EVALUATION AND MITIGATION OF ASPHALT PAVEMENT TOP-DOWN CRACKING

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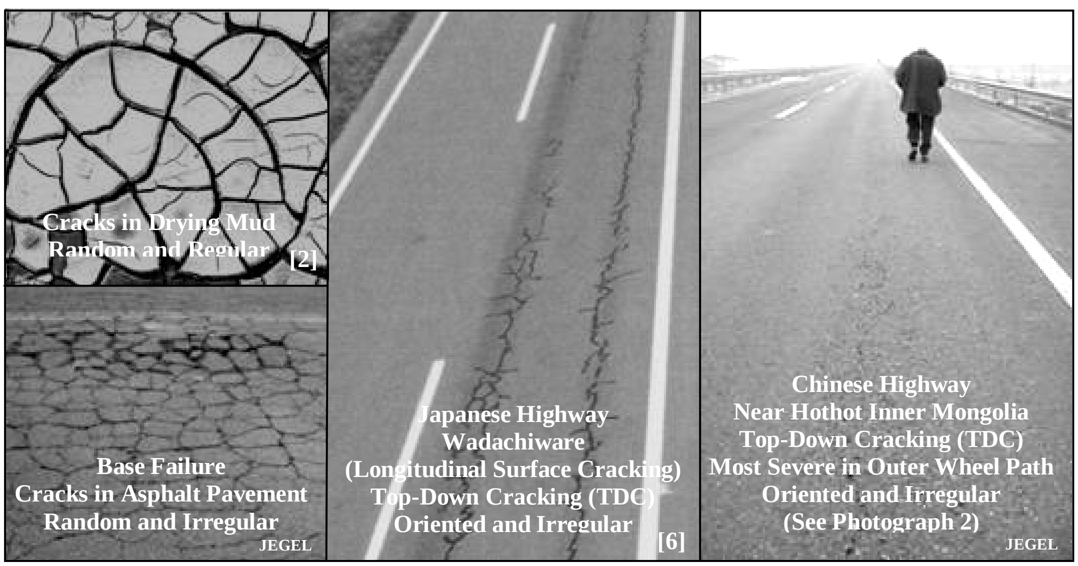
ABSTRACT

Top-down cracking has become an asphalt surface course distress of growing concern that must be dealt with during the design, construction, maintenance, and resurfacing of long-life asphalt pavements. The surface course is designed for heavy vehicle loadings and general traffic conditions in terms of rutting, resistance, durability, noise levels, smoothness, and frictional characteristics. The surface course must be properly maintained and should be renewable on an 18 to 22 year cycle. A pavement management and maintenance system is very important to achieving this objective. It is very important that top-down cracking, which is a rather complex surface distress mode related to tensile and shear stresses associated with non-uniform tire stresses, interlayer slippage, thermal stresses, stiffness gradients, construction problems such as segregation, and premature asphalt binder age hardening, is mitigated in order to achieve satisfactory overall pavement performance. While improved methods for pavement designs and rehabilitation to deal with top-down cracking are being developed, the most effective current approach appears to be enhanced asphalt materials and construction technology. The use of stone mastic asphalt and polymer modified asphalt binders have been shown to be very effective on a life-cycle performance and cost basis for instance.

1.0 INTRODUCTION

"Cracks in a surface look intricately random but actually develop rather systematically... Sooner or later the surface of almost anything will develop cracks." Jearl Walker, Scientific American's The Amateur Scientist, 1986 [2].

Loading associated fatigue cracking (bottom-up cracking) is traditional text book flexible pavement design information and the key consideration in empirical-mechanistic design methods that build on advances in asphalt pavement stress-strain analysis [3] and materials characterization [4]. Fatigue cracking is dealt with in long-life ('perpetual') asphalt pavements through: a stiff overall pavement structure (low surface deflections and limited repeated tensile strains at the bottom of the asphalt concrete); incorporating a strain absorbing ('soft') lower asphalt concrete lift; or a combined stiffness and strain absorbing approach. Recently, a new type of cracking has been recognized in North America; top-down cracking (surface-initiated longitudinal wheel path cracking) that is an asphalt concrete surface (wearing) course distress mode of growing concern that must be dealt with in the design, construction and maintenance of long-life asphalt pavements. Canadian asphalt technologists were actually introduced to top-down cracking (TDC) in 1984 during the Second Paving in Cold Areas Mini-Workshop (PICA) in Japan when "wadachiware" (longitudinal surface cracking of flexible pavements) as shown in Photograph 1 was described by Japanese colleagues [5,6]. The impact of top-down cracking on the life-cycle performance of asphalt pavements, and its complexity, is now widely recognized and the subject of considerable applied asphalt technology and improved pavement design research [7-12]. It is very important that these materials and design activities are now reflected in improved long-life asphalt pavements with resistance to top-down cracking and associated distresses such as secondary cracking and ravelling.

