Sustainable Pavements – Making the Case for Longer Design Lives for Flexible Pavements

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ABSTRACT

Over one quarter of the world's greenhouse gas emissions are caused by transportation and especially road transportation. It is critical for the road construction industry to become part of the solution by proactively implementing technology and construction practices that assist in achieving these challenging emission reduction goals. In addition to improved asphalt technology, better construction and rehabilitation methods, and optimized pavement selection based on life-cycle cost analysis, more attention needs to be focused on pavement sustainability. This concept can be defined as a safe, efficient and environmentally friendly pavement that meets the needs of present-day users without compromising those of future generations.

This paper will consider some aspects of perpetual pavement sustainability based on a practical application of the concept on the Red Hill Valley Parkway project in the City of Hamilton, Ontario. Essentially by designing and building low maintenance highways that have extended serviceable lives, there are environmental benefits in terms of reduced impact on the environment and reduced cumulative greenhouse gas emissions. The assessment of the overall impacts of construction on the environment during road building and maintenance operations used in this paper are based on European experience, particularly in France. In addition, the Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE) computer program developed at the University of California, Berkeley was used to calculate the energy consumption and gas emission during initial construction and the pavement maintenance and rehabilitation. The analysis shows that besides the lower life-cycle cost of the perpetual pavement alternative, the environmental impact of this type of pavement is significantly lower than that of the conventional deep strength pavement.

1.0 INTRODUCTION

The Kyoto Protocol was adopted in late 1997 to address the problem of global warming by reducing the world's greenhouse gas emissions [1]. It went into effect on February 16, 2005, with 141 countries signing on. Canada has committed to reducing its greenhouse gas emissions by six per cent by the time its first commitment period ends in 2012. It is estimated that transportation is responsible for 26% of the world's greenhouse gas emissions. Of this total, some 85% is from road transportation. It is therefore important for the road construction industry to become part of the solution by proactively implementing technology and construction practices that assist in achieving the challenging emission reduction goals. In addition to improved asphalt technology, better construction and rehabilitation methods, as well as optimized pavement selection based on life-cycle cost analysis, more attention needs to be focused on pavement sustainability. The sustainable pavement can be defined as a safe, efficient and environmentally friendly pavement that meets the needs of present-day users without compromising those of future generations (Figure 1). In essence, this is a pavement that has less maintenance demands and longer time between major rehabilitation interventions.

The main criteria for a sustainable pavement are as follows:

- Minimizing the use of natural resources;
- Reducing energy consumption;
- Reducing greenhouse gas (GHG) emissions;
- Limiting pollution (air, water, earth, noise, etc.);
- Improving health, safety and risk prevention; and
- Ensuring a high level of user comfort and safety.

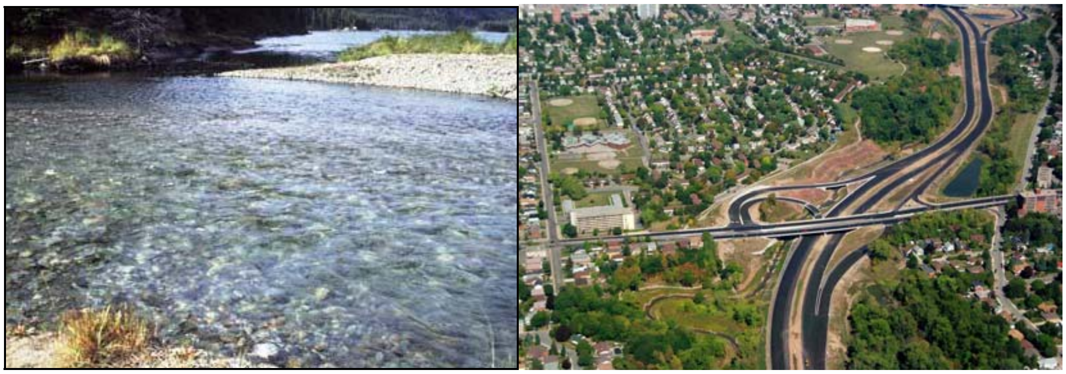

Figure 1. Sustainable pavements should be safe, efficient and limit the impact on the environment

Over the years, most municipal governments have been forced by political pressure and scarce financial resources into a short-term approach toward pavement design and management. This has led to a cycle of acceptance of pavements that lose ride quality very quickly and need major rehabilitation every 18 to 25 years. Even conventional life cycle cost analysis sometimes fails to fully demonstrate the folly of a short-term design philosophy when it comes to pavements. The twenty-first century realities of excessive energy consumption, dwindling natural resources, environmental impacts of construction and the importance placed by the public on making our roads safer, rarely get factored into the analysis. Nor do the direct costs sustained by the motorist in maintaining vehicles that are habitually driven on bad roads and the extra fuel consumption as a result of traffic delays from road repair activities get considered. In recent years, a number of enlightened road agencies in North America that deal with very high traffic volume highways have taken on this challenge. These pioneers have begun to implement a new philosophy that recognizes that current technologies that now allow us to design and build flexible pavements that can last 50 years or more without major rehabilitation.

