Impact of Recent Technology Advancements on Pavement Life

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ABSTRACT

Canada's roads keep our society mobile and contribute significantly to our economic infrastructure. The economic (cost-effective) design, and more importantly preservation, of these valuable national assets cannot be overstated. Advancements in asphalt and concrete technology, as well as pavement design methods, through research and development activities have made significant contributions to building longer lasting pavements with lower service costs. This has been accomplished through a better understanding of pavement design, rehabilitation, and maintenance methods and applications.

In this paper, the benefits of recent technology advancements such as the development of the new AASHTO 2002 pavement design guide, as well as the use of technology advancements such as, pavement smoothness specifications, open graded drainage layers, perpendicular transverse joints in concrete pavements, ultra-thin whitetopping, stone mastic asphalt, micro-surfacing and expanded/foamed asphalt are discussed. For each technology or technique, a synthesis and history of practice is provided along with a relative ranking of performance benefits and costs. For example, the use of stone mastic asphalt (SMA) in Canada has increased dramatically since its initial introduction to Canada in 1990. The use of SMA has progressed rapidly from its initial use on a trial basis to the primary mixture of choice for high volume urban highways and freeways. While the initial cost of SMA can be in the order of 30 to 50 percent higher than traditional asphalt mixes, its superior performance characteristics in terms of fatigue and rut resistance result in a longer service life with lower maintenance costs. When considered on an overall life-cycle cost basis, the use of a higher initial cost SMA will result in a lower life-cycle cost for the pavement. Similarly, the timely use of pavement preservation techniques such as micro-surfacing will reduce maintenance costs and provide a cost-effective extension in pavement life until such time as a more substantial rehabilitation can be considered. The potential cost savings resulting from an increase in pavement service life or reduction in the maintenance and rehabilitation costs is substantial and contributes significantly to sustainable municipal infrastructure.

Introduction

Canada's roads keep our society mobile and contribute significantly to our economic growth. The economic (cost-effective) design, and more importantly preservation, of these valuable national assets cannot be overstated. The need to improve the design and performance of highway pavements is paramount to insuring the viability of our highway infrastructure.

Infrastructure deterioration is expected with renewal programmed though a series of planned maintenance and rehabilitation treatments. The pressure of an increasing rate of deterioration due to a significant increase in both volume and commercial vehicle loading is outpacing our ability to maintain our infrastructure. Comprehensive monitoring of highway pavement performance through programs such as the Long Term Pavement Performance (LTPP) project have identified design and construction and maintenance improvements (SHRP, 1994) to extend the life of our infrastructure. This has been accomplished through a better understanding of pavement design, rehabilitation, and maintenance methods and applications. Advancements in asphalt and concrete technology, as well as pavement design methods, through research and development activities have made significant contributions to building longer lasting pavements with lower service costs.

The objective of this paper is to highlight some of the significant advancements in pavement technologies and identify their cost effectiveness in the context of pavement preservation.

New Advancements – Pavement Technology

In an effort to improve the state of pavement technology, considerable research and development activities have been directed towards improving paving materials and methods. A review of the state of practice in North America has highlighted a number of current and/or new technologies that appear to have beneficial impacts on pavement performance and on overall life-cycle cost. Some of the more promising items include:

- Pavement smoothness specifications;
- End-result specifications (ERS);
- Cement- and asphalt-treated open-graded drainage layer (OGDL);
- Stone mastic asphalt (SMA);
- Superpave;
- Foamed/expanded asphalt;
- Micro-surfacing;
- Concrete pavement technology improvements:
    - Perpendicular transverse joints in concrete pavement;
    - Texturization;
    - Fast-track concrete;
    - Dowel bar retrofit;
    - Pre-cast slabs for pavement repair
    - Thin or ultra-thin whitetopping;
- AASHTO 2002 Guide for the design of pavement structures.

Pavement Smoothness Specifications

Pavement smoothness is one of the most important indicators of pavement quality because it directly affects the way in which pavements serve the traveling public. Initial smoothness is also often considered one of the most important indicators of the overall quality of pavement construction and, consequently, an indicator of the expected life span of the pavement.

The effect of smoothness specifications on the overall life-cycle cost of highway pavements was investigated in great detail under U.S. National Cooperative Highway Research Program (NCHRP) Project 1-31 (Smith, 1997). Most agencies use some form of an initial smoothness specification (C-LTPP, 1999). For example, Alberta Transportation is using a California profilograph with specifications for both overall smoothness and localized profile deviations (scallops). The British Columbia Ministry of Transportation and Ministère des Transports du Quèbec are using GM type profilometers to determine the International Roughness Index (IRI) of the pavement.

Smith et al. obtained data on the effect of smoothness specifications on initial pavement smoothness from Iowa, Georgia, Illinois, and Wisconsin (Smith, 1997). The study reported that the effectiveness of initial smoothness specifications depends on the conditions before the specifications are introduced, the type of specification (including the specifications limits and associated incentives and disincentives), the length of time the specifications were in place, and the administration of the specifications. The study found that smoothness had nevertheless improved.

In a study prepared for the Ontario Ministry of Transportation (Hein, 2000), four provincial highway agencies (Alberta, British Columbia, Quebec, and Manitoba) were contacted regarding the impact of smoothness specifications on pavement smoothness. The responses received from Alberta, British Columbia, and Quebec indicate that pavements became smoother after the implementation of smoothness specifications, but these agencies have not carried out any studies to document and quantify the impact.