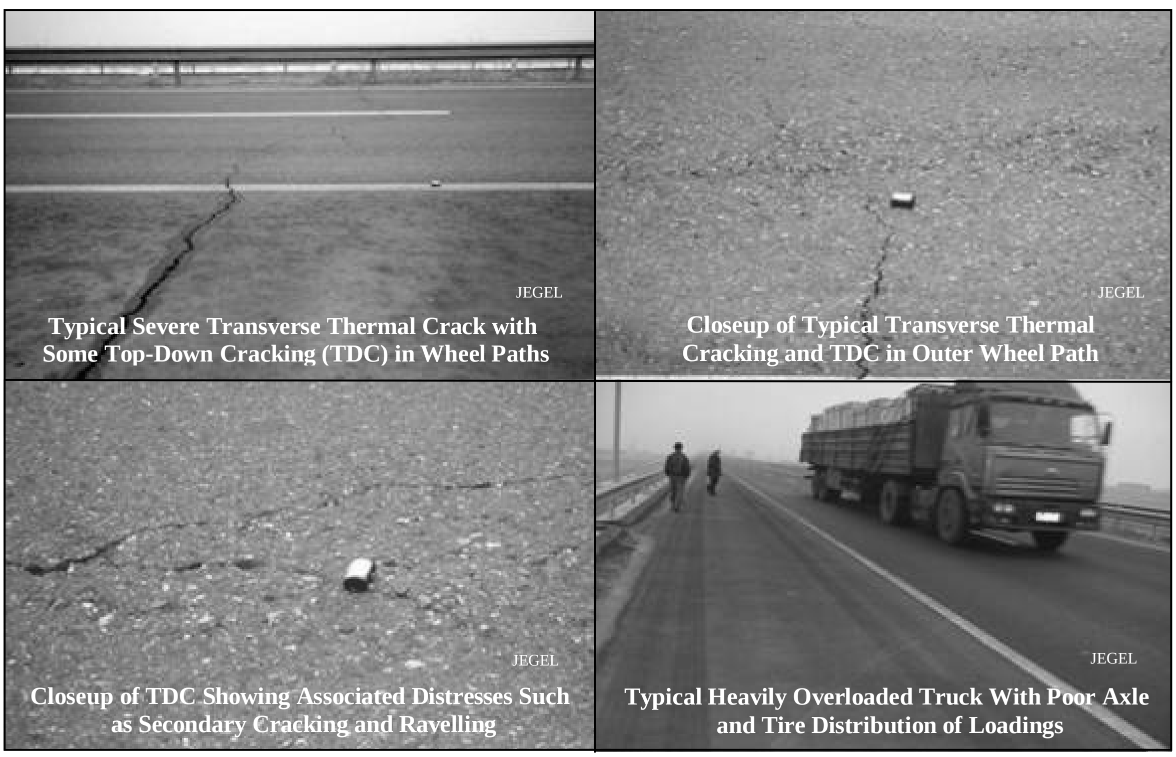


Photograph 1. Comparison of Top-Down Cracking (TDC) at the Surface of Asphalt Concrete Pavements With Cracks in Drying Mud and Cracks Associated With Flexible Pavement Base Failure. These Perpendicular Crack Networks can be Oriented or Random and Regular or Irregular and are Due to a Combination of Tensile and Shearing Stresses.

2.0 TOP-DOWN CRACKING

The asphalt concrete surface course of long-life pavement is a wearing surface (open-graded friction course, stone mastic asphalt or Superpave™ (Superpave), for instance) that is custom designed for specific heavy vehicle loadings and general traffic operating conditions (rutting resistance, durability, noise levels, smoothness and frictional characteristics, for instance). This asphalt concrete surface must also be renewable (systematic maintenance with appropriate periodic resurfacings or recyclings) on about an 18 to 22 year cycle [9]. It is imperative that surface distresses, such as top-down cracking, do not require more frequent resurfacings and, most importantly, that any top-down cracking does not extend below the surface course and impair the overall structural integrity of the pavement.

Top-down cracking does not significantly affect the structural capacity of the asphalt pavement during its early stages of mainly longitudinal surface cracking. However, with time, secondary multiple, interconnecting cracks as shown in Photograph 2, moisture damage and ravelling accelerate the surface distresses (potholing for instance) and impact severely on the functional serviceability of the pavement. Unfortunately, this can occur rather quickly, particularly with poorly constructed surface courses (materials, mix designs and practices) subjected to overloaded trucks as shown for the three to five year old Chinese expressway asphalt pavement in Photograph 2. Eventually, the top-down cracking and associated distresses, if not mitigated, will impair the structural integrity of the long-life asphalt pavement [9].



Typical Severe Transverse Thermal Crack with Some Top-Down Cracking (TDC) in Wheel Paths

Closeup of Typical Transverse Thermal Cracking and TDC in Outer Wheel Path

Closeup of TDC Showing Associated Distresses Such as Secondary Cracking and Ravelling

Typical Heavily Overloaded Truck With Poor Axle and Tire Distribution of Loadings

Photograph 2. Typical Severe Transverse Thermal Cracking and Top-Down Cracking (TDC) of Relatively New Flexible (Asphalt) Pavement Near Hothot, Inner Mongolia, China. The TDC and Associated Distresses are Most Severe in the Outer Wheel Path.

2.1 CAUSES OF TOP-DOWN CRACKING

The potential causes (initiators) of top-down cracking, that tend to be more severe in hot climates, high elevations (ultra-violet radiation, Bogotá experience, for instance) and developing countries ('poorer' materials and construction quality, and unregulated heavy vehicle loadings) are:

1. non-uniform vertical loadings (tire contact stresses) resulting in higher surface tensile and shear stresses (load, load distribution, axle and tire configuration, floating axles, pavement crossfall, wheelpath locations, axle and tire loadings, tire types and rigidity, and non-uniform tire conditions and pressures) [3];
2. poor or inconsistent hot-mix asphalt quality, production, placement and compaction (overheating mix, thermal or mechanical segregation and compaction check cracking, for instance);
3. interlayer slippage or delamination;
4. thermal stresses;
5. stiffness gradients within the surface course and between the asphalt concrete courses (lifts); and
6. premature asphalt concrete age hardening (asphalt binder stiffening) [7-12].

It should also be noted that, from practical experience, top-down cracking often appears to be more severe (time to develop, extent and distress severity) for asphalt concrete surface courses for more rigid pavements (semi-rigid asphalt pavements such as Photograph 2, composite pavements with concrete base and bridge decks, for instance) [12].