2.0 PERPETUAL PAVEMENT ON THE RED HILL VALLEY PARKWAY

Traditionally, flexible (i.e. hot-mix asphalt) pavements have not been designed to last for a significant period of time before a major reconstruction or repair.. The typical life cycle involves a program of routine maintenance and a major rehabilitation treatment every 18 to 25 years. With the rapidly increasing traffic volumes on urban arterial roadways, provincial road agencies and larger municipalities are looking for ways to extend the effective road service life so as to minimize the disruptions to normal traffic operations and the associated driver delays and inconvenience during road rehabilitation works. The desired strategy for road maintenance can be summed up as “Get in - get out quickly – stay out!” Clearly, huge benefits would accrue in terms of sustainability and value for infrastructure investment if the life of flexible pavements could be increased to 50 years or more. Recognizing the inherent economic, social and environmental value of this design concept, The City of Hamilton decided in 2006 to use the perpetual pavement concept on their major infrastructure project. the Ministry of Transportation of Ontario (MTO) initiated a trial project in 2003 to incorporate a perpetual pavement approach [2, 3].

2.1 Approach

This paper considers some aspects of perpetual pavement sustainability based on a practical application of the concept on the Red Hill Valley Parkway project in the City of Hamilton, Ontario. This high profile modern urban Expressway is the final leg of a longer Freeway project considered to be the largest municipal road project in Canada with an estimated final total cost of $430 Million. The City of Hamilton decided that, given the projected traffic volumes (which may be as high as 100,000 vehicles per day), the conventional wisdom of designing a deep strength pavement for a 20-year life was not acceptable. The advanced asphalt technology and materials used in the perpetual pavement design should allow the pavement structure to last 50 years or more with only periodic surface course replacements and without any major pavement rehabilitation. The associated benefits of delivering a highly durable and safe pavement surface , while avoiding major shut-downs of the Parkway (the surface course replacements can be completed during single lane closures at night), are in keeping with the City’s desire to be a leader in the application of sustainable design solutions for public infrastructure. Figure 2 shows the project location plan. The 7.5 km long portion known as the Red Hill Valley Parkway is located in an environmentally sensitive area in the City of Hamilton along the Red Hill Creek as shown in Figure 3.

Initial opening volumes of 35,000 to 40,000 vehicles per day and full capacity volumes in excess of 90,000 vehicles per day are expected for this section of the City’s crucial transportation artery. Any disruption to this highway in the future would cause a significant impact to traffic flow from the upper to lower levels of the City, which are divided by the natural features of the Niagara Escarpment. Adjacent escarpment crossing routes were already at capacity and waiting for this new road crossing to be completed. Eliminating or reducing the need for major reconstruction in the future was considered at the initial design stage for economies to be fully realized. The Red Hill Valley Parkway was considered to be a prime candidate for a perpetual pavement design.

The increased initial capital expenditure investment for a perpetual pavement and the risk associated with the adoption of a relatively new design approach appeared to be more than offset by the potential associated long-term advantages, both financially and from a traffic impact (and hence user/taxpayer) view. From a municipal view, even if the life cycle cost proved to be higher than that of a traditional deep strength pavement, as long as the longevity of the pavement is achieved and indirect traffic impacts are eliminated then a perpetual pavement would still be considered a success..