It is generally believed that initial smoothness is an indicator of the overall quality of construction, and that initially smooth pavements last longer than initially rough pavements. Several projects performed in Wisconsin and Kentucky strongly indicated that both flexible and rigid pavements with lower initial smoothness actually had longer service lives (Smith, 1997). Initial smoothness is often considered one of the most important indicators of pavement quality because achieving it requires a strong commitment on the part of the contractor to also control other factors that affect pavement smoothness, such as providing a stable and smooth paving platform, uniformity of asphalt and concrete mixtures, and capable paving operations.

The AASHTO pavement design models foster the concept that, all other things being equal, new pavements constructed with a smoother surface profile will last longer than new pavements with a rougher profile. The AASHTO models for the design of flexible and rigid pavements assume that a smoother pavement will last longer than a corresponding rougher pavement (AASHTO, 1993). A recent report prepared for the MTO on the adaptation and verification of the AASHTO

Pavement Design Guide for Ontario conditions maintains this concept (Hajek, 2000). The AASHTO model was also used by Zaghloul to evaluate the effect of smoothness on pavement LCCs (Zaghloul, 1996). This concept has also been carried forward in the latest edition of the AASHTO Guide.

There is a general consensus that pavements constructed smoother than an otherwise similar pavement will remain smoother over many years. This suggests that added pavement life may be achieved by building a pavement smoother, provided that pavement roughness is a major factor influencing the engineering decision to rehabilitate that pavement. While roughness directly affects the way the pavements serve the traveling public and user costs, freeway pavements are resurfaced for many other reasons, including deteriorated longitudinal lane joints, transverse cracks, rutting, and raveling.

End Results Specifications

End result, or performance related, specifications (ERS) are generally defined as specifications that describe the desired levels of key materials and construction quality characteristics (e.g., air voids in asphalt, concrete strength) that have been found to correlate with fundamental engineering properties that predict pavement performance. These characteristics are generally used for acceptance testing at the time of construction.

Up until the 1980s, most highway agencies controlled the quality of pavement construction through the use of method-based specifications, which provided a rigid framework in which a contractor produced the intended product. Construction specifications outlined the types of materials that were to be used and how contractors were to produce and place these materials to construct the highway. This methodology is predominately based on the qualifications and experience of the construction administration staff and the inherent assumption that if one controls all aspects of production and placement, the final product will have a high level of quality. Material and placement quality was confirmed by laboratory and field testing. While method-based specifications would generally result in a good quality product, they were not always consistent or effective.

ERS rely heavily on statistical analysis for the control and acceptance of a product and are therefore considered to be unbiased. Most ERS systems, while assessing penalties for the production and placement of substandard materials, also provide an incentive for higher levels of quality. The provision of bonus clauses would provide the incentive for contractors to construct a higher quality end product to receive the maximum allowable bonus.

Many highway agencies have implemented, or are implementing, ERS-type specifications for pavement construction (Weed, 1999 and Shilstone, 1998). In Canada, these agencies include the highway departments of British Columbia, Alberta, Québec, New Brunswick, Nova Scotia, Public Works and Government Services Canada, and the Department of National Defence.

Most Canadian highway agencies with the exception of Québec have only recently implemented an ERS-type system and are using ERS on a limited number of projects. In Québec, ERS are included in all of their major pavement construction and rehabilitation contracts. Québec has indicated that it is very difficult to evaluate how substantially the implementation of ERS has affected the service life, initial construction costs, and maintenance requirements for their pavements. The general consensus, however, is that the implementation of ERS has reduced the variability in pavement construction, which would likely result in an increased pavement life and reduced maintenance costs. There was also general agreement that the implementation of ERS has increased initial construction costs. It is likely that overall construction quality levels will be increased once owners and contractors are comfortable with ERS and its effects.

Drainage Improvements

Subsurface drainage is a fundamental element in pavement design that is often overlooked. The effects of excessive subsurface moisture are indisputable and include reduced structural support, soil particle migration, and increased frost susceptibility.

The most popular method of subsurface drainage consists of daylighted dense-graded bases in rural applications and subdrains connected to appropriate storm outlets in urban applications. Yu et al. conducted a survey of 40 U.S. highway agencies on the use and current design of subdrainage systems (Yu, 1998). By far, the most popular subsurface drainage design for HMA and PCC pavements is subdrains with a open graded drainage layer (OGDL). In Canada, OGDL is used for high volume roadways in Ontario and Québec. A summary of the findings of the U.S. study is presented in the following sections.

Ditches. The depth of the ditches (from pavement surface to bottom of ditch) ranges from 300 to 1500 mm, with an average depth of 850 mm. Some agencies measured the depth differently, such as 300 mm below the subbase or 600 mm below the top of the subgrade. Many States specified a depth of 300 mm, which would not give ample space for the outlet drains (these depths may be from the top of the subgrade). In general, the depths were in the range of 900 to 1200 mm from the surface.

Horizontal Location. The horizontal location of longitudinal edgedrains varies depending on other design factors, such as the pavement type and the base type. For pavements with OGDL, a majority of States (62 percent for AC pavements and 55 percent for PCC pavements) place the edgedrains at the outer edge of the shoulder. The remaining agencies place the edgedrains at or near the lane-shoulder joint.

Vertical Location. The vertical edgedrain location also varies with different designs. For AC and PCC pavements with permeable bases, the edgedrains are situated below the permeable base course in 47 and 55 percent of the States, respectively. An additional 16 and 14 percent of the States place the drains below the surface layer for asphalt and concrete pavements, respectively. The remaining States place the drains at a specified depth from the surface.