2.2 SOLUTIONS FOR TOP-DOWN CRACKING

The two major potential solutions for top-down cracking focus on the most controllable factors:

1. improved heavy vehicle loadings control (weigh-in motion scales for instance - difficult but imperative for developing countries) and appropriate mechanical, axle and tire technology implementation (suspension systems and tires properly matched, inflated and kept in good operating condition - very difficult, but again imperative for developing countries); and
2. improved renewable, specialized asphalt surface courses (open graded friction course, stone mastic asphalt and Superpave, for instance) with good permanent deformation (rutting) resistance, and enhanced tensile and shear stress endurance.

While current applied asphalt technology activities to improve the design and rehabilitation of flexible pavements to resist top-down cracking (tensile and shear stresses from heavy vehicle loadings) is most promising [11,12], implementation will take some time and enhanced, available and proven, asphalt materials and construction practices must form an integral part of any systematic approach to mitigating top-down cracking of long-life pavements, and most are being implemented now [13-19]. The key aspect of the applied asphalt technology for these durable, renewable surface courses is enhanced cracking (tensile and shear fracture) resistance, while maintaining rutting resistance, through improved gradations and mix volumetrics, appropriate mix design performance monitoring and the use of asphalt binder modifiers such as polymers (crumb rubber and styrene-butadiene-styrene (SBS), for instance) [18]. These performance requirements are in addition to the desirable functional surface characteristics of noise level, smoothness and frictional properties as summarized in Table 1 [15].

Table 1. Dense Graded Hot-Mix Asphalt (HMA) Requirements Checklists

Functional and Structural Performance	Materials, Mix Design and Construction
Workable During Placement and Compaction Contributes to Strength of Pavement Structure Resistance to Permanent Deformation (Rutting) Resistance to Fatigue Cracking Resistance to Thermal Cracking Resistance to Effects of Air and Water (Durability) Impermeable to Protect Structure from Water Easily and Cost-Effectively Maintained **Plus for Surface (Wearing) Courses** • Resistance to Top-Down Cracking • and Associated Distress Adequate Frictional Properties (Skid Resistance) Acceptable Level of Tire-Pavement Noise Acceptable Riding Quality (Smoothness) Adapted from Infraguide Rut Mitigation Techniques at Intersections [15]	**Aggregate Physical Characteristics and Quality** For heavy duty performance, incorporate 100 % crushed, cubical, clean coarse and fine aggregates. Experience has shown that a limited amount (≤ 10%) of natural fine aggregate assists in achieving surface course compaction and mat quality. **Asphalt Cement (Binder) Performance Grade (PGAC)** For heavy duty performance, increase high temperature grade and use an engineered PGAC such as polymer modified PGAC (PMPGAC) as necessary. **Superpave Mix Design System** Build on practical Marshall design experience. Consider fines generation during HMA production. Check potential HMA performance with rutting resistance, fatigue endurance and water susceptibility tests. **Contractor Quality Control/Agency Quality Assurance** **Proper Construction Techniques** Prepare substrate properly (clean and tack), avoid segregation, place uniform and smooth mat, construct joints properly and meet compaction requirements.

3.0 ASPHALT SURFACE COURSES

The surface (wearing) course of a long-life asphalt pavement requires systematic preventive maintenance and periodic resurfacings (new or recycled hot-mix asphalt), or hot in-place recycling, as shown schematically in Figure 1. A pavement management and maintenance system is a key component to achieving the desired long-life structural and functional performance. Of course, for any pavement and maintenance management system to be effective, appropriate maintenance and resurfacing materials and methods must be adopted. It is important that the system incorporate top-down cracking as a new distress type (surface characteristic), and its mitigation for long-life asphalt pavements, which will require considerable potential performance extrapolation.

3.1 STONE MASTIC ASPHALT

Stone mastic asphalt (SMA), typically incorporating polymer modified asphalt cement (binder), has demonstrated excellent overall performance compared to conventional surface course mixes, such as improved frictional characteristics (skid resistance), improved resistance to permanent deformation (rutting resistance), improved fatigue endurance, reduced reflective cracking, reduced noise and reduced spray [16-18]. This has resulted in stone mastic asphalt use as a standard high quality, superior performance, surface course mix in Ontario. While stone mastic asphalt has higher initial costs (20 to 40 percent) than conventional hot-mix asphalts, life-cycle studies have indicated