Figure 2. Project Location Plan

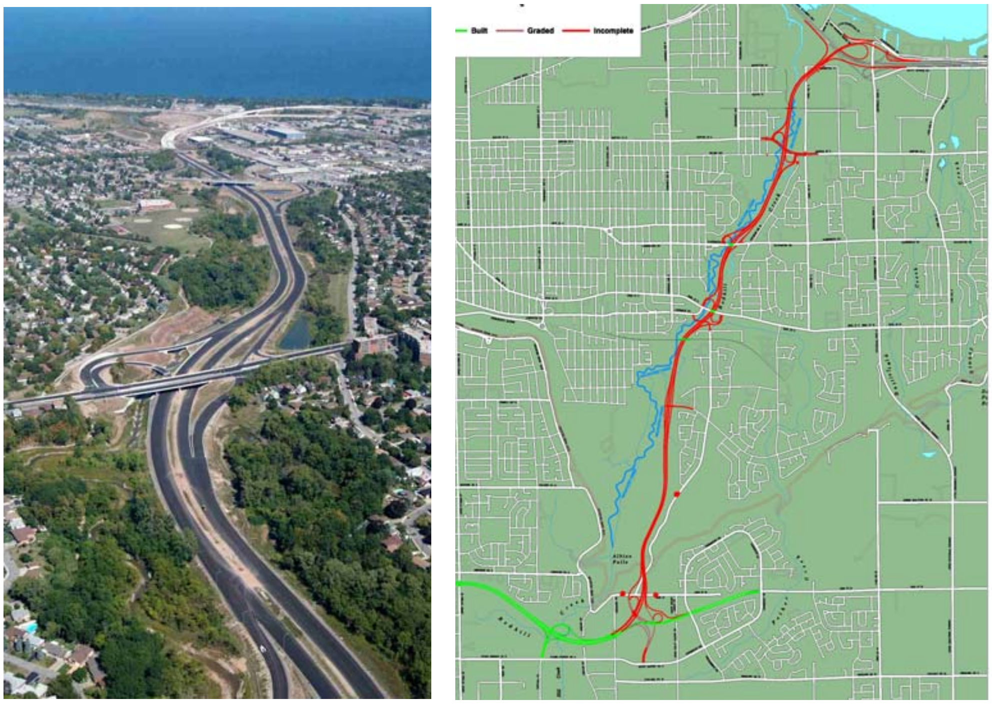

Figure 3. The Red Hill Valley Parkway is located in the Red Hill Creek Valley in the east end of the City of Hamilton.

In undertaking the life cycle cost analysis, projections of cost and risk were made over a 50-year period. Identifying realistic cost estimates for complex highway construction projects is known to be difficult. The costs used in this case were based on the data gathered by the staff involved in the design and construction of the initial portion of the Expressway project, the Lincoln M. Alexander Parkway.. The "LINC" is the east-west portion of the highway system joining the south end of the Red Hill Valley Parkway (RHVP) with Highway 403 in Ancaster. The LINC was constructed between 1991 and 1997 and utilized a conventional deep strength pavement. Comparing the alternative 50-year pavement design strategy to conventional design allowed an evaluation of the financial benefits to the tax payers and reduced use of materials and reduced environmental impact in the perpetual pavement design approach.

In order to recognize and reduce the uncertainty related to pavement construction, maintenance and rehabilitation on the Parkway, the overall goal was divided into smaller steps with each one analysed separately in terms of its time, cost and the amount of material required. This approach was based on experience from other large infrastructure projects [4, 5]. Then both the conventional deep strength and perpetual pavement alternatives were compared. The benefits of the perpetual pavement alternative are considered to be much clearer, since with perpetual pavements the magnitude of future construction interventions are reduced with associated reduction in financial risk.

The Red Hill Valley Parkway is projected to sustain more than 30 million Equivalent Single Axle Loads (ESAL's) over a 20-year period. The original deep strength pavement design, based on geotechnical investigations completed between 1999 and 2004 for various sections of the Parkway, was to support a 20-year traffic loading. Perpetual pavement designs were then completed for all sections to support the traffic loading over a period of 50 years. The selected pavement designs for both alternatives are shown in Figure 4. The perpetual pavement incorporates an 80 mm layer of an asphalt-rich mix (Rich Bottom Mix, RBM), which will protect against the initiation of load induced fatigue (bottom-up) cracking. More information on the perpetual pavement design on the Red Hill Valley Parkway is provided in the TAC 2008 technical paper titled "Innovative, Comprehensive Design of Perpetual Pavement on Red Hill Valley Parkway in Hamilton".