Trench. The typical trench design consists of a 300 x 460 mm geotextile-lined trench filled with a porous aggregate material. However, many ranges and variations of this typical design are employed. For the most part, the trench widths are between 250 and 460 mm, although they range from 150 mm in California to 910 mm in New Hampshire. The narrow trenches are likely used for geocomposite edgedrains rather than pipe drains. In general, the trenches are between

300 and 600 mm deep. However, wide variations were noted, with depths ranging from 150 mm in California to 1,520 mm in Alaska.

Backfill. The trenches are typically filled with some kind of porous material. Nearly 60 percent of the agencies use the same material as used for the permeable base course. Other States specified various porous materials, including crushed stone, aggregate chips, and porous concrete.

Pipe Drains. The most widely used material for pipe drains is polyethylene (PE), followed closely by polyvinyl-chloride (PVC) and plastic. Combined, these materials make up about 84 percent of the pipe drains. Another 9 percent of the pipes are made of metal. The majority of the agencies use a 100-mm diameter pipe. However, 75- and 150-mm pipes are also widely used. A few States specified pipe diameters of 200 mm, and New Hampshire indicated pipes as large as 300 mm are used in their state. About 20 percent of the agencies stated that the pipes are wrapped (typically with a geotextile material), whereas the other 80 percent do not wrap the pipe drains.

Outlets. The spacing of the outlets varied considerably from agencies to agencies. Most agencies typically use an outlet spacing between 60 and 150 m, with outlets also being provided at low points. Ohio uses a longer outlet spacing, generally between 150 and 300 m, and West Virginia uses a much shorter outlet spacing of 30 m.

Permeable Base. In general, three types of permeable bases are available: untreated OGDL (UTPB), asphalt-treated OGDL (ATPB), and cement-treated OGDL (CTPB). For asphalt pavements, 22 agencies indicated that permeable bases are used. The most common type of permeable bases are ATPB (19 agencies), although UTPB are also used extensively (14 agencies). CTPB are used only sparingly (4 agencies). Many agencies use more than one type of permeable base. This is also the case in Ontario where either ATPB and CTPB are permitted on most contracts.

For asphalt pavements, 38 percent of the agencies extend the permeable base just beyond the lane–shoulder joint (within 900 mm), whereas 62 percent extend the permeable base to the outer edge of the shoulder. For concrete pavements, 42 percent extend the permeable base to the lane-shoulder joint, and 58 percent extend the permeable base to the outer edge of the shoulder. An example of the subdrain detail used by the MTO in Ontario is shown in Figure 1.

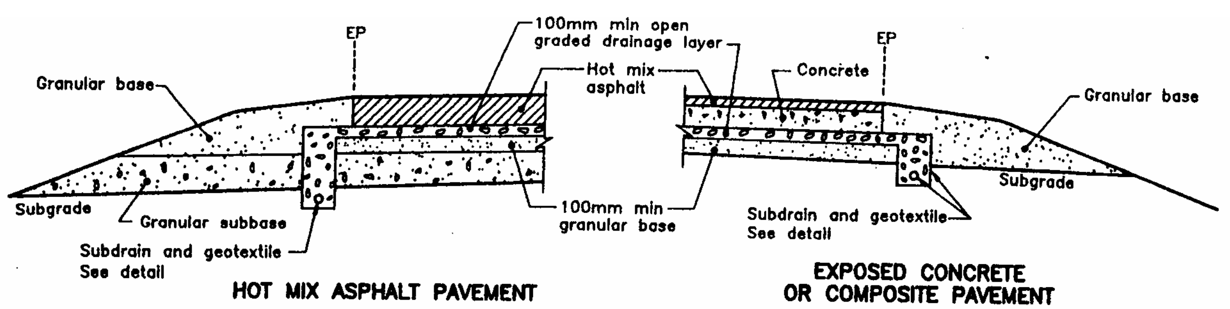

Figure 1. Ministry of Transportation of Ontario subdrain detail.

While the specific methods used to ensure pavement structure drainage are variable, almost all agencies agree that pavement life is increased by the provision of adequate drainage.

Stone Mastic Asphalt

Stone mastic asphalt (SMA) was developed about 30 years ago in Germany and was called split-mastic asphalt, which effectively translates to stone mastic asphalt, since the term "split" refers to crushed stone chips. It should be noted that SMA has also been called stone *matrix* asphalt by many in the U.S. and refers to the course stone "matrix" that is developed through the gap-graded skeletal structure. Despite the two different terminologies used to describe this mixture, they are considered the same. The terminology that seems to be used the most in Canada, and is considered by some to be a more precise translation, is stone *mastic* asphalt. An example of a stone mastic asphalt surface is shown in Figure 2.

Figure 2. Typical stone mastic asphalt surface.

SMA is a gap-graded asphalt mix that typically contains 100 percent crushed stone materials. The addition of asphalt cement and some type of filler to the coarse stone skeleton produces a rich and relatively thick asphalt/filler mastic (or paste) that provides excellent durability while also providing increased resistance to permanent deformation through the stone-to-stone contact and increased fatigue resistance due to the thick mastic coating on the aggregate.

SMA use in North America was first introduced in Ontario (Miller Avenue) in 1990 and was used in the U.S. shortly thereafter (Kennepohl 1992 and 1999). SMA usage has steadily been on the rise across North America, especially in the U.S., and it continues to be used in large quantities in Europe as well as Japan. In Ontario, the Ministry of Transportation recommends SMA pavements for roadways with traffic loadings in excess of 3 million equivalent single axle loads per year.

A considerable amount of SMA has been placed in the U.S., with nearly all state DOTs participating to one degree or another. In some instances, SMA is the primary mixture of choice for high-volume urban interstates (e.g., Georgia DOT in and around Atlanta).

