CONCRETE PAVEMENTS IN CANADA: STATE-OF-THE-ART PRACTICE

Susan Tighe, Ph.D, P.Eng.
Assistant Professor of Civil Engineering,
University of Waterloo,
200 University Avenue West
Waterloo, Ontario, Canada
N2L 3G1

Rico Fung, P.Eng.,
Structural Engineer Ontario Region,
Cement Association of Canada,
1500 Don Mills Rd, Suite 703
Toronto Ontario Canada
M3B 3K4

Tim Smith, M.Sc.Eng., P.Eng
Director, Transportation and Public Works
Cement Association of Canada
1500-60, rue Queen Street
Ottawa ON K1P 5Y7

ABSTRACT

Approximately 12 billion dollars is spent on pavements annually in Canada as indicated by Public Works Canada. This massive investment is aging and requires timely and cost effective renovation, repair and rehabilitation technologies and good management. With increased demand for innovative solutions to repair the existing infrastructure, there has been a growth in the use of concrete pavements and the innovative concrete pavement products. The objective of this paper is to provide a state-of-the-art review on the design, construction, performance and maintenance of various concrete pavement structures in Canada. The evolution of the Canadian experience in design and construction techniques will be described and "best practice" concrete paving strategies will be presented. The aim of this paper is to provide guidance on the concrete paving techniques for use in cold climates and under various traffic loading conditions.

INTRODUCTION

With increasing traffic volumes and an increased demand for innovative rehabilitation and repair of the aging transportation infrastructure, the growth of the concrete pavement product usage in Canada has been continuous over the past decade. This massive investment is aging and requires timely and cost effective renovation, repair and rehabilitation technologies and good management. The basic objective of pavement design is to provide structural alternatives that are feasible both technically and economically. This is achieved by specifying pavement layer thickness with proper types of materials based on the traffic and environmental conditions and by life cycle cost analysis. Figure 1 describes the general framework for design [Tighe 01].

The first step in design involves collecting information relating to materials, traffic, climate and costs. Other important inputs include the selection of a design period, structural and economic models, identification of objectives and constraints and variance on data inputs. The inputted information enables for the generation of design alternatives with specified life cycle strategies, including the material types and thickness, criteria on structural and economic analysis and various other factors. The structural analysis and economic evaluation of alternatives would be carried out such that the best strategy for implementation would be selected. The most appropriate design should be selected based on both the technical and economic merits of the design [Tighe 01].

In Canada, trucks transport 90 % of all exports to the United States. Approximately, eleven million trucks cross the Canada-United States border every year, which means a truck crosses every three seconds. In terms of traffic loads, these trucks have a significant impact on pavement performance. These heavy loads combined with warm summers and cold winters, result in very demanding requirements particularly in these border areas. In an engineering sense, the pavement structure must be designed to carry extensive loads and resist fatigue, associated damage and freeze thaw conditions.

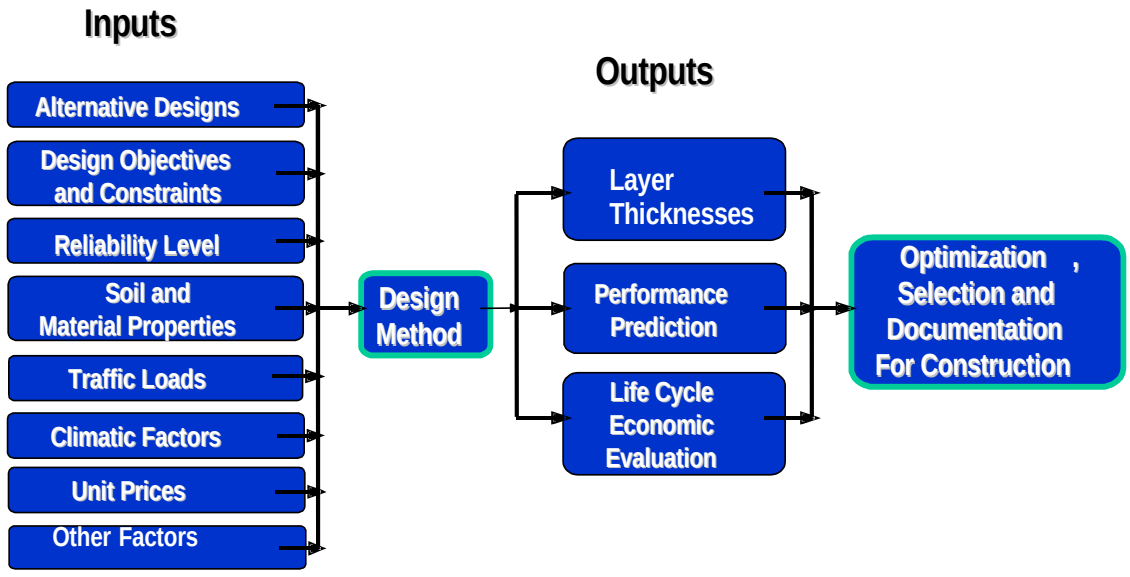

Figure 1 Framework For Pavement Design

In addition to the aforementioned engineering requirements, fiscally responsible governments and the Canadian public are demanding improved roads and reduced user delays associated with construction. These factors bring special attention to life cycle economic analysis, especially on high volume facilities. The objective of this paper is to provide a state-of-the-art review on the design, construction, performance and maintenance of various concrete pavement structures in Canada. The evolution of the Canadian experience in design and construction techniques will be described and "best practice" concrete paving strategies will be presented.