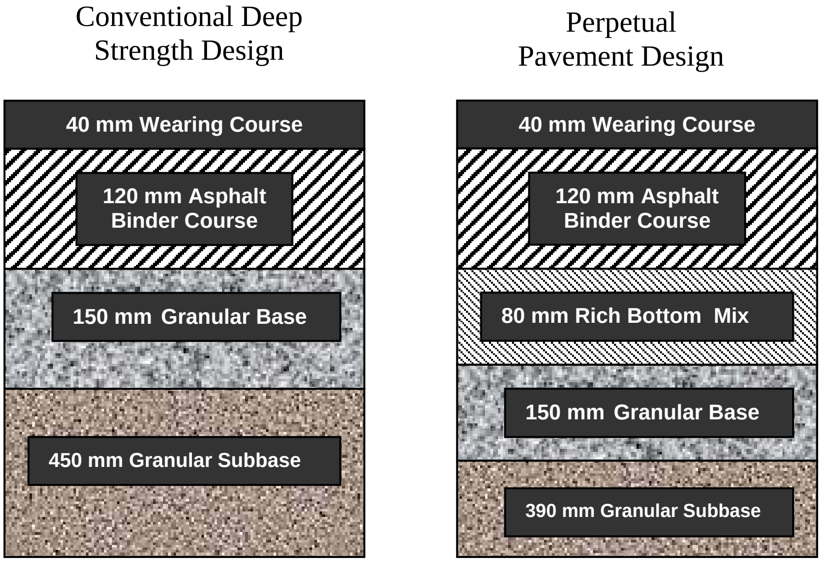

Figure 4. Comparison of conventional deep strength and perpetual pavement structures.

2.2 Life Cycle Cost Analysis

A detailed Life Cycle Costing (LCC) analysis was undertaken to compare perpetual pavement design to a conventional deep strength asphalt pavement alternative. Two approaches were used in the LCC analysis. The first was the same approach used on previous MTO projects as covered in [6] and [7], while the second incorporated local experience in terms of the type of materials, costs, anticipated life and frequency of pavement maintenance and rehabilitation. Table 1 shows a summary of the LCC analysis for the main line for both alternatives, including the construction, maintenance, rehabilitation and user-costs (present worth). The unit costs were obtained from the City of Hamilton. User-cost estimates included user delay costs only (showing delay costs and queuing costs); vehicle-operating costs were not included.

Table 1. Summary of Life Cycle Cost Analysis – Mainline Only

OPTION 1 – DEEP STRENGTH PAVEMENT					
Construction Item		Quantity	Unit	Unit Cost ($)	Cost, Present Worth ($)
SMA	-	23,381	t	125	2,922,625
Superpave 19 & 25	-	53,913	t	70	3,773,910
Granular Base	from stockpile	84956	t	5.5	467,258
Granular Base	from quarry	30447	t	18	548,046
Subbase	from stockpile	27950	t	4.5	125775
Subbase	from quarry	264531	t	17	4,496,027
Other	-	-	-	-	57,090
Total Construction					12,391,731
M&R Cost		7.5	km	600,626	4,504,695
User Delay Cost		7.5	km	170,606	1,279,545
Total LCCA Cost without Initial Construction Costs					5,784,240
TOTAL LCCA COST OF DEEP STRENGTH ALTERNATIVE					18,175,971

OPTION 2 – PERPETUAL PAVEMENT					
Construction Item		Quantity	Unit	Unit Cost ($)	Cost, Present Worth ($)
SMA	-	23,381	t	125	2,922,625
Superpave 19 & 25	-	44,928	t	70	3,144,960
RBM	-	32,128	t	80	2,570,240
Granular Base	from stockpile	84956	t	5.5	467,258
Granular Base	from quarry	30447	t	18	548,046
Subbase	from stockpile	27950	t	4.5	125,775
Subbase	from quarry	225534	t	17	3,834,078
Other	-	-	-	-	45,962
Total Construction					13,658,944
M&R Cost		7.5	km	308,839	2,316,293
User Delay Cost		7.5	km	60,407	463,056
Total LCCA Cost without Initial Construction Costs					2,769,349
TOTAL LCCA COST OF PERPETUAL PAVEMENT ALTERNATIVE					16,428,293

2.3 Benefits

The objective of the approach used on the Red Hill Valley Parkway was to design a pavement that is safe, cost effective and has less impact on the environment in terms of the quantity of materials used, less impact on the traveling public and local neighbourhoods, and less energy consumption and greenhouse gas emissions.

Both pavement design alternatives incorporate Stone Mastic Asphalt (SMA) as the surface course mix. SMA is considered to have improved skid resistance and offers some noise reduction [8] when compared with conventional hot-mix asphalt mixes. This mix type also offers superior rutting resistance, fatigue endurance and durability.

The overall cost benefits of the perpetual pavement design approach for high traffic volume applications for a 50-year analysis period have been demonstrated with life cycle cost analyses. However, apart from cost considerations, the other benefits include:

- Conservation of aggregate and bituminous resources by reducing the need for major rehabilitation or reconstruction.
- Reduced energy consumption by reducing the extent of construction materials hauling and hot mix asphalt production during road rehabilitation.
- Reduced need for routine maintenance activities by eliminating base rutting and major structural and environmental cracking.
- Reduced vehicle damage and greenhouse gas emissions by providing a higher ride quality and reducing the frequency of traffic disruption and lane closures.
- Reduced impacts of construction, dust and noise in an urban environment.