Beginning in 1994 and concluding in 1996, the National Center for Asphalt Technology (NCAT) visited and documented over 140 SMA pavement sections representing 86 SMA projects for a study funded through the Federal Highway Administration. The study also summarized many observations about SMA mix design in the U.S. and these are listed below:

- Almost all SMA projects contain a cellulose or mineral fiber or a polymer to avoid draindown problems.
- Early SMA mixtures (1991 to 1993) were designed at 3.5 percent air voids; however this has been increased to 4 percent air voids in recent years to help decrease the probability of "fat spots" on the pavement during construction.
- In most cases, 100 percent crushed materials are used, with Los Angeles abrasion values below 30.
- Most SMA aggregate gradations have 20 to 35 percent passing the 4.75-mm sieve and have 7 to 11 percent passing the 0.075-mm sieve.
- VMA ranges from 15 to 20 percent, with a recommended minimum VMA of 17 percent.
- Typically, asphalt cement contents are 6.0 percent or greater.
- In-place air voids are recommended to be in the range of 5 to 7 percent; however initial projects had values outside these ranges. This is probably related to the inexperience of paving crews with the high-stability SMA mixtures.
- Coarse aggregate segregation is generally not a problem, however areas with very little coarse aggregate resulting in fat spots can be a problem if mixing temperatures are too low or if the mineral filler is not blended properly.

In recent years, the melding of SMA design and Superpave design has been utilized. This has been reported in Maryland to offer promise in providing extremely durable pavements (Kuennen, 1999). Generally, these mixes are gap-graded SMA mixes with Superpave PG binders and fiber fillers, and are designed with the Superpave gyratory compactor to 4 percent air voids. These mixtures are reported to be performing well by resisting freeze-thaw cycles and permanent deformation from heavy traffic loading.

Costs associated with constructing SMA pavements vary, but are almost always greater than traditional high-quality, dense-graded HMA mixes. HMA material producers and contractors in North America indicate that costs associated with producing and placing SMA are typically 15 to 20 percent higher than traditional, surface course mixtures. However, some indicated that the additional costs could be as high as 30 to 40 percent, depending on the SMA design and the construction requirements of the project (Hein, 2000).

Some agencies are anticipating significant increases in pavement life as a result of using SMA. Factors of between 1.3 and 2.0 have been estimated (Kuennen, 1999), however, there is significant variability associated with these estimates. The increase in life is a function of the traffic class of the roadway, the thickness of the SMA placed, the criteria incorporated in the mix design specification and the quality of the conventional mixtures that are being compared to the SMA.

For example, agencies that have poor performing dense graded mixtures that begin placing high-quality SMA mixtures could possibly see a life expectancy of twice the conventional pavement.

In addition, the thickness of the SMA will also have an impact on the expected increase in life. Thin applications of SMA may not necessarily provide twice the life of a thin dense-graded overlay, especially if the underlying pavement is in poor condition.

It is expected that SMA surfaced flexible pavements will provide approximately 1.3 times the initial life of the conventional asphalt designs. This is based upon reported expectations of service life as well as mechanistic analysis of SMA mixtures from Canada and the U.S. (Brown, 1998 and Ali, 1994). It should also be noted that there is considerable variability associated with these life expectancies, which will affect the life-cycle cost associated with SMA designs.

Superpave Mixture Design System

The Strategic Highway Research Program (SHRP) was established in the U.S. in 1987 as a 5 year, $150 million research program to improve the performance and durability of roadways in North America. One product of the asphalt pavement research was the development of the Superpave mixture design system (*Su*perior *Per*forming Asphalt *Pave*ments).

The Superpave system is a performance based method for designing asphalt pavement. The Superpave system currently comprises three main components; asphalt binder characterization, aggregate characterization, and volumetric mix design. Other aspects of the Superpave system, currently under development, include performance testing and prediction modeling.

Performance graded asphalt cement (PGAC) binders are classified by performing a series of performance-based tests and denoting the temperatures at which the asphalt meets a set of fundamental criteria. The PGAC specification is a key part of the overall Superpave mixture design system and incorporates criteria based upon the anticipated environmental conditions. The PGAC specification also incorporates a statistically based reliability component that allows the designer to choose the appropriate material based upon the anticipated risks, which is normally a function of the expected traffic.

Although there is a significant amount of asphalt pavement in place with PGAC, there is relatively little performance data that can be used to judge the long-term effect that specifying PGAC may have on HMA pavements.

Municipalities in Ontario and Québec have begun using PGAC and are being encouraged by the provincial highway agencies and industry groups to continue (or begin) the use of this technology. Specifically, the City of Toronto has been specifying PGAC since the mid-1990s. Their experience has also been similar to the highway agencies in that they expect moderate extensions to initial pavement service life and anticipate cost savings due to using PGAC.

As of year 2001 in the U.S., 49 of 50 States have reported adopting the Superpave PG binder specification (FHWA 2001). There is a wealth of information available regarding the use of PG binders and many of the more proactive states are documenting performance of pavements utilizing PG binders versus pavements built with their standard viscosity or penetration-graded asphalts. Some agencies are already reporting significant performance improvements using PG binders, including reduced thermal cracking, reflective cracking on overlays, and permanent deformation (Wegman, 1999). Although most will agree that using binders meeting the requirements of the PG specification will improve pavement performance, they also acknowledge that long-term data are not available to determine the degree of improvement over many years.

Aggregates comprise up to 95 percent (by weight) of an asphalt mix. The quality and characteristic properties of component aggregates are major contributors to the overall performance of any mix. The Superpave system has determined the aggregate properties considered most important for pavement performance divided them into two groups; consensus properties and source properties.