DESIGNING CONCRETE PAVEMENTS FOR THE CANADIAN ENVIRONMENT

Although the weather conditions vary greatly across Canada, the most challenging design conditions for concrete pavements include those structures that are placed in areas where they experience large extremes in temperature. Special attention is required so that the structure is able to withstand freeze thaw conditions and de-icing chemicals. The structure must also be designed to meet the flexural strength requirements to support and distribute the estimated loads over the design life and maintain a stable volume to minimize the potential of cracking and deterioration. It must also be workable so it can be properly placed and consolidated without excessive segregation or bleeding and designed so that hardening and curing rates are such that the pavement can be put into service at the earliest possible time [TAC 97].

Joint Design

Pavement joints play a major role in resisting distresses related to loading and the environment. They are engineered to control the natural transverse and longitudinal cracking from internal distresses. Natural crack development usually occurs within the first 12 – 24 hours and can be largely attributed to volume loss and thermal contraction [CPCA 99]. Other critical factors such as temperature gradients, moisture gradients, thermal cycles and loading can occur sometime after 12 hours and may take months to appear. The purpose of the joint design is to provide a series of joints by saw cutting to create a plain of weakness in the slab to control the location of the crack. Other functions of joints include dividing the pavement into construction lanes or increments, accommodating slab movements, provide load transfer and provide a uniform sealant reservoir [CAC 00]. In Canada, all four of the general types of joints are used including: transverse contraction joints which are perpendicular to the center line of the pavement, transverse construction joints installed at the end of a day's paving or during an extended interruption; longitudinal joints typically at the center line or at the lane edge; and expansion or isolations joints placed to isolate a more rigid structure e.g. manhole or pavement movement on a different axis [TAC 97]. Joints spacing should be short, uniform, perpendicular, simple and practical. A joint plan should be designed so that existing joints or cracks are matched to new joints and the joint must be placed at the appropriate time.

Concrete Materials

The aggregate selection is extremely important for providing adequate strength and good resistance to in-service pavement conditions. The coarse and fine aggregates which make up approximately 60 – 75 % of the mix are generally tested prior to construction to ensure they meet gradation, resistance to alkali silica reactivity, freeze thaw and absorption requirements. Other tests may be required based on the particular mix design [CPCA 94].

The paste which makes up the remaining portion of the concrete is broken down as approximately 2 – 15 % cement, 14 – 21 % water and the air entrained ranges up to about 8% of the volume depending on the size of the maximum aggregate size. The admixtures are those ingredients added to the concrete immediately before or during mixing. The most common admixtures can be categorized by function as: air entraining, water reducers, superplasticizers, retarders and accelerators. Special care should be taken when adding the admixtures and it is essential that the concrete be placed according to the specific admixture manufacturer instructions [CPCA 94].

Air entraining agents are extremely important in Canada to ensure the concrete is able to withstand freeze thaw. This admixture improves workability, reduces segregation and enables earlier finishing in fresh concrete. In hardened concrete, it increases freeze thaw resistance, improves scaling resistance to de-icers, improves sulfate action and provides improved water tightness. Air entrained concrete is an "engineered" void system. The spacing factor, specific surface and voids per areas are important characteristics as they describe how close the air bubbles are, how they are distributed and the number of bubbles present. The bubbles essentially act as mini shock absorbers to prevent damage due to stresses in the pavement [CPCA 94].

Supplementary cementing materials (SCM) assist portland cement with various performance properties of the concrete. Fly ash, blast-furnace slag and silica fume are the most commonly used SCM in Canada. When a finely ground SCM is placed in the presence of water, the SCM reacts with the calcium hydroxide released from the cement hydration process. This reaction is paramount as it forms the compounds, which possess the cementing properties [CPCA 94]. The three aforementioned SCMs are byproducts from the production of coal, iron and silicon or silicon containing alloys respectively. The Canadian Standards Association (CSA) recognizes three groups of SCM namely pozzolans, granulated slags and silica fume. For more details on the SCM and how they influence the concrete mix and hydration process, please refer to [CPCA 94].

Thickness Design

The thickness of the pavement structure is determined based mainly on traffic loading (ESALs) and frost protection where appropriate. As noted earlier, the subbase provides a working platform for paving operations. Typical concrete pavement thicknesses are provided in Table 1 [CAC 00].

Table 1 Typical Designs

Object	Typical Thickness
Sidewalks	100 mm – 125 mm
Driveways	100 mm – 125 mm
Parking Lots	100 mm – 125 mm
Streets / Access Roads	150 mm – 200 mm
Secondary Highways	150 mm – 200 mm
Major Highways	200 mm – 250 mm
Major Freeways	Over 250 mm

Curing

Curing ensures that adequate moisture is available for the hydration process and is very important to performance of the rigid pavement. Hydration continues with age as long as any unhydrated cementing materials and water are present at the right temperature range. Based on the fact, the hydration process is temperature sensitive, it is necessary to provide protection to ensure hydration or strength gain is continuous in both hot and cold weather conditions. Low temperatures retard the hydration process while high temperatures increase the demand for water and need for protection to prevent shrinkage in addition to various other problems. Although, there are various methods for curing concrete, curing compounds are the most common choice for pavements. These are selected for pavements based on the ease and speed of application [CPCA 99].