As well as these direct sustainability benefits, there are also the indirect benefits of reduced driver frustration and delay caused by reconstruction of major traffic arterials. There is also reduced risk and liability exposure associated with work zone traffic accidents. Any disruption of the traffic flow in the future on this route will cause a significant impact on travel times from the upper to lower levels of the City, which is divided by the natural features of the Niagara Escarpment. As noted previously, adjacent escarpment crossing routes are already at capacity and cannot cope with the consequences of a shut-down of the Parkway. The reconstruction zone delays are not only considered to be fuel wasters but also lead to increased short-cutting and rerouting of traffic through local adjacent neighbourhoods. This short cutting causes further traffic tie-ups and increased potential for accidents as well as over stressing of a street system already in need of repair.

The perpetual pavement will not be subject of deep-seated structural failure but rather will deteriorate due to wear and tear on the surface. These types of distresses can be remedied easily by milling and replacement of the surface course, an operation that may be accomplished with an overnight lane closure and minimal traffic disruption. In addition, the intervention may be less frequent than for the conventional asphalt pavements. Therefore, less material will be used over the pavement life span. Table 2 shows a summary of material use for construction, maintenance and rehabilitation for deep strength and perpetual pavement alternatives. It is anticipated that over the 50-year analysis period, the perpetual pavement will require about 30,000 tonnes less hot-mix asphalt, 22,000 tonnes less granular base and 95,000 tonnes less granular subbase material over the 7.5 km section.

Energy consumption and greenhouse gas emissions are discussed in Section 3 of this paper.

Table 2. Summary of Materials Use for Construction, Maintenance and Rehabilitation

Pavement Type	Materials	Quantity* (tonnes)			Difference (tonnes)
		Construction	M&R	Total	
Conventional Deep Strength	SMA	23,381	69,750	93,131	
	HL 8 (HS)	53,913	54,000	107,913	
	Granular Base	115,403	21,926	137,329	
	Granular Subbase	292,477	55,571	348,048	
Perpetual	SMA	23,381	69,750	93,131	0
	HL 8 (HS)	44,928	-	44,928	- 62,985
	RBM	32,128	-	32,128	+ 32,128
	Granular Base	115,403	-	115,403	- 21,926
	Granular Subbase	253,480	-	253,480	- 94,568

* Ramps and temporary crossovers not included.
SMA is Stone Mastic Asphalt
HS is High Stability
RBM is Rich Bottom Mix
M&R is Maintenance and Rehabilitation

3.0 REDUCING THE ENVIRONMENTAL IMPACT OF ROADS

A good understanding of pavement failure mechanisms is paramount in the development and application of perpetual pavement technology. For instance, one of the key findings [9] indicated that in pavements incorporating high modulus asphalt layers certain failures did not occur e.g. conventional bottom-up fatigue cracking. Similar findings have been reported in the US by several leading researchers [10].

Assessment of the overall impacts of construction on the environment during road building and maintenance operations used in this paper is based on European experience, particularly in France [11]. It has been observed that energy consumption and Greenhouse Gas (GHG) emissions during construction and maintenance activities are significant. However, the emissions from vehicles delayed by lane closures during road works are even larger. As conventional pavements require expensive periodic major rehabilitation every 18 to 25 years that cause serious disruptions to traffic and require the construction of temporary ramps and crossovers, the perpetual pavement approach has obvious advantages that can be quantified in terms of improved environmental quality and reduced GHG emissions. This is especially important in environmentally sensitive sites such as the Red Hill Valley. Additional benefits are the conservation of aggregate and bituminous resources by reducing the need for repeated removal and replacement of major road elements.

France is committed to specifying and implementing a National Sustainable Development Strategy and has adopted an Environmental Charter (25 June 2003) [12]. This is intended to be incorporated into the French Constitution. The government has made a conscious decision to design and build extremely durable, long lasting pavement sections on their motorway system. The mixes incorporate very hard grade asphalt at a higher binder content (about 6 percent). These mixes have higher modulus, which allows, with equal thickness, a reduction in stresses and strains transferred to the subgrade [9]. The high modulus pavements have high structural capacity and the maintenance can be focused on the surface course using low cost seals, thin overlays or mill and overlays.