The consensus properties include: coarse aggregate angularity, fine aggregate angularity, flat and elongated particles, and clay content. The source properties include: toughness, soundness, and deleterious materials. Consensus properties are mandatory aggregate requirements, while source property requirements are specified by local authorities to reflect regional differences in aggregate quality and characteristic properties.

Superpave mix designs combine aggregate and asphalt binder at optimal proportions to produce a mix that meets design criteria for the anticipated traffic loading. Target design criteria for the Superpave method include, air voids, voids in the mineral aggregate (VMA), and voids filled with asphalt (VFA).

The Superpave method involves selecting PGAC and component aggregates in accordance with the Superpave system for the geographical region of application. Trial specimens are then prepared and subjected to a volumetric assessment to confirm the adherence to the design criteria. The method is an iterative process until the desired mix properties are achieved. The principal difference with the method is the use of a gyratory compactor for preparing laboratory samples using compactive effort specific to the expected traffic loading for the service application.

The Superpave Needs Assessment report (FHWA 2001), reported that 42 States will have implemented the Superpave mix design method by 2002. The survey found that the production of Superpave mixes has exceeded that of conventional HMA by 53 percent in 2000 and was projected at 70 percent in 2001. The respondents reported overall improvements in rutting characteristics but expressed concerns with permeability issues related to under asphalted mixes.

In Canada, the implementation of the Superpave mix design method is proceeding but at a slower pace. The City of Vancouver has used Superpave mixes for several years. The Province of Ontario will specify Superpave for 25 percent of all 2003 construction contracts and expects full implementation in 2005.

Expanded Asphalt

One of the many techniques for rehabilitating pavements is the expanded/foamed asphalt method. The expanded/foamed asphalt method is a cold in-place recycling technique that uses foamed asphalt as a stabilizing agent. Foaming occurs when small amounts of water are added to hot asphalt in a controlled expansion chamber. The advantages of foamed asphalt stabilization over other stabilization techniques, include: lower costs, an acceptable driving surface immediately after placing and compaction, and the method is less sensitive to environmental constraints (ambient weather) during placement.

The process of expanded asphalt pavement rehabilitation starts with the in-place pulverization of the existing hot mix asphalt (HMA) with some of the underlying granular base. The pulverized material is then graded to provide the desired roadway cross section. A pulverizer equipped with a foaming device is used to introduce asphalt cement and water to the pulverized material. Hot asphalt cement is mixed with water in a foaming chamber. The foamed asphalt is then mixed with the pulverized material to assist in stabilizing the pulverized material as shown in Figure 3.

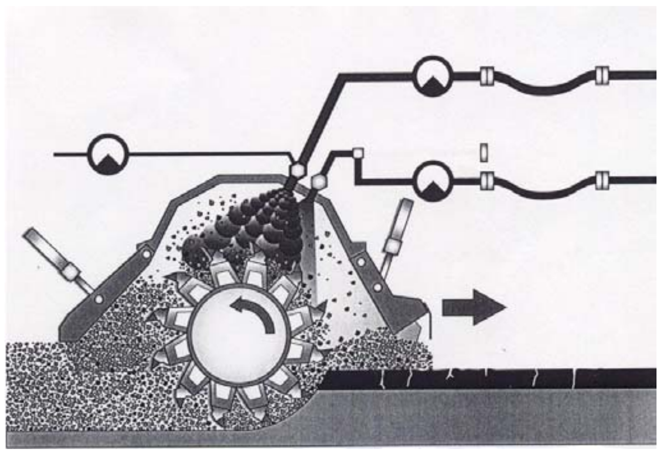

Figure 3. Combining the Pulverized HMA/Granular Base with the Foamed Asphalt

The foamed pulverized material is then compacted using heavy rollers and re-graded as necessary to provide the final base for the new HMA or surface treatment. Photographs of a typical foamed asphalt rehabilitation project are shown in Figures 4 and 5.

Figure 4. Foamed Asphalt Recycling Train.

Figure 5. Final Pavement Surface Prior to HMA Overlay.

The processed material has a structural equivalence that approaches new asphalt, which reduces the amount of new material required for a rehabilitation project resulting in reduced project costs and conservation of high quality aggregate sources. This process also eliminates reflective cracking by recycling all the in-situ asphalt layer.

Micro-surfacing

The use of micro-surfacing in Canada started early in the early1990s. It has been applied to airports, urban streets (Hein, 1994), local highways (Kazmierowski et al, 1993), and freeways (Kazmierowski, 1995). Micro-surfacing was introduced to the USA in 1983 (Hixon, 1993). The results of the field studies referenced above indicate that micro-surfacing is a viable alternative rehabilitation technique, and can provide a durable, highly skid-resistant surface.

Micro-surfacing material is a bituminous mixture consisting of the following components:

- *Aggregate*. Aggregate is a crushed densely graded aggregate with the maximum size of about 10 mm. The crushed aggregate is necessary to provide internal stability to the mix and high skid resistance.
- *Emulsified asphalt*. Emulsified asphalt enables the mixing and placing the material at ambient temperatures. The amount of asphalt cement in the emulsion is about 7 percent by weight.
- *Polymer additive*. Polymer additive, usually latex, provides increased stability and flexibility of the mix. The weight of the polymer additive represents about 3 percent of weight of asphalt.
- *Mineral filer*. Mineral filler is used to control set times of the micro-surfacing material. It is usually Portland cement, and constitutes about 1 percent of the total dry mix weight.

Micro-surfacing has been used for asphalt concrete, concrete and even surface-treated pavements. An example of micro-surfacing equipment is shown in Figure 6.

Figure 6. Micro-surfacing equipment.