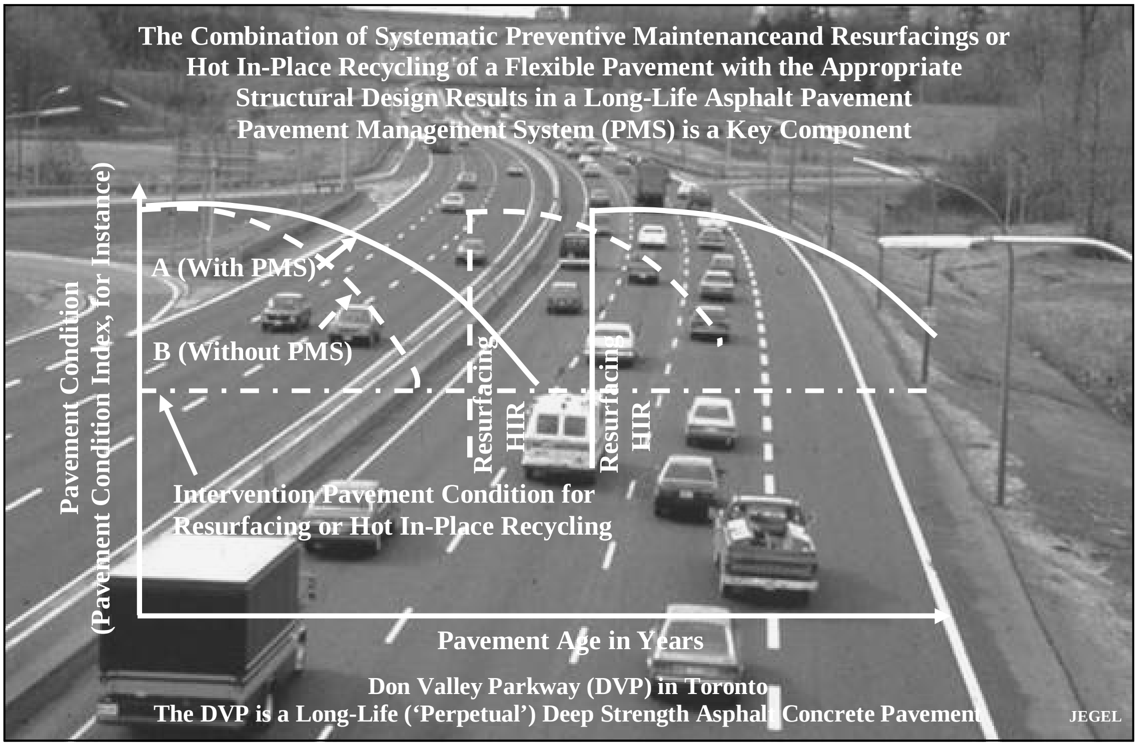
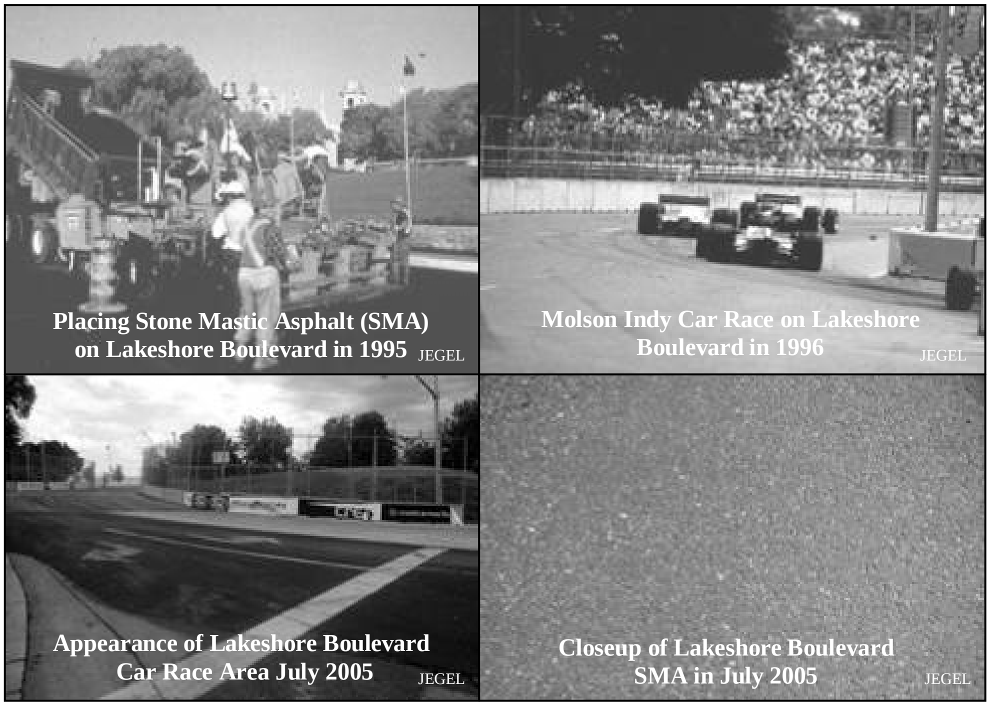


Figure 1. Schematic of Deterioration Curves For Long-Life Asphalt Pavements With and Without Preventive Maintenance (Pavement Preservation)

a service life extension of about five years and favourable overall life-cycle performance and costs [18]. The use of stone mastic asphalt for the 1995 resurfacing of the Toronto Lakeshore Boulevard (adjacent to Exhibition Place (composite pavement) shown in Photograph 3) that forms part of the annual Molson Indy Car Race, has provided considerable performance information for severe operating conditions [16]. The overall current condition of this stone mastic asphalt after ten years is good with a pavement condition index (PCI) of 86 and ride comfort rating (RCR) of 8.0. The use of stone mastic asphalt will undoubtedly continue to grow based on its demonstrated good performance in relatively thin surface courses.

3.2 POLYMER MODIFIED ASPHALT BINDERS

The use of polymer modified asphalt cements (binders), typically SBS, in asphalt surface courses for enhanced resistance to top-down cracking (resistance to tensile and shear stress fracture) is commonly recommended [11]. Polymer modified asphalt binders also offer other performance improvements (rutting resistance, fatigue endurance and durability) and have been shown to extend the service life of asphalt pavements with favourable life-cycle costing [18,19]. Practical experience in developing countries with 'poorer' quality domestic asphalt binders (China and Colombia, Photograph 4, for instance) has shown the overall cost-effective benefits of polymer modification to achieving satisfactory asphalt pavement performance, including enhanced resistance to top-down cracking.