BEST PRACTICE

Jointed Plain Concrete Pavements (JPCP)

The jointed plain concrete pavements (JPCP) are most commonly constructed pavement in Canada. These pavements can be either doweled or undoweled and have closely spaced contraction joints. The undoweled type of JPCP, which relies on the aggregate interlock or shear interaction of the aggregate particles transfers the load across the joints [CAC 99]. These types of pavements are most effective with short joint spacing and are suitable where there are less than 80 – 100 trucks per day. Many pavements that were constructed in the early 70 ‘s and 80’s in urban areas in Canada are undowelled JPCP.

Most JPCP’s that have been constructed in the last decade include dowels. This is definitely the case on those high volume facilitates that service extensive traffic loads. If a pavement is properly designed and the thickness is 200 mm or more dowels should be used. If the design thickness is less than 175mm then dowels are not required, as there will not be sufficient truck volume to cause faulting. Design thickness between 175 and 200 mm are in the gray zone and may or may not require dowels depending on several factors such as, amount of trucks, traffic pattern (channelized or non channelized) and speed. The doweled JPCP generally has a joint spacing of 4.5 m, which has been found to minimize transverse slab cracking [TAC 97]. Other factors that influence joint spacing include the aggregate type, climate, and prior experience.

With increased demand for innovative solutions to repair the aging infrastructure, there has been a growth in the use of concrete pavement products in Canada. This is evidenced by the recent construction of JPCP structures on Highway 407 in Toronto, ON, AutoRoute’s 40 and 15 in Montreal, QC, AutoRoute 440 in Laval, QC, Highway 104 in NS and several other roads in Windsor, ON and Winnipeg, MB. Highway 407 is an express toll route located in Toronto, ON. It is a 69-km, 6-lane divided highway. The selected design was a JPCP consisting of 280 mm concrete over 100 mm asphalt treated open graded drainage layer (OGDL) and 200 mm granular base (Modified Granular A). The compressive strength was designed at 5 MPa at 28 days and dowels were placed at transverse contraction joints [CAC 00]. This design was selected because the private consortium that won the bid to design and build this road felt that concrete pavement was the most effective design based on both technical and cost considerations.

Ministère des Transports du Québec (MTQ) has been the most active provincial department of transportation in constructing concrete highways in recent years. Since 1994 MTQ has placed over 317,600 cubic meters of concrete pavement or approximately 145 kilometers of 2-lane highway. In 2000, 10 km of concrete pavement was constructed on AutoRoute 13 in Laval, QC. The 270 mm thick pavement included three-3.65 m lanes with 3.0 m concrete shoulders on each side. Transverse joints were spaced at 5 m intervals with 35 mm dowel bars used for improved load transfer. A ternary blended cement consisting of fly ash, silica fume and type 10 cement was used during construction on an experimental basis. The concrete produced using this blended cement performed very well during construction and will provide more durable concrete due to the lower permeability of this value-added product.

Continuously Reinforced Concrete Pavements (CRCP)

The second type of rigid pavement is CRCP. These pavements contain continuous steel reinforcement in the longitudinal direction to eliminate joints. The steel is designed to provide load transfer and it is engineered so that transverse cracks develop at short intervals. The initial construction costs of CRCP's are expensive due to the amount of steel within the structure. They are not commonly used in Canada. However, they are frequently used in the United States and in Europe on high volume facilities [TAC 97]. One example of CRCP use in Canada is the two-kilometer test section constructed on AutoRoute 13 in Laval, QC in 2000. In this test section transverse shrinkage cracks are to be held tightly together by 20 mm longitudinal reinforcing steel spaced 250mm apart and 90 mm from the top of the concrete surface. This maintains a high degree of load transfer. The longitudinal bars were supported by 20 mm skewed transverse steel bars. Surface texture consisted of turf drag with transverse random tinning on both sections.

Jointed Reinforced Concrete Pavements (JRCP)

The JRCP usually contains a steel rebar mesh are designed to control the natural crack progression. Joint design spacing is generally larger than the JPCP. However, not greater than 13.0 m. Doweled joints are often required in colder climates to assist with load transfer. JRCP usually have a higher capital cost related to the steel mesh. Based on the high initial construction cost and longer slab lengths, which can cause potential problems in colder climates, these pavements tend not to be constructed in Canada [TAC 97].

Prestressed or Post Tensioned Concrete Pavement

The fourth type of rigid pavement is the prestressed or post tensioned concrete pavement. These concrete pavements tend to be placed in specialized locations and are predominantly used at airports [TAC 97]. Speed of placement is the key reason these pavements are chosen for use at airports. Due to the logistics of transporting and placing these panels, they are not commonly used on highways, as the construction procedure is not as efficient as a slipform operation.

CONCRETE PAVEMENT PRODUCTS

In addition to utilizing the conventional concrete pavements noted above for new highway construction, there are several other concrete pavement products used for both new construction

and rehabilitation and maintenance purposes. Concrete products which have been used in Canada include: three types of whitetopping (WT) – conventional overlay, concrete inlay and ultra-thin whitetopping (UTW); roller compacted concrete (RCC) and interlocking concrete block pavements. These products have demonstrated various benefits in both a technical and economic sense.