For asphalt concrete pavements, micro-surfacing has been used to correct surficial distresses (e.g., ravelling and segregation, loss of friction, rutting, and minor cracking). Because micro-surfacing contains crushed aggregate and can be laid at various thicknesses, it can be used to fill-in ruts to the depth of up to about 25 mm. It is also used as a preventive maintenance treatment to seal pavement surfaces from intrusion of water. For concrete pavements, micro-surfacing has been used to improve or maintain surface friction and smoothness.

New or Improved Concrete Pavement Techniques

There are several new or improved concrete pavement techniques or procedures which have contributed to improved pavement service life.

Perpendicular Joints in Concrete Pavement

The skewed joint was first used in California in the 1950's to reduce roughness and vibrations in cars due to the faulting of non-doweled perpendicular transverse joints. This became standard practice for many years for many highway agencies in North America for non-doweled joints.

Over time, truck traffic increased dramatically causing increased non-doweled joint faulting. Many agencies found that properly sized dowel bars could control joint faulting and, in the past decade, jointed plain concrete (JPC) pavement with dowels at transverse joints has become the most popular type of design. Nearly every highway agency now requires dowels for heavily trafficked JPC pavement.

Highway agencies initially added dowel bars and retained the skew of the joints. However, over the past few years, some 80 percent of highway agencies in North America have either switched to perpendicular doweled joints for JPC or maintained their original perpendicular joints with dowels. The high percentage of highway agencies across North America specifying perpendicular doweled joints is important because it demonstrates that many agencies have confidence in perpendicular doweled joints as they have provided good performance and are cost-effective.

The issue of joint orientation was also addressed in the FHWA "Good and Poor" study (Khazanovich, 1997), where over 200 LTPP General Pavement Studies (GPS) test sections were examined with respect to faulting, cracking, and roughness. The GPS sections consisted of many designs and represented various climates and traffic loading scenarios. The LTPP Information Management System (IMS) database was analyzed to identify the specific design features that lead to improved faulting performance. A total of 181 doweled JPC pavement sections throughout United States and Canada were investigated and, through a t-test analysis of faulting levels, it was shown that there was no significant difference in performance between the skewed and perpendicular joint designs. Hence, it was concluded that there is no need to skew doweled joints from a faulting performance standpoint. Further, the increase in cost, as a result of both joint sawing and sealing and construction layout and placement, has been shown to be in the order of 2.5 percent of initial construction cost (Smith, 1998).

Texturization

Texturization of exposed PCC pavements usually involves the removal of a shallow depth of pavement surface material by chemical means (etching), by impact forces of materials projected against the pavement surface (high pressure water or shot blast), or by grinding/grooving. The most common method is diamond grinding/grooving. For composite and asphalt concrete pavements, impact methods are typically used.

Texturization is an important maintenance activity that is required to improve the surface texture and hence skid resistance of the pavement along with making minor profile adjustments to improve the ride quality. Texturization can effectively address pavement surface polishing. Slab faulting is also mitigated, but unless the underlying cause of faulting is removed (e.g., lack of support or load transfer) it is likely to reoccur.

As a layer of pavement material is removed from the pavement surface, texturization should only be used on pavements that are structurally adequate. Also, texturization will not address the underlying cause of pavement structural problems.

Diamond grinding employs a large drum equipped with diamond-tipped teeth that is mounted on a moving heavy-set framework. The framework spans the entire traffic lane and is 1.2 to 3 meters long. In this way, the diamond grinding can improve pavement smoothness. The diamond grinding operation should be against the direction of the traffic flow. A typical diamond ground surface is shown in Figure 7.

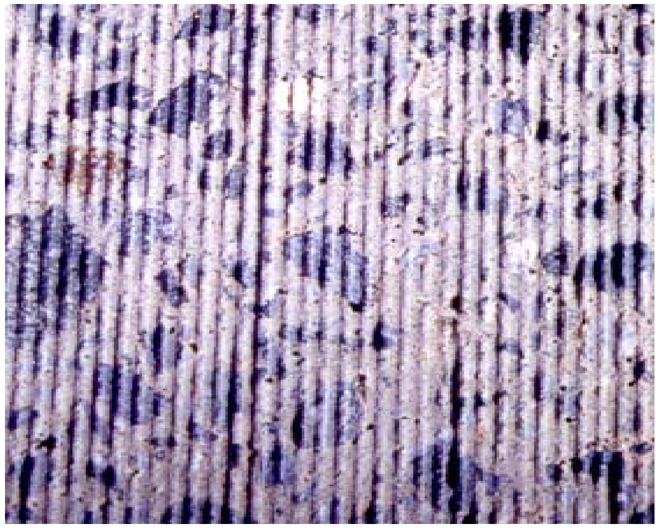

Figure 7. Typical diamond ground surface.

Shotblasting involves projecting small steel balls against the pavement surface. It is expected that the projectiles will remove softer cement paste and expose harder aggregate particles. Shotblasting does not improve pavement smoothness.

The long-term effectiveness of a diamond-ground pavement depends on numerous factors, but the most significant factors are the condition of the existing pavement structure and level of CPR applied. It is important to recognize that diamond grinding addresses serviceability problems. If the existing pavement is structurally deficient, an overlay or reconstruction may be more appropriate. Pavements with a material problem such as D-cracking or reactive aggregate are also not good candidates for diamond grinding. Inappropriate use of diamond grinding is likely to lead to premature failures. However, even for pavements in poor condition, it may be appropriate to consider diamond grinding as an economical short-term (5 years) solution to a roughness problem until the pavement section can be overlaid or reconstructed. Based on surface texture life, faulting performance, and survival trends, a diamond-ground surface may be expected to provide a minimum of 8 to 10 years of service with a high degree of reliability, depending on climatic conditions and traffic (Rao et al, 1998).