Photograph 3. Placement, Molson Indy Car Race and Current Condition of Stone Mastic Asphalt (SMA) on Lakeshore Boulevard, Toronto

Photograph 4. Typical Polymer Modified Asphalt Cement (Binder) Central and Portable Blending Plants Incorporating Three to Six Percent Styrene Butadiene (SBS) Linear Block Copolymers

3.3 HOT IN-PLACE RECYCLING

The current practice with long-life asphalt pavements is periodic, conventional milling and resurfacing (milling/filling). However, third generation hot in-place recycling (HIR) of functionally deteriorated (top-down cracking distress, for instance), but still structurally sound, asphalt pavements is a very cost-competitive alternative that can be of equivalent quality and performance, with less road-user disruption and a positive contribution to sustainability [20]. Monitoring of the Ontario Highway 401 1999 hot in-place recycling demonstration project (Photograph 5) in 2005 clearly supports the Ontario Ministry of Transportation 2002 findings, for this highly trafficked route, that the third generation hot in-place recycled section is in excellent condition and performing the best of the sections including milling/filling with new or recycled hot-mix asphalt [20]. Current hot in-place recycling asphalt technology activities at John Emery Geotechnical Engineering Limited (JEGEL) include: the selection and incorporation of low viscosity rejuvenators based on rubber extender (process) oils; and replacing the Abson recovery/viscosity blending approach with asphalt concrete stiffness (indirect asphalt binder stiffness) testing (resilient modulus) in the Nottingham Asphalt Tester (NAT) to determine rejuvenator rates and influence on the actual asphalt concrete stiffness. This is being complemented by full recycled asphalt concrete laboratory performance characterization in the Asphalt Pavement Analyzer (APA) [20].

Photograph 5. Ontario Highway 401 September 1999 Hot In-Place Recycling (HIR) Demonstration Project, 5.6 Lane-km Section as Part of Five Rehabilitation Strategies Comparison

3.4 LONG-LIFE ASPHALT PAVEMENT MAINTENANCE, RESURFACING, RECYCLING AND REHABILITATION

A 'standard' decision tree (Foundation for Pavement Preservation [21], for instance) for flexible pavement maintenance and rehabilitation has been adapted to incorporate hot in-place asphalt recycling (HIR) as an alternate to milling/filing as shown in Figure 2. Cold in-place asphalt recycling (CIR) and full depth reclamation (FDR) are also included to cover the full range of maintenance, resurfacing, recycling and rehabilitation technologies available to the long-life asphalt pavement