Whitetopping

Whitetopping overlays or inlays involve placing over 100 mm of concrete on top of an existing flexible pavement [ACPA 98]. The overlay is placed directly on the aged flexible pavement while the inlay is placed in a trench milled out of an aged flexible pavement [ACPA 98]. The pavement thickness is calculated similar to a new pavement structure on an asphalt-stabilized base assuming that it is not bonded to the existing flexible pavement. The WT provides improved structural capacity and functional condition of the highway. Another benefit of this technique is that it requires minimal amounts of pre-overlay treatment and has been shown to perform effectively over the long-term life of the pavement. Thus if a flexible pavement has experienced a large amount of cracking, it would be a good candidate for WT. WT has also been shown to mitigate reflective cracking. Once constructed, WT requires low maintenance with no seasonal weakening. It is resistant to rutting and provides good skid resistance. It is very successful in cases where rutting has occurred on high volume facilities with heavy truck traffic [CPCA 99, CAC 00].

Case Study # 1: Highway 3 Rehabilitation -- Bonded Whitetopping, Windsor, Ontario

In the fall of 1999, a section of Highway 3 in the City of Windsor was rehabilitated with a thin bonded concrete overlay, the first whitetopping project by the Ministry of Transportation of Ontario (MTO). This four-lane divided highway is part of the major truck route for the USA-Canada Trade Corridor. It leads into Highway 401 in Canada and Interstate 75 in the United States, which is one of the three busiest border crossings in Canada with extremely heavy traffic loading. Historically, rutting has also been a recurring problem at the intersections. The rehabilitated section was 500 meters long, two through lanes in each direction, including the intersection. This stretch of Highway 3 was milled and paved with asphalt concrete in 1998 with a 40 mm dense friction surface course and 150 mm of heavy duty binder course. The existing pavement structure consisted of 250 mm asphalt over 225 mm concrete and it was deemed to be structurally adequate as determined by a field investigation. By the summer of 1999, the pavement exhibited significant flushing and rutting, in particular, very severe rutting and shoving at the three signalized intersections. Field investigation revealed that the rutting and shoving was confined to the bituminous layers with a measured depth of 80 mm. Based on these considerations, the decision was made to apply the whitetopping technology to address the severe rutting and shoving problem. The specification called for 125 mm of concrete overlay, dosed with a minimum of 1.6 kg/m^3 of 40 mm synthetic fiber. The construction spanned over two weekends in October 1999. The air-entrained concrete mixture was specified with a compressive strength of 20 MPa at 24-hour and 35 MPa in 28-day. Soff-Cut technology was used to saw cut the overlay to a minimum depth of 1/3 of the thickness. The transverse and longitudinal contraction joints were spaced at 1.25 meter on centre and 3 mm wide. These joints were not sealed. The construction was completed on time and each direction was opened for

traffic on the following Monday at 7:00 a.m. This whitetopping is in service today taking the beating from the heavy truck traffic, outlasting the last repair.

Ultra-Thin Whitetopping (UTW)

UTW is a relatively new pavement rehabilitation strategy used to address the rutting and washboarding problems of existing asphalt pavements, in particular at intersections. A thin layer of concrete from 50 to 100 mm, usually high strength and fiber reinforced is placed on a prepared surface of distressed asphalt. Other key UTW characteristics include: a substantial degree of bond between the concrete overlay and the remaining sound asphalt, minimum of 75 mm of asphalt remaining after milling off the distressed asphalt and much shorter joint spacing than on conventional concrete pavements.

Case Study # 2: Intersection at Britannia and Dixie Roads in Mississauga, Ontario

The first controlled Canadian UTW project was constructed in August of 1995, in Mississauga at the intersection of Britannia and Dixie Roads. This intersection is located in an industrial area on the west side of the Toronto International Airport. One leg of this intersection had severely rutted after 8 years of heavy truck traffic. The rut was measured to a maximum depth of 175 mm from the top of the heaved asphalt to the bottom of the rut. Initially, approximately 100mm of asphalt was to be removed and replaced with the same thickness of concrete. Due to the poor condition of the existing asphalt, the actual milling depths and resulting concrete thickness ranged between 118 to 166 mm based on the cores taken from the project. Two lanes were constructed with a polypropylene fiber reinforced concrete mix, saw cut at a 1.6 m square joint spacing. A third lane was constructed without fibers and a conventional 30 MPa mix. The concrete was hand placed and there was no vibration to consolidate the concrete in any of the lanes. This lead to a poor bond to the underlying asphalt bases [Morris 98]. The intersection is in good condition today without any major distress and little or no maintenance. Since then, four more UTW projects have been constructed in the City of Brampton along a busy thoroughfare, Queen Street East, to address the rutting problem caused by both heavy commercial and transit traffic. Recently this technology was used in Canada's capital city Ottawa on a transit way station. These areas had experienced severe rutting with the speed and braking forces. To address this problem, a Stone Mastic Asphalt was placed however, two years into the service life, it required rehabilitation related to severe rutting. To restore the safety and ride requirements, UTW was selected.