<u>Fast-track Concrete</u>

Several relatively new techniques make it possible for concrete contractors to rehabilitate and resurface highways efficiently with minimum traffic interruption. Among these is fast-track concrete pavement technology, in which high-early-strength concrete is used to allow reconstructed roads to open more quickly. While conventional concrete mixes might require a curing time from 5 to 14 days, fast-track concrete can meet roadway opening strengths in 12 hours or less. Generally, fast-track concrete provides good durability because most of these concretes are air entrained and have a relatively low water content—factors that improve strength and decrease the chloride or salt permeability that damages steel reinforcement and contributes to deterioration.

Dowel Bar Retrofit

Another relatively new technique that promises to improve highway smoothness and longevity is dowel retrofitting of existing concrete pavement that has undowelled slab joints. Load transfer restoration of exposed PCC and composite pavements usually involves cutting a slot, placing a dowel bar in the slot, and backfilling/grouting the slot. Load transfer restoration operations are suitable for pavements that exhibit poor load transfer but are considered structurally adequate (to have adequate thickness). To ensure structural adequacy, evaluation of the concrete condition at the joint should be carried out. Rigid pavements with little remaining structural capacity are not suitable candidates for load transfer restoration. Evaluation of load transfer efficiency should be based on falling weight deflectometer (FWD) testing.

The most common type of load transfer device is the smooth round dowel bar. The size of the dowel bars depends on the slab thickness and anticipated loads. Typically, dowel bars have the diameter of 30 to 40 mm and the length of 400 to 600 mm. Other types of load transfer devices include deformed reinforcing steel, small beams, and shear devices. Smooth dowels are preferable because they can withstand shear loads while allowing for expansion and contraction of the slab. Corrosion protection such as epoxy coating is recommended. Prior to placement, dowels should be oiled, fitted with expansion caps, and placed on chairs within the slot.

Highway 407 ETR (Ontario) has used load transfer restoration for selected slabs with good results. Mamlouk et al (2000) evaluated the performance of dowel retrofitting of transverse cracks in Michigan. Some dowels were placed at a depth shallower than the mid-depth of the concrete slab for the purpose of reducing construction costs. Initial results indicate that dowel retrofitting of transverse cracks is a viable method for preventive maintenance of PCC pavement. Washington State Department of Transportation has been using dowel retrofitting since 1992 with good results (Pierce, 1994). Typical photographs of load transfer restoration using dowel bars are shown in Figure 8.

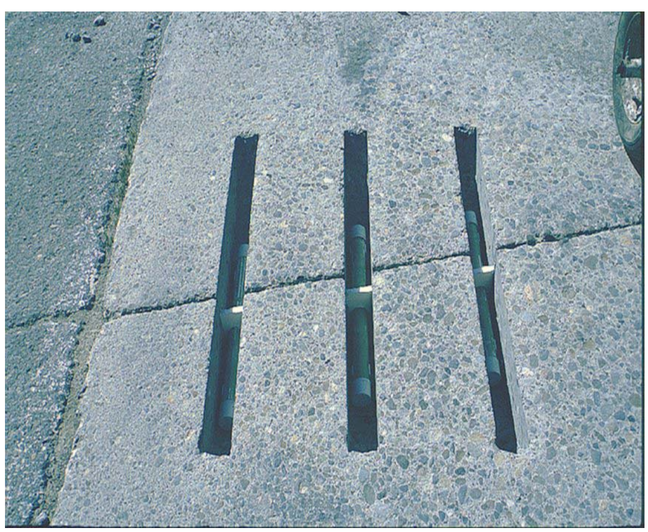

Figure 8. Load transfer restoration using dowel bars.

A variation on the use of dowel bars for load transfer restoration is slab stitching. Slab stitching involves drilling holes for dowels at about a thirty degree down angle through cracks in the concrete slabs. An alternating pattern is used as shown in Figure 9.

Figure 9. Load transfer restoration using slab stitching.

Dowel bars are then placed in the holes and grouted flush with the top of the pavement. Slab stitching is relatively inexpensive compared to complete concrete panel removal and can cost-effectively extend the service life of the pavement. Slab stitching is not widely used in Canada but has been used effectively for Highway 407 ETR in Toronto and by the MTQ in Quebec.

Pre-cast Slabs for Pavement Repair

The use of pre-cast concrete slabs for new and rehabilitated pavements is becoming more popular. Fort Miller Construction in the United States has pioneered the use of pre-cast slabs for large area paving. The Michigan Department of Transportation has experimented for several years with the use of pre-cast slabs for concrete pavement restoration. The concrete slabs are pre-cast and are typically one lane width by a standard length. In the case of the Fort Miller method, the slabs are cast with a dovetail slot along one side of the slab and dowel bars in the perpendicular direction (Figure 10). The dovetail slots are then grouted to provide joint load transfer.

For the Michigan method, the concrete slabs are cast with the dowel bars the full lane width and 2 m in length. The concrete repair area is marked out, cut and the deteriorated concrete removed. Slots are then cut into the adjacent good concrete and the pre-cast slab is placed in the repair area (Figure 11). The slots are then grouted to provide joint load transfer.

Figure 10. Fort Miller precast concrete slab placement technique.

Figure 11. Completed pre-cast slab repair.