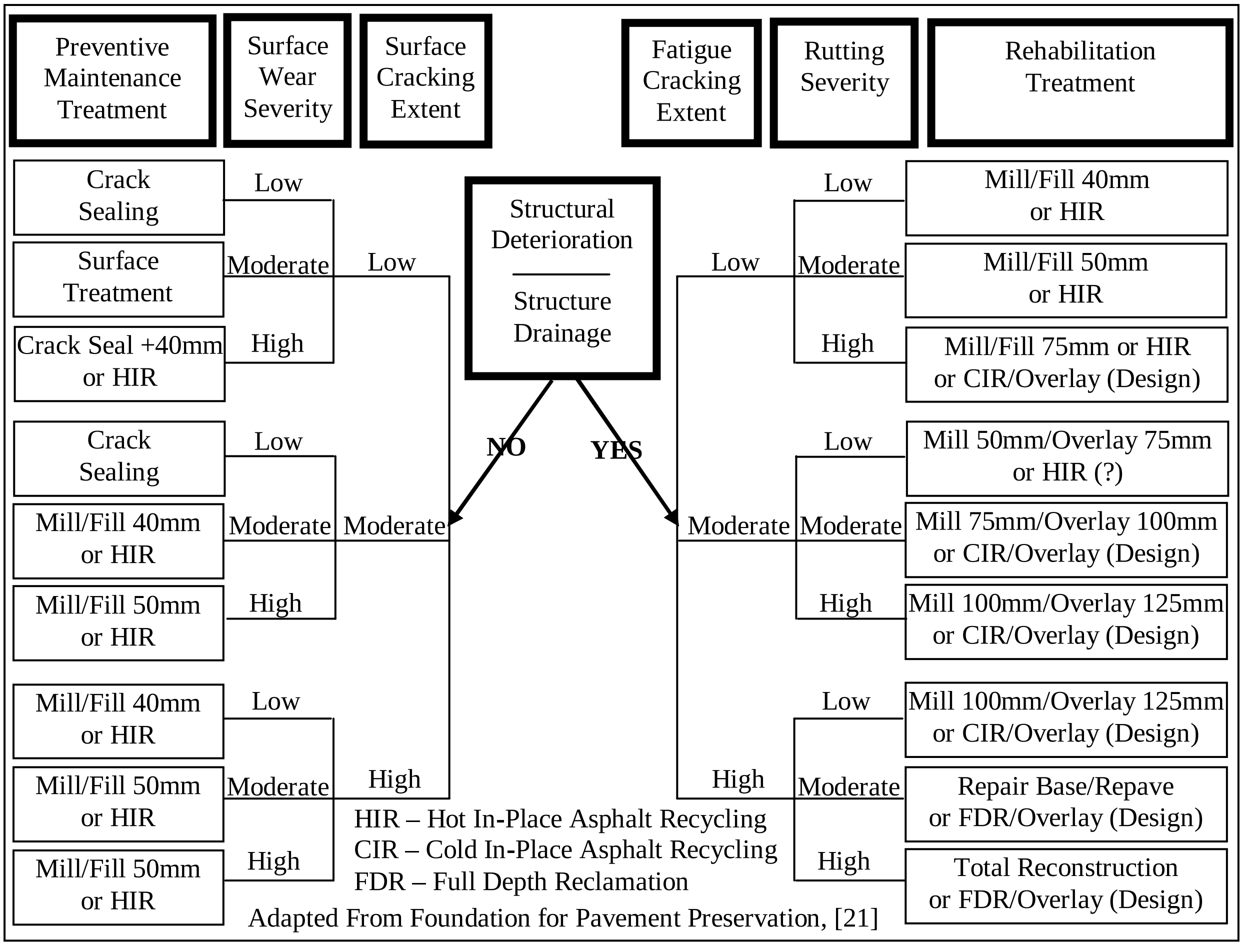
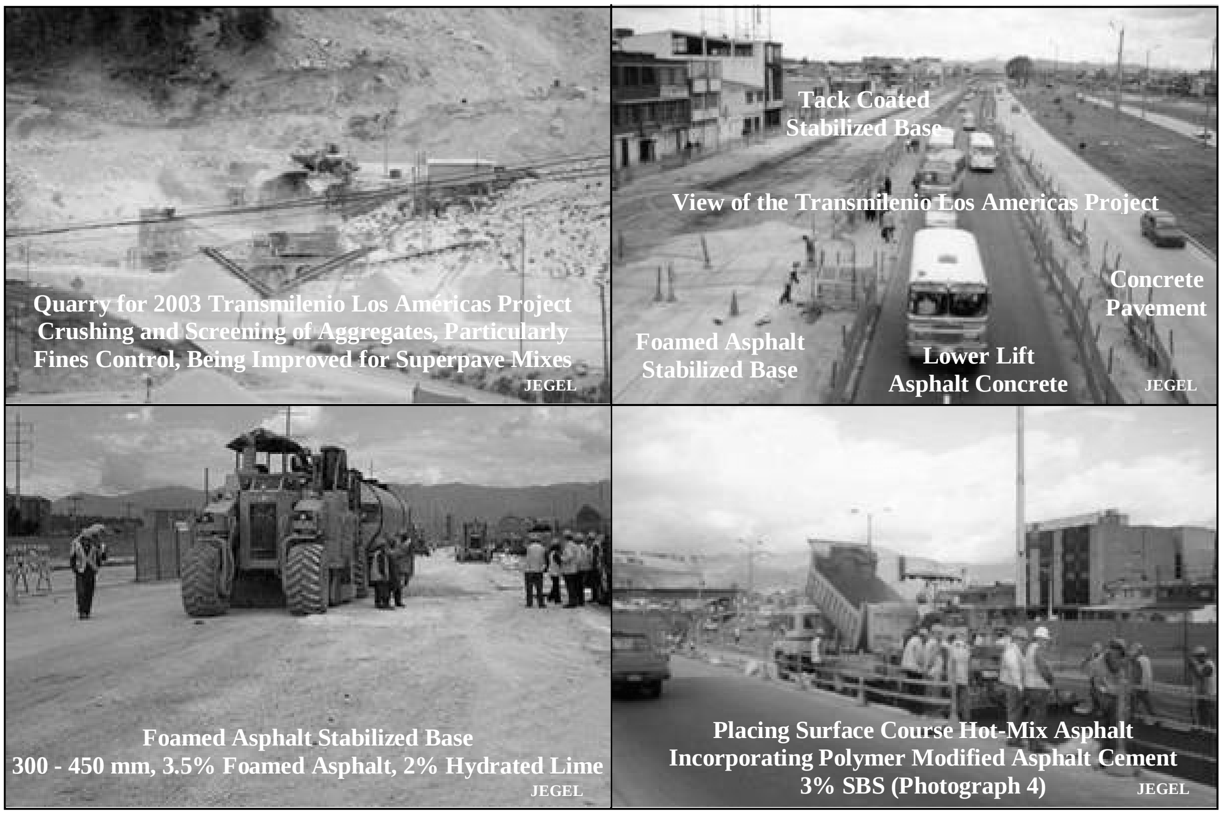


Figure 2. Decision Tree for Flexible Pavement Maintenance and Rehabilitation

designer. The importance of systematic maintenance (pavement preservation), including treatment of top-down cracking distress and timely, periodic resurfacings or hot in-place recycling, to achieving satisfactory long-life asphalt pavement performance must be again emphasized.

4.0 APPLIED LONG-LIFE ASPHALT PAVEMENT TECHNOLOGY

The practical application of long-life ('perpetual') asphalt pavement technology, including mitigation of top-down cracking, to major pavement projects in China and Colombia, is based on both Ontario technology transfer and recent JEGEL Bogotá Transmilenio experience shown in Photograph 6. This asphalt technology includes contractor project quality control (end result hot-mix asphalt specifications, for instance); empirical-mechanistic asphalt pavement structural designs (use of falling weight deflectometer and dynamic cone penetrometer for insitu materials characterization for instance); improved hot-mix asphalt materials (polymer modified asphalt binders, Photograph 4, for instance); Superpave mix designs, including fatigue characterization in the Nottingham Asphalt Tester [22] as shown in Figure 3 (noting a mode/shift factor must be applied to the laboratory controlled-strain loading for the field controlled-stress loading condition for 'thick' asphalt pavements [7,23]; and foamed asphalt mix designs (incorporating lime), with typical resilient modulus testing as



Photograph 6. Development of Long-Life Asphalt Pavements Technology, Including Top-Down Cracking (TDC) Mitigation, for Colombia Based on Ontario and Recent Bogotá Transmilenio Experience with Focus on Urban Expressways and Design-Build Project Delivery

shown in Figure 4. Long-life asphalt pavement performance and the importance of dealing with potential top-down cracking is being emphasized throughout. The long-life asphalt pavement technology transfer, including a new Superpave laboratory, has been successfully completed for Bogotá's poor subgrade conditions, and heavy rainfalls with strong sunshine, high elevation climate.

