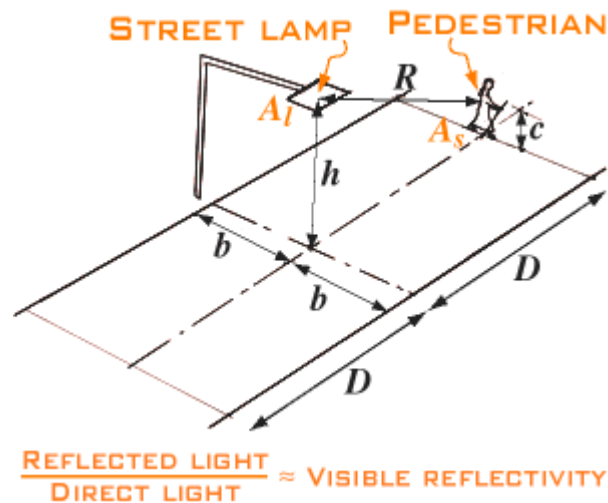


Figure 5: Street Lamp Light Reflectance Geometry



Concrete Pavement

Asphalt Pavement

Figure 6: Illustration of Light Reflectance of Concrete Pavement versus Asphalt Pavement

Source: The Benefits of Concrete Highways Information Bulletin, CAC 2001

This superior reflectance characteristic of concrete pavement provides better illumination of the roadway when driving at night. The figure above provides a visual example of the difference in the light reflectance of a concrete pavement and asphalt pavement.

3.3. *Improved Fuel Savings and Reduced Pollution*

A concrete pavements largest societal benefit is the potential of increased fuel savings and reduced pollution. For example, if highway 20 between Montreal and Quebec City was entirely be built with concrete, the 2,920,000 trucks circulating annually on this portion of highway, and assuming a 4 % fuel savings, there would be 74.3 tonnes of CO₂ saved per day or 27,106 tonnes of CO₂ every year. Already on this same highway there is 12 km of PCCP, which provides annual CO₂ savings of 5.78 tonnes per day and 2,111 tonnes per year.

Based on the evidence identified above it is conservative to say that there are significant GHG savings when operating tractor-trailers on PCCP versus HMA, which means less pollutants being emitted into the environment.

3.4. *Improved Health and Micro-Climate through Smog Reduction*

The use of lighter (high albedo) pavement materials in urban areas where high spring, summer and fall temperatures can exacerbate smog and ozone development, have been shown in recent tests to significantly reduce local air and surface temperatures. Responsible pavement surface material selection when combined with other heat island mitigation measures have been shown to

reduce local air temperatures by 3+ degrees centigrade. These practices directly promote reduced smog/ozone production, as well as other micro-environmental and human health threatening pollutants, resulting in improved air quality, reduce incidents of respiratory distress and reduced damage to local flora, fauna and structures.

3.5. *Improved Stopping Distance*

For the user, a concrete pavements rigid surface is important when considering personal safety. During wet weather, ruts in flexible roads will collect water and increase the potential for hydroplaning. Furthermore, wetness trapped in these ruts can turn to ice during freezing temperatures.

A study by the University of Illinois entitled, “Safety Considerations of Rutting and Washboarding Asphalt Road Surfaces” demonstrates that overall stopping distances on concrete surfaces are shorter than for asphalt surfaces, especially when asphalt is wet and rutted, as shown in Figure 7. The values in this figure do not take hydroplaning into account, which would increase the asphalt stopping distance values. ACPA (1998)