In an analysis of energy consumption and greenhouse gas emissions, the entire production and construction cycle must be taken into consideration. Thus we must consider the full life duration from the extraction of raw materials to the end of the pavement's life, including product manufacture, paving operations, and maintenance works. A study completed in France [12] shows that over a 30 year period, traffic consumes between 10 and 345 times more energy than road construction over the same period, depending on the traffic volume. Therefore, traffic is responsible from 10 to 400 times more GHG emissions (the ratio rising with the amount of traffic) than construction and maintenance of the pavement. At first this may suggest that the impact of road design and construction is not a significant contributor to emissions. On the contrary, when one considers that transportation accounts for 26% of all GHG emissions and 85% of these are generated by road transport, the contributions from design and construction activities cannot be ignored. Road agencies, road designers and contractors need to be aware of and consider these issues in policy and decision-making.

Energy consumption and GHG emissions also depend on the type of pavement structure. Both were lower for the long lasting high modulus pavements than for the conventional asphalt pavements [12]. Pavements incorporating cold mixes and mixes with hydraulic binders showed the lowest energy consumption and GHG emissions.

Figure 5 shows that energy consumption for pavement construction and maintenance was about 9 percent lower for high modulus pavement than for conventional asphalt pavement over a 30 years analysis period. A similar difference can be anticipated for perpetual pavement and it is likely that this difference would be even higher for an analysis period of 50 years.

Figure 6 shows that greenhouse gas emissions for pavement construction and maintenance were about 10 percent lower for high modulus pavement than for conventional asphalt pavement over a 30 years analysis period. Similar to the energy consumption case, it can be anticipated that this difference would be even higher for a perpetual pavement analysis period of 50 years.

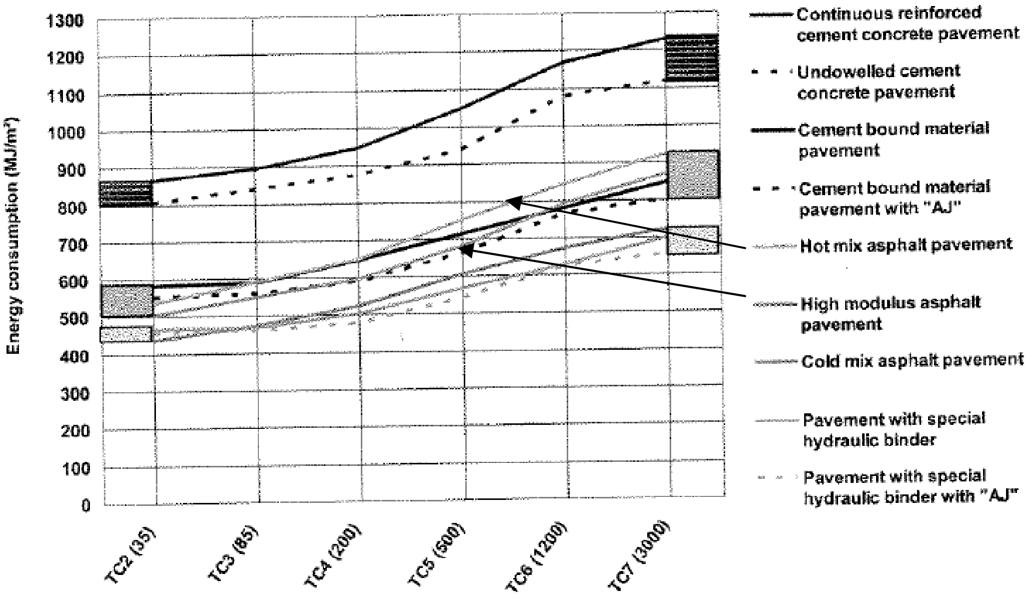

Figure 5. Energy consumption for pavement construction and maintenance over a 30-year period [12].