Case Study # 3: Bus Stop in Vancouver, British Columbia

A demonstration UTW project with no contraction joints has also been constructed at a rutted and shoved asphalt bus stop on West 41st Avenue near West Boulevard in Vancouver, BC. The reconstructed area is 3.2 m wide and 21 m long. The existing asphalt pavement thickness ranged from 229 to 248 mm from the site investigation. The mill depth of rutted asphalt was 92 to 95 mm and was replaced with the same thickness of high volume synthetic fiber reinforced concrete. The remaining asphalt has a minimum thickness of 134 mm. The joints were eliminated to minimize the paths for potential water ingress into the pavement, in particular, to the Vancouver's frequent wet weather. Class C-1 exposure was specified for the UTW concrete with 7 kg/m^3 of Grace Structural Fibre. These fibers would provide the concrete with pseudo-ductility [AMEC 00]. The minimum compression strength requirements were 20MPa at 2 days

and 35MPa at 28 days. A cement/sand bonding slurry, with a 0.40 water/cement ratio was placed on the milled asphalt surface immediately prior to the placement of UTW concrete. The concrete surface was textured with a broom finish and wet cured afterwards. The UTW construction was finished on schedule and the lane was opened to traffic with a 48-hour compressive strength of 22.7MPa.

Roller Compacted Concrete (RCC)

Since it's initiation in the 1970s, RCC has been used in a number of applications in Western Canada. Typical applications would be container terminals, heavy industry storage yards, truck stops, intersections, intermodal terminals, recycling depots, and haul, municipal, and agricultural roads. In fact, there are several hundred RCC pavement projects constructed in North America today. The thickness of the RCC pavement ranges from 100 mm to 600 mm for the heaviest loading areas. Multilayer construction for industrial uses has been as much as 900 mm thick, with a maximum single layer lift of 200mm, but typical pavement thickness for major arterials and residential streets range between 100 mm – 200 mm. RCC has been paved on various major arterials in Western Canada, which carry upwards of 65,000 average annual daily traffic (AADT) [Stern 94]. Various sections have been placed on both arterial highways and residential streets in Alberta. Other RCC sections on both residential and arterials have been placed in British Columbia, Saskatchewan and Quebec [Serne 98]. Through these trials, RCC has demonstrated it can provide high volume production, rapid lay down and the potential for readily accommodating early traffic opening.

Recently, Portland Cement Association completed a study on the long-term performance of RCC pavements and published its findings. In this study, 34 RCC pavements were inspected in United States and Canada [PCA 99]. The oldest in-service RCC pavement inspected during the study was constructed in 1978 and the most recent one was constructed in 1997. These pavements have performed well and many jurisdictions are now considering using RCC for arterial roads, lanes, subdivisions and for composting storage sites and snow dumping sites [Serne 94, Serne 98].

Case Study # 4: Likely Road near Williams Lake, British Columbia

In 1987 the British Columbia Ministry of Transportation & Highways, chose RCC to be used on the Likely Road to carry approximately 60 loaded logging trucks per day down an 8% grade. The down hill lane was milled out and replaced with 200 mm of RCC over 1.5 km distance. A chip seal surface was applied following completion of the RCC. The mix design for the RCC included 252kg/m^3 and of portland cement, 85 kg/m^3 of fly ash and a maximum size aggregate of 20 mm. The chip seal was abraded away at the main highway intersection where the trucks stop within the first three years. This exposed the RCC surface to winter conditions of sand and deicing salt. The pavement still performed satisfactorily with only ± 2mm of the RCC surface being abraded away. In 1995 a 25 mm asphalt overlay replaced the chip seal surface. At the time of inspection, even this surface is showing traffic wear at the intersection, again exposing a small area of RCC base. Shrinkage cracks have reflected through the asphalt and crack sealing maintenance has been done. There is no evidence of faulting at the transverse shrinkage cracks. Initial concern about performance of the longitudinal centerline joint between the RCC lane and pre-existing asphalt pavement on the uphill lane has proven to be unfounded. There is no

faulting and the longitudinal centerline reflection crack is hairline in appearance. At eleven years of service, this pavement provides strong evidence to support the use of RCC for secondary highways [PCA 99].

Case Study # 5: 112th Avenue, Edmonton, Alberta

This project was constructed in 1992 as an experimental pavement. Participants in the project included the City of Edmonton, Standard General Construction (now known as Inland Construction) and Portland Cement Association. The 200 mm thick RCC was placed at a two lane collector urban street in Edmonton, Alberta, on 150 mm of soil cement. After leaving the RCC exposed for three years a planned 75 mm asphalt overlay was placed. As part of the experiment saw cuts were made in a portion of the RCC to help control the cracking. Saw cut intervals ranged from 4.5 m to 15 m with shrinkage cracks being allowed to form in a random fashion on the rest of the pavement. Most saw cuts and random shrinkage cracks have reflected through the asphalt overlay. There is no difference in the performance of either type of crack. No crack sealing was evident at the time of inspection [PCA 99]. Other observations identified during the site inspection include the following: evidence of occasional longitudinal cracking (less than 5% of the total lane length) at the mid-point of the traffic lanes, small amount of longitudinal cracking in the wheel paths, no reflection cracks were seen at the centerline joint, no apparent distress in the pavement due to any of the reflection cracking and the rideability of this pavement is excellent [PCA 99].

Interlocking Concrete Block Pavements

Interlocking concrete block pavements can also be used in places where construction must occur over soft ground or land that has been reclaimed from beneath water. They are also used over utility cuts in various urban cities, including London Ontario and on industrial pavements such as intermodal transfer facilities, tidewater terminals and log sort yards. If large settlements occur, the blocks can be picked up and replaced as required [TAC 97].