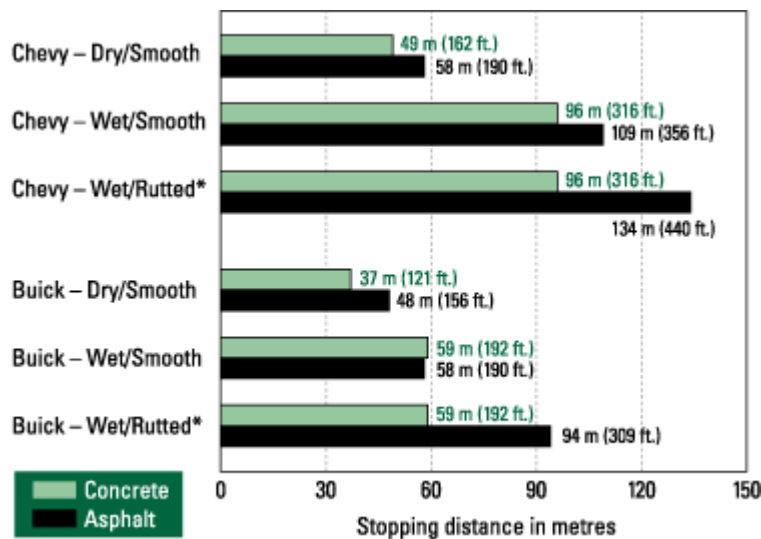


Figure 7: Measured Stopping Distances of Two Different Vehicles on Various Surface Conditions

Source: American Concrete Pavement Association Engineering Bulletin
 - Whitetopping – State of the Practice, ACPA 1998

3.6. *Quiet Ride*

Roadside noise levels are also a public concern when determining highway surface material. A report by the U.S. Department of Transportation in 1996

concluded that, “Properly constructed PCCP, with transversely tined surface, matches the performance of dense-graded asphalt considering both safety and noise factors.” FHWA (1996) In addition, a report by the Wisconsin Department of Transportation concludes, “That it is possible (very simply and at no extra expense) to build a PCC pavement that does not “whine” and has the desired frictional properties. Such a pavement is a “good neighbour”, is safe, provides user comfort and is durable.” WIDOT (1997) Based on the comments of these two reports it is possible to build quiet PCCP similar to that of an HMA surface. Initial pavement smoothness can also affect the quietness of a highway as rougher pavements are noisier pavements. New paving equipment and construction techniques have allowed paving contractors to construct smoother concrete pavements.

3.7. *Smooth Ride for Longer Period*

The Nova Scotia Department of Transportation and Public Works (NSTPW) completed a five-year study on an adjoining section of asphalt and concrete pavement built in 1994 on Highway 104 TransCanada Highway. [NSTPW 1999] Results of the study, which concluded in 1999, showed both pavements performed well over the evaluation period. However, the concrete pavement section out performed the adjoining asphalt pavement in both riding comfort and road smoothness.

Data from the comparative study by the NSTPW indicated that although the new asphalt pavement had a higher riding comfort index (RCI) initially, over time it deteriorated to a lower level than the adjoining concrete pavement. Figure 8 provides an illustration of how the RCI values changed over the 5-year evaluation period. The RCI reading at year five on the concrete pavement was 7.4 compared to 6.9 on the asphalt pavement. NSTPW (1999) Note, the higher the RCI value the more comfortable the ride.

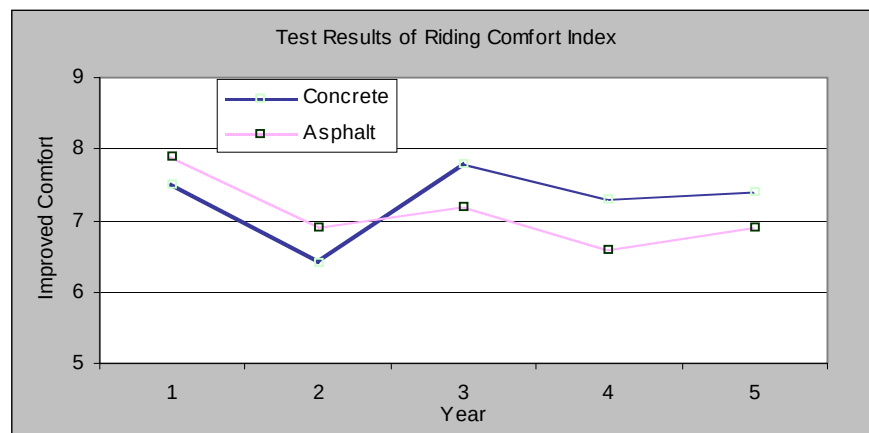
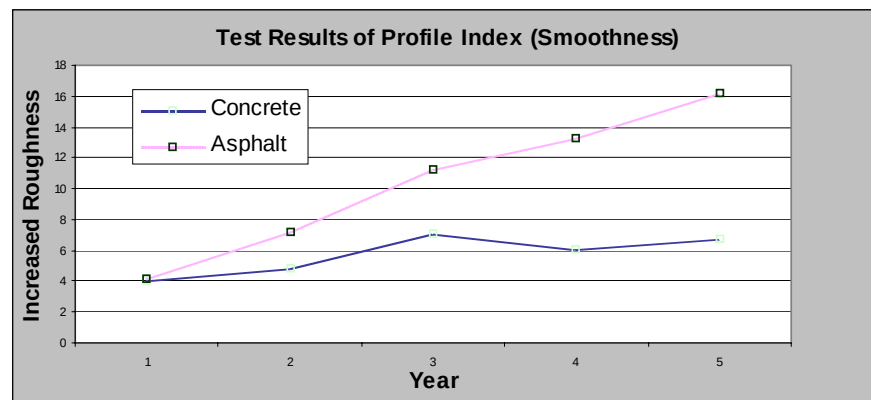