Thin or Ultra Thin Whitetopping

Thin or ultra thin whitetopping (UTW) is a relatively new technique to address rutted asphalt pavements. A thin layer of concrete ranging from 50 to 100 mm is placed over a milled asphalt surface. The concrete is usually fiber reinforced and is cut into small panels generally 1 to 1.2 m square as shown in Figure 12 and the joints are not sealed as with traditional concrete paving. It is very important that the overall pavement be structurally sound and that a sufficient thickness of asphalt concrete remains under the UTW to ensure that the concrete remains in compression. The first UTW project in Canada was constructed in the City of Mississauga in 1995. Since that time, UTW projects have been constructed in Vancouver, Edmonton, Windsor, Brampton, Hamilton, Markham and Ottawa (Fung, 2002). UTW shows significant potential for addressing asphalt concrete rutting at intersections and bus bays for urban roadways.

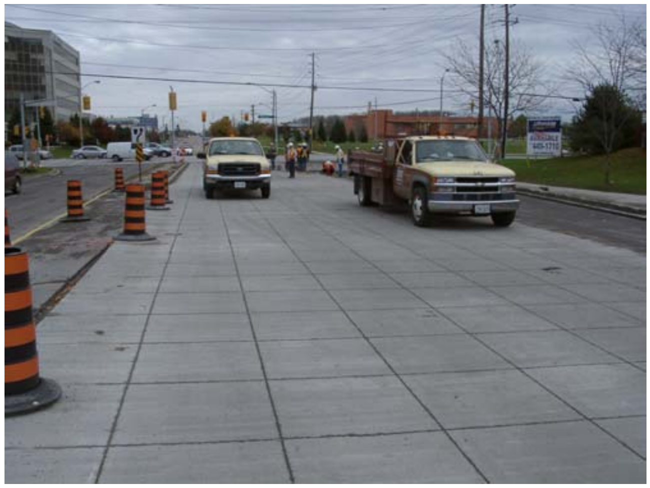

Figure 12. Ultra thin whitetopping.

AASHTO 2002

AASHTO's *Guide for the Design of Pavement Structures* [AASHTO 1993] is one of the most popular pavement design references in use today. While this guide has been regularly reviewed and updated, the 2002 version, which is soon to be released, will provide a significant leap forward in the design and rehabilitation of pavements.

Previous versions of the Guide relied heavily on the results of the AASHO Road Test, which was conducted near Ottawa, Illinois in the late 1950s/early 1960s. The design procedures emanating from the Road Test were significant extrapolations of pavement layer and subgrade properties used for this rather limited experiment. Advancements in computer and modeling technologies coupled with the significant pavement performance information now available from the Strategic Highway Research Program (SHRP) and the Long Term Pavement Performance Program (LTPP) has permitted the development of more rigorous pavement design procedures. The 2002 Guide will incorporate a mechanistic-empirical design approach and will allow pavement designers to improve design reliability, predict specific failure modes (which can minimize premature failures), better characterize seasonal/drainage effects and reduce overall life cycle costs.

Through the use of mechanistic principles and more comprehensive input data, the new design procedure is capable of producing more reliable and cost-effective designs, even for design conditions that vary significantly from previously experienced designs (e.g., much heavier traffic loadings). The 2002 Design Guide will contain procedures for the design and analysis of all types of new and rehabilitated pavement systems (e.g., flexible, rigid, and semi-rigid pavements). The mechanistic-empirical design procedure to be included in the 2002 Guide will allow the designer to evaluate the effect of variations in materials (both inherent and due to construction procedures) on pavement performance.

The mechanistic-empirical design procedure used in the AASHTO 2002 Guide characterizes the pavement structure and subgrade in terms of its primary mechanical properties such as modulus of elasticity and Poisson's ratio. An environmental modeling procedure is then used to 'modify' the mechanical properties to account for their susceptibility to changes in the environment such as temperature and moisture condition. Earlier Guide versions converted all traffic into Equivalent Single Axle Loads (ESAL). For the 2002 Guide, traffic data is characterized in terms of axle load spectra so that the actual impact, of the passage of a vehicle, on the pavement condition and performance can be determined.

Summarizing the procedure, a trial section using a pavement structure model is developed. Each trial section is then 'subjected' to the traffic and environmental conditions and analyzed by accumulating load and environmental damage incrementally over time using the pavement structural response and performance models. The design models simulate field conditions and the risk, or probability of exceeding a critical level, of each distress. The expected amounts of damage over time and traffic can then be estimated through calibrated distress models. This relationship between the mechanical properties of the pavement structure and the distress observed over time is the 'empirical' portion of the mechanistic-empirical design procedure. The trial design can then be modified and further iterations are preformed until a satisfactory design is obtained for the selected reliability.

The design process developed through the 2002 Guide includes:

- Pavement performance; structural, functional, and safety.
- Traffic Characterization; considers axle load spectra rather than the concept of ESALs used by previous versions of the Guide.
- Material Characterization; comprising, pavement response model material inputs (elastic moduli and poisons ratio), material-related pavement distress criteria (shear strength, compressive strength, etc), and other material properties (special properties such as thermal expansion and contraction coefficients of PCC and AC).
- Structural Modeling; including response models and incremental damage accumulation.

The potential cost savings resulting from an increase in pavement service life or reduction in the maintenance and rehabilitation costs can be considerable.

Conclusion

Considerable research and development activities have been directed towards improving paving materials and methods. This has resulted in a better understanding of pavement design, rehabilitation, and maintenance methods and applications.

This paper has highlighted some of the significant advancements in pavement technologies and their effect on the design and preservation of our pavement infrastructure. While it is not the definitive state-of-practice for pavement design and preservation, it does bring to the forefront some of the technologies that are being considered by pavement professionals.

As with all new technologies, long term performance monitoring identifying both successes and failures, will prove to be invaluable for advancing the concept of long-life pavements.

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