Case Study # 6: North Bay, Ontario

A recent study by John Emery Geotechnical Engineering Limited or Toronto was involved in examining the life cycle cost associated with using interlocking concrete block pavements in North Bay Ontario. Since 1983, 15000 m^2 of concrete pavers have been placed in streets and walks in North Bay. North Bay experiences very harsh winters and it was identified that the pavers must resist de-icing salts and sands. To examine the effectiveness of using the interlocking concrete block pavements on streets, which carry both car and truck traffic a life cycle cost analysis was carried out. An analysis period of 40 years was selected and a discount rate of 4% was used. Initial construction costs and future maintenance costs were included in the analysis. The interlocking concrete block pavements were compared the using an asphalt pavement. The pavement performance was assessed using the PCI U.S. Army Corps of Engineers system. The results of the study indicated that the interlocking concrete block pavements were more cost effective over the 40-year life cycle. In addition, the study noted that user delay costs associated with repairs are postponed as the pavers where shown to last longer

than the asphalt. Other benefits identified that these block pavers were desirable in urban redevelopment areas such as historic cues and in reinstatement areas [ICPM 01].

OTHER CANADIAN CONCRETE PAVEMENT PROJECTS

Nova Scotia Department of Transportation and Public Works Study

The Nova Scotia Department of Transportation and Public Works (NSTPW) undertook a study to evaluate flexible and rigid pavement structures on a portion of the Trans-Canada Highway (Highway 104) near Oxford. The two adjoining pavement structures, one flexible and one rigid were constructed in the same year, 1994. Based on the similar characteristics in terms of construction, the NSTPW decided to undertake a five year study to compare their performance based on a number of criteria. The flexible structure was designed as follows: 38 mm Type Special C asphalt; 114 mm Type Special B asphalt; 150 mm of Type 1 gravel; and 420 mm of Type 2 gravel over 300mm of Class E gravel. Compaction records from three test sites showed the following ranges: 46 to 49 mm Type C Asphalt, 114 to 127 mm Type B Asphalt, 224 to 302 mm Type 1 Gravel, 499 to 650 mm Type 2 Gravel, and 300 mm Class E Gravel. Similarly, the rigid structure was designed as a 250 mm doweled pavement on 150 mm granular base. Due to contamination of the 150 mm of granular material during the spring thaw the design was modified to 100 to 330 mm of granular base under the concrete pavement. Cores and compaction records showed the pavement varied in thickness from 253 mm to 280 mm and the new subbase varied from 250 to 330 mm over the contaminated 150 mm modified Class B granular [Smith 00]. Both structures included a geotextile. The two sections were evaluated in terms of surface distress, profile ride index, riding comfort index, surface friction and roadside noise level. Evaluations were performed by NSTPW over a five year period [NSTPW 99]. Table 2 summarizes the results based on the five evaluation parameters.

Table 2 Highway 104 Pavement Comparison [NSTPW 99]

Evaluation Criteria	Flexible Structure	Rigid Structure
Surface Distress Survey 1999	Minor rutting, minor raveling with a few raveled areas, slight to moderate flushing, poor longitudinal joints, longitudinal cracking throughout pavement but mainly on shoulders, settlement of asphalt due to erodiable base, settlement of fill at abutments adjacent to bridge	Minor edge damage due to plow, minor spalling portion of some slabs, some sporadic aggregate pop-outs, settlement at two culverts, diagonal crack in two slabs over culvert, minor loss of joint sealant, settlement of shoulder gravel in some locations
Profile Ride Index (Year)	4.2 (1995), 7.2 (1996), 11.2 (1997), 13.3 (1998), 16.2 (1999)	4.1 (1995),4.8 (1996), 7.1 (1997) 6.1 (1998), 6.8 (1999)
Riding Comfort Index (Year)	7.9 (1995), 6.9 (1996), 7.2 (1997) 6.6 (1998), 6.9 (1999)	7.5 (1995), 6.4 (1996), 7.8 (1997) 7.3 (1998), 7.4 (1999)
Friction Number British Pendulum Test (Year)	68 (1995), 56 (1996), 53 (1997) 65 (1998), 48 (1999)	84 (1995), 71 (1996), 70 (1997) 68 (1998), 60 (1999)
Noise Levels dBa at Shoulder (Year)	89 (1995), 87 (1996), 88 (1997) 93 (1998), 87 (1999)	93 (1995), 89 (1996), 90 (1997) 96 (1998), 89 (1999)

Overall the results presented in Table 2 indicate that both pavements at five years have performed well. After five years of service, the JPCP has a superior profile ride index (6.8 versus 16.2), riding comfort index (7.4 versus 6.9) and friction numbers (60 versus 48). Little difference was noted between roadside noise levels (89 dBa concrete versus 87 dBa asphalt) and the surface distresses observed. Based on these findings, the report states the department should consider utilizing concrete in another paving project as no major defects were observed [NSTPW 99].