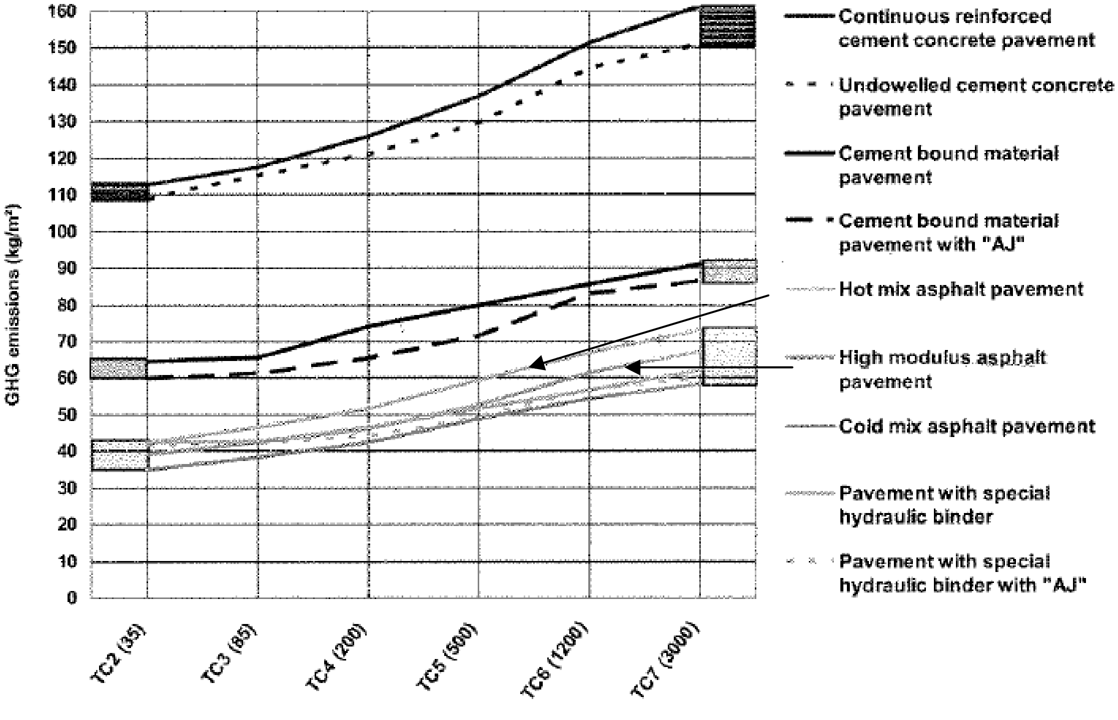

Figure 6. Greenhouse Gas (GHG) emission for pavement construction, and maintenance over 30 year period [12].

Figure 7. One of the objectives of sustainable pavements is to reduce GHG emission for pavement construction and maintenance.

Table 3 shows the number of times that greenhouse gas emission of cumulative traffic is higher than that of pavement construction and maintenance over a period of 30 years. The difference between the conventional asphalt pavement and high modulus asphalt pavement in the heavy traffic range, such as Traffic Class 7 (TC7), is significant at about 10 percent [12].

Table 3. Greenhouse Gas Emission Summary for Conventional and High Modulus Asphalt Pavements [12]

Traffic Class	Number of times GHG emission of cumulative traffic is higher than that of pavement construction and maintenance					
	TC2	TC3	TC4	TC5	TC6	TC7
Daily Heavy Truck Traffic (per direction)	35	85	200	500	1200	3000
Asphalt Pavement	21	46	98	114	153	239
High Modulus Asphalt Pavement	22	50	110	130	165	265

In order to quantify the environmental benefit of perpetual pavement over a deep strength pavement on the Red Hill Valley Parkway at the construction and maintenance and rehabilitation stage, the Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE) software was used. The program was developed by Dr. Arpad Horvath from the University of California, Berkeley as a decision-making tool used to evaluate road construction in terms of life-cycle costing and environmental impact [13]. Ontario Ministry of Transportation uses this program for the evaluation of benefits of recycled technologies in highway construction [14 and 15]. PaLATE does not take into account emissions during the user phase of the pavement, i.e. emissions from vehicles [16]. Both, perpetual and deep strength pavement designs were entered into the program. The emission during the initial construction and then pavement maintenance and rehabilitation was calculated. The environmental impact includes energy consumption, CO_2, NO_x, PM_{10} and SO_2 emissions. The results are summarized in Table 4.

Table 4 Summary of Environmental Impact of Pavement Construction and Maintenance/Rehabilitation

Pavement Type	Energy [MJ]	CO_2 [Mg]	NO_x [kg]	PM_{10} [kg]	SO_2 [kg]
Deep Strength	338,000,000	19,000	182,000	151,000	3,900,000
Perpetual	230,000,000	13,000	123,000	101,000	2,600,000
Difference	108,000,000	6,000	59,000	50,000	1,300,000

Over the analysis period of 50 years, the energy consumption and the emission of gases and particulates due to construction and maintenance and rehabilitation of the perpetual pavement is reduced by about 1/3 as compared with the conventional deep strength pavement structure. Figures 8 and 9 compare the energy consumption and CO2 emission for both alternatives.