5.0 CURRENT RESEARCH ACTIVITIES AND CONCLUDING COMMENT

Current JEGEL long-life asphalt pavements performance and top-down cracking mitigation applied research and development activities include:

1. development (in association with the Greater Toronto Airport Authority) of high performance hot-mix asphalts, and special construction methods such as polymer modified emulsion tack coating, for heavy duty applications (airport taxiways and runways, for instance) where rutting and shoving problems can develop (Photograph 7);

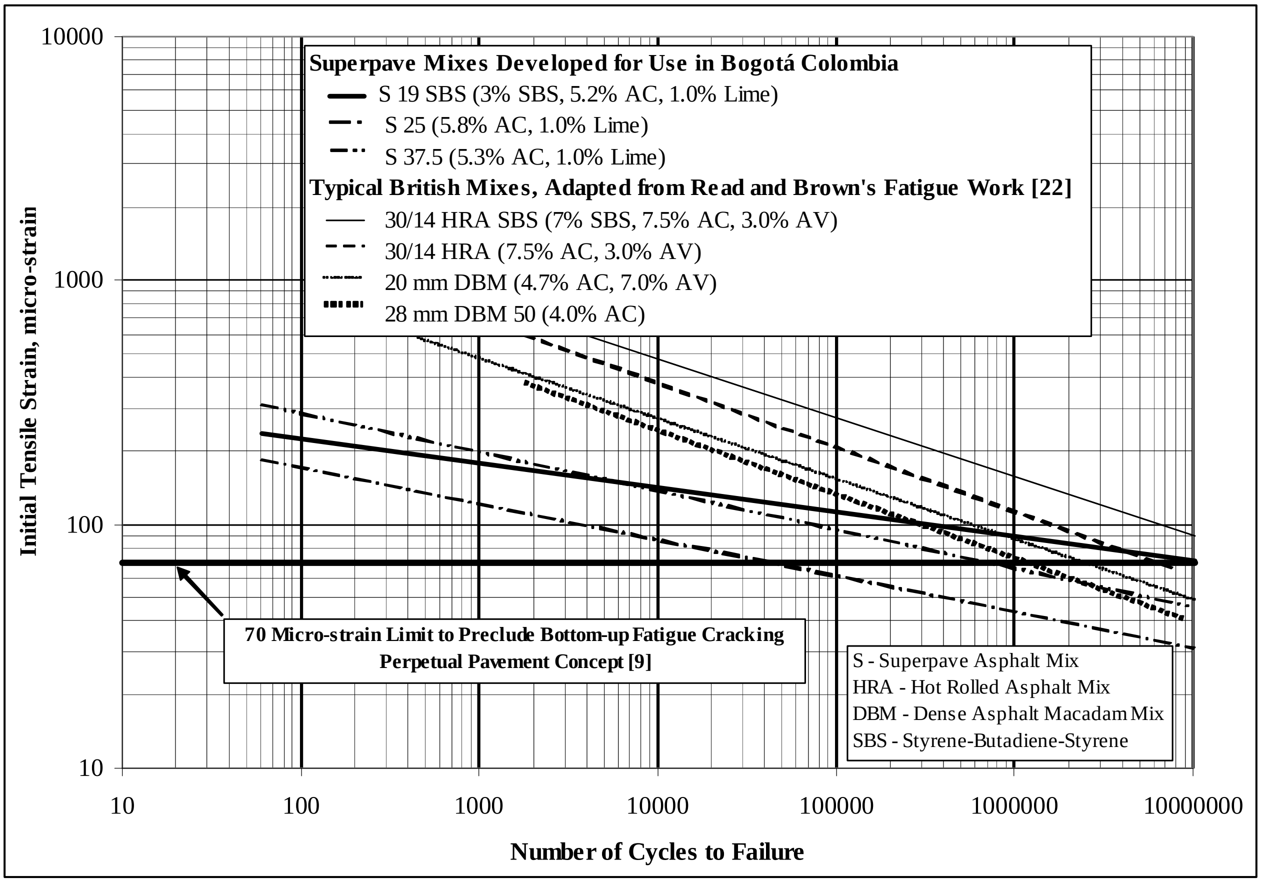


Figure 3. Fatigue Characteristics of Typical British Asphalt Mixes and New Colombian Superpave Mixes Determined Using the Nottingham Asphalt Tester

2. development (in association with the Henan Province Transportation Research Institute in Zhengzhou) in China of long-life, high performance, expressway asphalt pavements for unregulated heavy loadings (not currently realistic to limit) [25], mitigation of reflective cracking problems with semi-rigid asphalt pavements (Photograph 8), and asphalt surface course mixes (stone mastic asphalt and Superpave) with enhanced resistance to top-down cracking;
3. research (in association with McMaster University) on the influence of surface colour on the thermal behaviour of asphalt concrete and the potential use of a light coating of hydrated lime (lighter colour) to reduce the black body absorption and hot-weather temperature of asphalt surface courses (particularly new surfacings that are very black before aging to a greyer colour, initial measurements at Toronto Pearson Airport have shown a reduction of 4 to 10°C), with the additional potential hydrated lime advantages of reduced age hardening (oxidation), enhanced moisture resistance, absorption of initial 'oil' sheen and resistance to surface scuffing (Photograph 8) [26-29]; and
4. research (in association with McMaster University) on the extension of the impact-echo method for the nondestructive testing of concrete and masonry structures, based on the use of impact-generated stress waves [30], to the testing of surface course asphalt for thickness, shear modulus (to complement falling weight deflectometer testing for pavement layer moduli), moisture damage and surface distresses such as top-down cracking (Photograph 9).