Asphalt Recycling Using A New Cement-Slurry Stabilization Technique

The need for new and innovative techniques to rehabilitate our roadway systems is more and more evident as the sources of good quality aggregates continue to be depleted and environmentally friendly processes are required. One potential solution is on-site processing of the deteriorated asphalt by pulverization and on-site reprocessing techniques to create a modified roller compacted concrete (RCC) pavement. A large research project undertaken by the Centre de Recherche Interuniversitaire sur le Beton, Laval University, Saint-Foy, Canada was aimed at investigating the use of cementitious binder in roadway reprocessing as a potential rehabilitation process [Tremblay 98]. In 1996 eight different tests sections were constructed on Borne Street in Quebec City and in 1998 two different test sites were constructed on Benoit Road at St. Jean Batiste de Rouvelle, near Montreal. The reprocessing technique consists of utilizing special pulverization equipment, which pulverizes the asphalt and part of the granular base material up to 500 mm in depth. The reprocessing operation also requires the introduction of a cement slurry by a second pass of the of the pulverization equipment over the crushed material in order to achieve good homogenization of the granular material and he cement slurry. The material is then leveled by a conventional grader and compacted using a tandem type compactor, with or without vibration, depending on the consistency of the mix. Cement contents of 9%, 12% and 15% by weight of the dry material was used in the tests [Tremblay 98].

The following conclusions were made based on detailed tests performed on the material [Tremblay 98]. Before beginning the reprocessing of a roadway, it is essential to establish the complete grading characterization of the materials of the site. The determination of the grading curves of the pulverized roadways has demonstrated that it is possible to obtain a material with a grading well suited for the production of RCC mixtures. Globally, the study has shown that RCC made with pulverized materials (containing crushed asphalt particles) is a material that offers many advantages for road applications. Indeed, this concrete exhibits good flexural strength, reduced stiffness, higher deformability and a fatigue behavior comparable to that of conventional concrete. Due to the presence of asphaltic aggregate (insufficient amount) in the granular material, this type of concrete shows a post- cracking ductile behavior analogous to that of a fiber-reinforced concrete. The compressive strength of RCC made from pulverized materials is lower than that of ordinary RCC. The presence of recycled aggregate also leads to an increase in the drying shrinkage deformations. Good performance has been observed on the two test sites since their installation. Thin transverse cracks were observed on each pavement at 12 meter (Borne Street) and 20 meter (Benoit Road) intervals after one year and no additional cracks have developed. In addition, no frost-induced degradation has been observed at either side.

Fuel Studies and Pavement Type

Differences in fuel consumption as a function of pavement type are an important element for users. Heavy vehicles cause greater deflection on flexible pavements than on rigid pavements. This increased deflection of the pavement absorbs part of the vehicle 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 89]. Concrete's rigid design reduces road deflection and corresponding fuel consumption. The difference in fuel consumption performance of heavy vehicles operating on concrete and asphalt pavements was first identified by Zaniewski. In 1982, Zaniewski was part of a team, which conducted a study for the Federal Highway Administration (FHWA) to update vehicle operating costing tables of an earlier study by the World Bank and Brazilian Government. This comprehensive study of the relationship between highway design and vehicle operating costs looked at several cost components, of which one was fuel consumption. Based on this analysis it was found that the savings in fuel consumption for heavy vehicles traveling on concrete versus asphalt pavements was up to 20% [Zaniewski 89]. Detroit Diesel considers pavement type when determining vehicle fuel efficiency in their Spec Manager™ 2.1 computer program. The program assigns factors for the surface type of 1.0 for concrete, 1.2 for cold asphalt and 1.5 for hot asphalt. When performing a typical truck configuration program run with all variables constant except the surface type, the resulting estimated fuel consumption is 8% lower on the concrete surface compared to the cold asphalt, and 17.5% lower than on the hot asphalt when traveling at 100 km/hr [Detroit Diesel 00].

1) To confirm the potential fuel savings in the Canadian climate a year long study was performed by the National Research Council of Canada (NRC) for the Cement Association of Canada and concluded driving on concrete highways reduces heavy truck fuel consumption up to 11%. Some of the key findings of the report are as follows:

- Using a linear fuel consumption model for a tractor semi-trailer with respect to pavement temperature to estimate the percentage differences from a concrete pavement's performance at a variety of pavement temperatures, the following observations are made. There was higher fuel consumption over all temperature ranges on Highway 417 asphalt compared to concrete pavement on Highway 440 for the fully loaded tractor semi-trailer at all test speeds averaging 11%, 8% and 6% at 100, 75 and 60 km/h respectively. It was also found that there were inconsistent trends on all other pavements and load conditions with smaller differences from concrete values observed. No explanation of the cause of these differences was identified in the variables that were collected in this study.

2) The measurement of road roughness during each season allowed for a comparison of the change in various pavements' IRI and indicated that:

- For the smooth pavement sections, the highest IRI rating occurred in the winter period; on the smooth sections, the asphalt pavements had the highest amount of seasonal change. Highway 417 in particular had very large IRI increases in the winter test period (63% higher than the other seasons). The Highway 440 concrete IRI was the most stable of all pavements throughout all seasons and there is evidence of progressive degradation of the Highway 401 composite IRI throughout the year.

3) The analysis of the effect of road roughness on fuel consumption showed no dependency of fuel consumption on IRI over an IRI value of 1.0. However, a consistent reduction, compared to rougher pavements, in fuel consumption of about 10% was observed at all test conditions when the vehicle was operating on very a smooth roadway having an IRI average of 1.0.

4) There is some evidence of non-linear fuel consumption behavior in the higher temperature ranges (the fuel consumption values stabilize or increase at the highest test temperatures), which may be an indication of the increasing deformability of asphalt at the higher temperatures. However, there are not enough data in this temperature region to statistically determine if this is a valid observation [NRC 00].

Table 3 below summarizes predicted fuel savings estimates as outlined above and shows the growing evidence that concrete highways offer greater cost efficiencies than asphalt pavement.