Figure 8: Comparison of Test Results of Riding Comfort Index

Source: Asphalt Concrete Pavement and Portland Cement Concrete Pavement, Highway 104, Cumberland County, Year 5 of 5 Year Study, October 1999.

The NSTPW also measured the profile ride index (PRI) which is a measure of the pavement smoothness where higher numbers represent increased roughness. Results from measurements taken over the first five years of the pavements' lives indicated that the new concrete and new asphalt had approximately the same smoothness after one year. However, over the next four years, the concrete pavement maintained close to its original smoothness, while the asphalt section showed increased roughness. Figure 9 illustrates how the two pavement structures performed. Note, the roughness of the asphalt pavement more than doubled that of the concrete pavement after five years of service (i.e., 6.8 mm/100 metres on concrete versus 16.2 mm/100 metres on asphalt). NSTPW (1999)

Figure 9: Comparison of Test Results of Profile Ride Index



Source: Asphalt Concrete Pavement and Portland Cement Concrete Pavement, Highway 104, Cumberland County, Year 5 of 5 Year Study, October 1999.

4. ECONOMIC BENEFITS

Concrete pavement provides many economic advantages compared to other types of pavement structure including the following: life cycle cost advantage, truck fuel savings driving on concrete pavement reduced fuel costs, reduced lighting requirements, and energy and maintenance cost savings using higher albedo pavement materials.

4.1. Life Cycle Cost (LCC) Advantage

As previously stated, it is generally accepted that concrete pavement requires less frequent maintenance than asphalt pavements. In fact, several Department of Transportations (DOTs) in Canada have called alternate bids on recent highway pavement projects and provided a LCC advantage to the PCCP

options. Table 1 below shows several alternate bids tendered by various DOTs in Canada the last few years and the LCC value the DOTs assigned to the PCCP and HMA options. From this table it is clear the DOT's recognized the LCC advantage of PCCP over HMA. Therefore, this fact needs to be considered when comparing the cost of different pavement options – PCCP, HMA or composite pavement.

Table 1: List of Alternate Bid Highways Projects Across Canada and LCC Advantage Given to PCCP Options

Location	Year Tendered	Project Length (Lane km)	LCC HMA Option (\$)	LCC PCCP Option (\$)	LCC Advantage for PCCP Option (HMA – PCCP) (\$)
Highway 101, NS	2003	21.8	N/A	N/A	\$1.5 Million or 20% More Than Lowest HMA Bid
Highway 417 East	2000 – 2001	78.2	2,014,041	1,580,720	433,321
Highway 417 West	2004 - 2005	73.8	3,421,988	2,561,269	860,719
Highway 401	2004	63.6	2,869,866	2,249,647	620,219
Deerfoot Trail	2003	44 + PCCP Shoulders	5,997,000	2,475,000	3,522,000
Anthony Henday	2004	58 + Lane Width PCCP Shoulders	6,009,700	3,636,900	2,372,800

Source: tender documents

4.2. *Truck Fuel Savings Driving on Concrete Pavement Reduced Fuel Costs*

As discussed in the environmental and social benefits sections concrete pavement provides reduced CO₂ emissions due to truck fuel savings. These fuel savings reduce trucking firms' or independent truckers' operating costs which could lead to reduced consumer prices if the savings are passed on to the public.