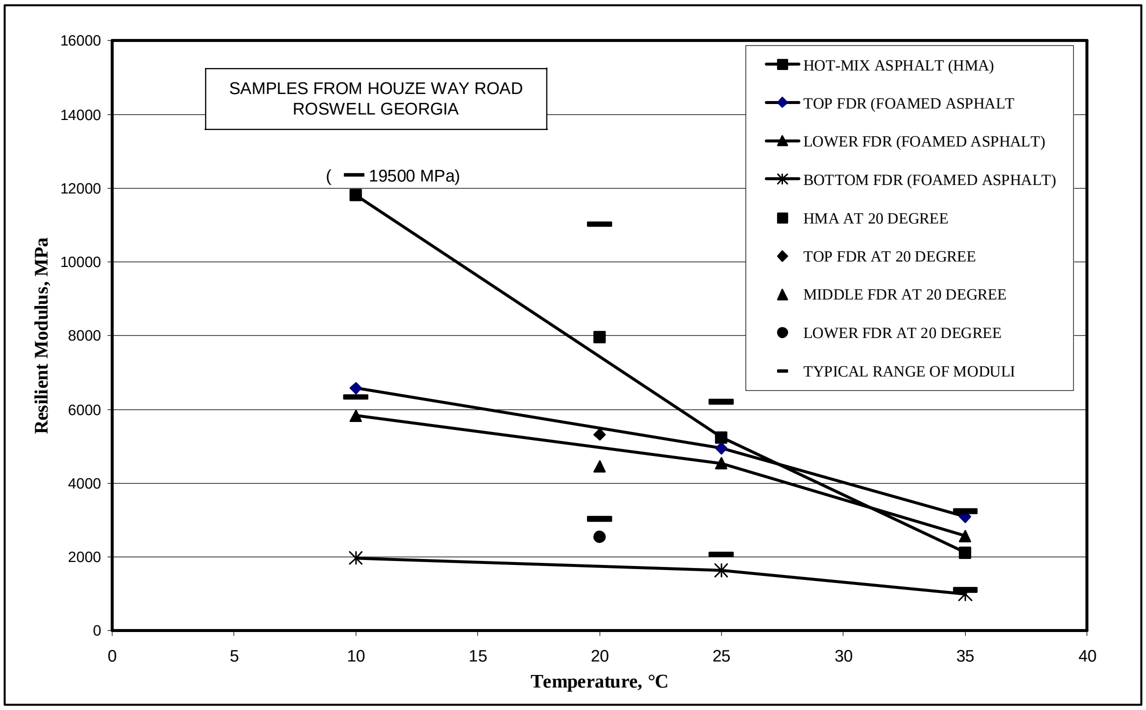
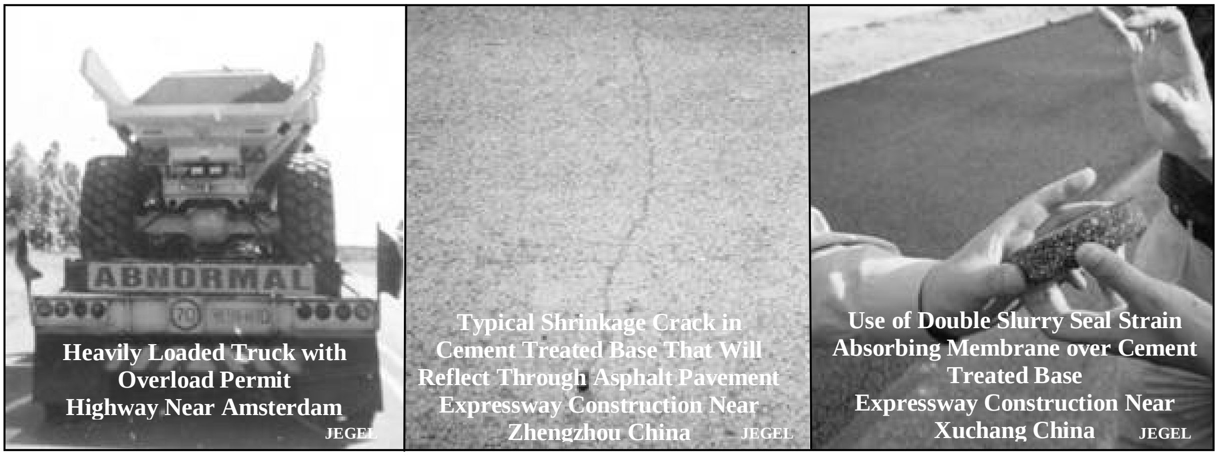


Figure 4. Resilient Modulus – Temperature Relationship
Hot-Mix Asphalt and Foamed Asphalt Stabilized Mix for Full Depth Reclamation (FDR)

Photograph 7. Localized Severe Shoving of New Asphalt Concrete Resurfacings of Some Heavy Aircraft Traffic Areas at Pearson International Airport in Toronto Has Required the Development of High Performance Hot-Mix Asphalts and Special Construction Methods Such as Polymer Modified Emulsion Tack Coats

It is anticipated that these research and development activities will assist in a better understanding of long-life asphalt pavements, particularly the rather complex nature of top-down cracking and more effective mitigation of this distress.



Photograph 8. Overloads With Permits and Unregulated Loads, Particularly in Developing Countries, are a Significant Pavement Performance Problem (Left) Mitigation of Reflective Cracking for Semi-Rigid Asphalt Pavements is Very Important to Satisfactory Performance (Centre and Right)

Photograph 9. Laboratory Surface Temperature Testing of Asphalt Concrete Specimens (Left) and Field Testing of Asphalt Concrete Pavement With Impact-Echo Equipment (Right)

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