Table 3: Estimated Fuel Savings When Operating on Concrete Pavement Compared to Asphalt Pavement

Source	Vehicle Type	Highway Fuel Savings
Detroit Diesel Spec Manger Program	Trucks	8-17.5%
Zaniewski 89	Trucks	Up to 20%
NRC 00	Trucks	Up to 11 %

SUMMARY

Canadian roads are aging and require timely and cost effective renovation, repair and good management. Concrete pavement products can provide innovative solutions in terms of both technical and cost efficiencies. This paper provides a broad summary of the concrete pavement products most commonly used in Canada. The best practice technologies have been presented in terms of the technical considerations. Various examples of typical designs used in Canada have been presented. The new electronic toll highway in Toronto was constructed as a dowelled JPCP based on both the technical and economic merits. In addition, various designs and examples of CRCP in Quebec, whiteopping and ultra-thin white topping have been presented. Three addition studies from Nova Scotia, Quebec and a National Research Council study were summarized. The results of a 5-year study comparing the performance of adjoining asphalt and concrete pavements constructed in 1994, on a portion of the Trans Canada Highway in Nova Scotia, indicate that the concrete pavements can provide superior performance over a flexible pavement. Another important consideration for further examination would be comparing fuel consumption related to pavement type. The results presented on fuel savings can be achieved and should be further examined as a social cost when considering pavement design alternatives. The cement stabilized asphalt recycling work provides an environmental friendly means of rehabilitation method. The technologies presented provide innovative solutions for the preservation of Canadian infrastructure. The information presented can assist pavement designers to ensure the most appropriate pavement strategy is selected when designing new highways or rehabilitating old highways. Concrete pavements provide a viable paving option for highway construction and maintenance.

REFERENCES

[ACPA 98] American Concrete Pavement Association, "Whitetopping, State of the Practices American Concrete Pavement Association, Skokie IL, 1998.

[AMEC 00] AMEC Earth & Environmental Limited, "High Volume Synthetic Fibre Reinforced Ultra-thin Whitetopping", Report submitted to Lafarge Canada Inc., Burnaby, BC, 2000.

[CAC 00] Cement Association of Canada, "An Overview of Concrete Pavements In Canada", PowerPoint Presentation –Tim Smith, Cement Association of Canada, Ottawa, 2000.

[CPCA 94] Canadian Portland Cement Association, Design and Control of Concrete Mixtures, Canadian Portland Cement Association, Ottawa, ON, 1994.

[CPCA 99] Canadian Portland Cement Association, "Basics of Pavements", PowerPoint Presentation, Concrete Pavements Canadian Portland Cement Association, Ottawa, ON, 1999.

[Detroit Diesel 00] Detroit Diesel, Spec Manager Computer Program, 2000

[ICPM 01] Interlocking Concrete Pavement Magazine, "Life-Cycle Cost Study Demonstrates Long-Term Cost Savings of Concrete Pavers", Interlocking Concrete Pavement Magazine, Volume 8, Number 1, Milton Ontario, February 2001

[Morris 98] David Morris and Harry Sturm, "Ultra-Thin Whitetopping:Ontario Experience", City of Mississauga and Canadian Portland Cement Association, Joint paper for IRF, 1998.

[NRC 00] National Research Council of Canada, "Effect of Pavement Surface on Fuel Consumption – Phase 2, Seasonal Tests", National Research Council of Canada, Centre for Surface Transportation Technology, Ottawa, Ontario, April 2000.

[NSTPW 99] Nova Scotia Department of Transportation and Public Works, Highway 104 Cumberland County, Year 5 of a 5 Year Study Asphalt Pavement and Portland Cement Concrete Pavement, October 1999.

[PCA 99] Portland Cement Association, RP366, "Roller Compacted Concrete Pavements -- A Study of Long Term Performance", ISBN 0-89312-200-9, 1999.

[Serne 94] Serne, Robert A., "Roller Compacted Concrete A pavement Option For Municipal Roads", Canadian Portland Cement Association Western Region, Edmonton, AB, 1994.

[Serne 98] Serne, Robert A., "Trends In The Use of Roller Compacted Concrete Pavements In Canada", Canadian Portland Cement Association Western Region, Edmonton, AB, 1998a.

[Smith 00] Smith, Tim, " Results of HWY 104 Nova Scotia, 5-Yr Comparing Performance of Adjoining Asphalt & Concrete Pavements", Paper at CSCE 2000 Conference London, ON, 2000.

[TAC 97] Transportation Association of Canada, Pavement Design and Management Guide, Transportation Association of Canada, Ottawa, ON, 1997.

[Tighe 01] Tighe, S, Z. He, and R. Haas, "Environmental Deterioration Model For Flexible Pavement Design: An Ontario Example", Transportation Research Board, Washington D.C., 2001

[Tremblay 98] M. Tremblay, J.Marchand, M.Pigeon and L. Boisvert, "Recycling of Asphaltic Roadways Using A New Cement –Slurry Stabilization Technique", Centre de Recherche Interuniversitaire sur le Beton, Laval University, Sainte-Foy, Canada, G1K 7P4, 1998.

[Zaniewski 89] Zaniewski, J.P., "Effect of Pavement SurfaceType on Fuel Consumption", SR289.01P, Portland Cement Association, Skokie, Illinois, 1989.