Using the same assumptions as in the environmental section an example of the magnitude the potential truck fuel savings can be shown. Based on a tractor - trailer with a diesel engine travelling 160,000 km / year, averaging 2.48 km/L, and diesel fuel cost of \$ 0.70 per litre the fuel savings for truckers would be as follows:

At 2% fuel economy over one year the truck fuel savings would be \$ 903 per year per truck.

At 4 % fuel economy over one year the truck fuel savings would be \$ 1,806 per year per truck.

At 7% fuel economy over one year the truck fuel savings would be \$ 3,161 per year per truck.

This could provide substantial savings to company operating costs depending on the number of trucks the firm is operating.

4.3. *Reduced Lighting Requirements*

As stated in the environmental and social benefits section PCCP's light reflective surface provides a pavement surface that minimizes heat island effect in urban areas as well as provides better night time visibility for the driving public. These advantages can also translate into an economic savings. A report entitled "A Comparison of Six Environmental Impacts of Portland Cement Concrete and Asphalt Cement Concrete Pavements" notes that concrete pavement's mode of reflectance is mostly diffuse (R1 class) compared to asphalt pavement's mode of reflectance typically falling in slightly specular (R3 class). Therefore, HMA requires more lights per unit length of HMA pavement to achieve the same illumination as PCCP. The report goes on to identify the potential cost savings when utilizing concrete pavement compared to asphalt pavement based on a 1985 Chicago example. The results show the cost savings represent 31 % decrease in initial, energy and maintenance costs for lighting PCCP versus HMA pavement. Gajda J. and Miller, M., (2000)

4.4. *Energy and Maintenance Cost Savings using Higher Albedo Pavement Materials*

Higher temperatures in urban areas contribute to additional local energy loads, due in large part to a greater demand for air conditioning. As a result, power plants burn more fossil fuels, increasing both pollution and energy costs. The impact of related savings is directly exemplified by the following facts developed through the LBNL Urban Heat Island Group:

"On warm afternoons in Los Angeles, the demand for electric power rises nearly 2% for every degree Fahrenheit the daily maximum temperature raises. In total, we estimate that about 1-1.5 giga-watts of power are used to compensate for the impact of the heat island. This increased power costs the Los Angeles ratepayers about \$100,000 per/hour, equivalent to about \$100 million per year." LBL (2004)

From the perspective of reduced maintenance and congestion, pavement materials that reflect more sunlight (higher albedo materials) last longer because they are not subject to excessive heat stresses. As access to information on the heat load

characteristics and performance of locally available pavement types improves, informed local pavement selection decisions will also improve, helping to reduce the increased frequency in road closures, delays and associated user costs attributable to pavement failures due to heat related stress. “Many cities would have cooler summers at no extra cost by simply specifying cooler paving materials for new roads and the resurfacing of old ones when needed as a part of their pavement management programs.” LBL (2004)

5. CONCLUSION

It is clear from the preceding sections of this paper that concrete pavement is a very sustainable product with many environmental, social and economic advantages. Environmental benefits include important issues such as reduced energy and aggregate consumption, reduced CO₂ emissions, reusable construction material, use of industrial by-products in the concrete mix design, reduced heat island effect and reduced smog. Social benefits include improved fuel savings, reduced pollution, smooth ride and safe driving surface. Economic advantages include life cycle cost advantage, truck fuel savings, reduced lighting requirements, and energy and maintenance cost savings using higher albedo pavement materials. Therefore, all levels of government should consider evaluating roadway maintenance and construction costs in a more complete manner by considering the sustainability of the roadway structures. This will provide the decision makers with a true cost of the roadway and help them make a more informative decision rather than just considering initial costs of the pavement structure.

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