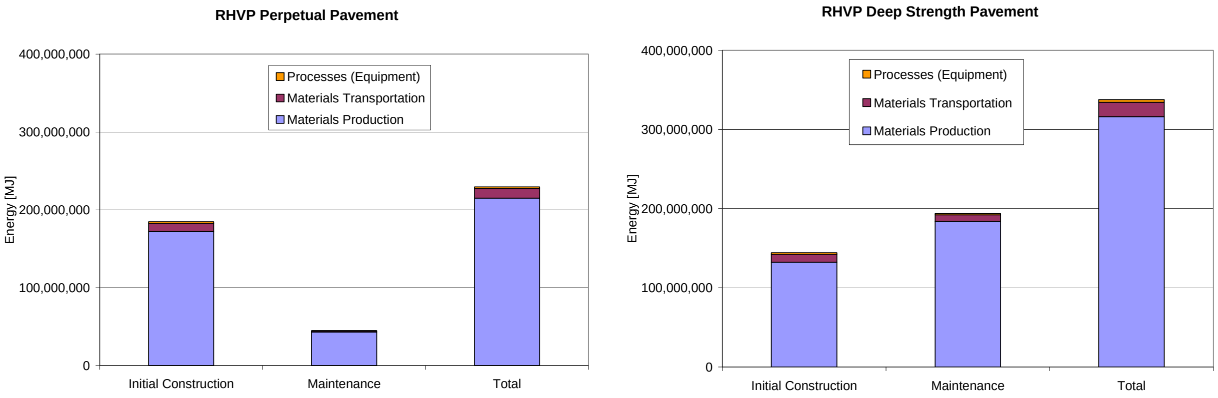

Figure 8. Life-cycle energy consumption for perpetual and deep strength pavement alternatives.

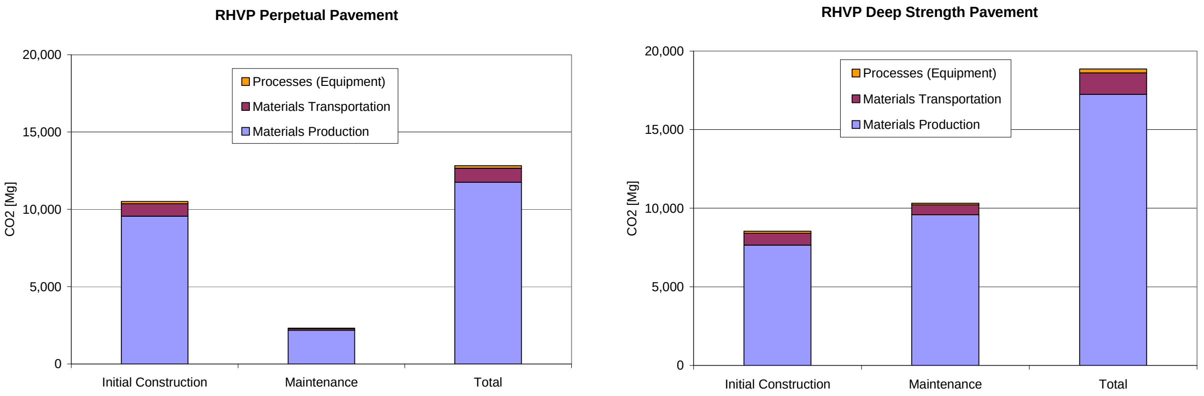

Figure 9. Life-cycle CO_2 emissions and global warming potential for perpetual and deep strength pavement alternatives.

Selection of pavement type is important from an environmental protection point of view. Long lasting or perpetual pavements appear to have clear advantages over conventional asphalt pavements. New mix technologies such as warm asphalt mixes, the continued and increased use of HMA recycling in some jurisdictions are also considered to be very promising strategies to achieve more sustainable pavements.

However, the subject of the impact of pavement type selection on the environment requires more investigation and further research and development will be necessary to design tomorrow's structures.

4.0 CONCLUSIONS

The increasing awareness of the damage to the environment caused by industry, agriculture and transportation increases the demand for new technologies that will reduce this negative impact. More attention should be paid to pavement sustainability as a significant step in this direction.

Better materials and improved analytical techniques now allow asphalt pavements to be designed to last 50 or more years. These long lasting (perpetual) asphalt pavements have lower impact on the environment over their entire service lives in terms of use of materials, energy consumption, greenhouse gas emissions, and impact on road users and on local neighbourhoods.

Life cycle cost analysis indicate that for heavy volume roads, long lasting pavements are likely to be more cost effective over their service lives than conventional deep strength asphalt pavements. If user costs were included in the life cycle cost analysis, the advantage of long lasting pavements would be even stronger.

Further innovations in pavement design and material selection should be encouraged to lessen the pavement impact on the environment. Sustainability concepts need to be considered in pavement design selection.

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