City of Regina Field Demonstration of Engineered In-Place Recycling and Structural Rehabilitation of Roads to Develop Sustainable "Green Urban Structural Asset management"

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PSI Technologies Inc.

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1.0 INTRODUCTION

Many City of Regina local streets are experiencing structural deterioration. As well, quality aggregate sources are becoming increasingly scarce in the Regina area. To compound matters, the City of Regina is constructed on highly expansive lacustrine clay which makes construction with heavy equipment and potential adverse weather conditions a severe construction challenge. The City of Regina is investigating the use of cold in-place recycling and full depth strengthening rehabilitation of their urban streets in an attempt to reduce not only capital costs, but holistic user delay and environmental emissions costs within the City of Regina. However, innovative cold in-place recycling and full depth strengthening systems do not fit the conventional pavement design inference. Therefore, the City of Regina is also investigating advanced mechanistic laboratory design and non-destructive road structural diagnostic technologies to accurately quantify *in situ* structural composition, condition ststae, and material constitutive properties to enable them to design cold in-place recycling systems.

As a result of the relatively high cost of conventional full depth excavation and replacement treatments, the structural rehabilitation of many City of Regina streets cost prohibitive. Therefore, the City of Regina in conjunction with PSI Technologies are investigating advanced road structural diagnostic technologies to accurately prioritize rehabilitation projects based on current structural deterioration state, and are investigating alternative cold in-place recycling road rehabilitation and strengthening systems.

This project is being submitted for the TAC Environmental Achievement Award because this field project proved to require significantly less energy to rehabilitate urban roads, yet still provide an equivalent or superior structural asset value relative to conventional energy intensive pavement rehabilitation systems. This field demonstration project also employed state-of-the-art mechanistic road engineering design and asset management methods to help select and document the field performance of in-place road recycling construction systems.

In terms of value for the Canadian transportation infrastructure industry, this field demonstration project was intended to address five primary factors that are limiting the commercial implementation of innovative road recycling and full depth rehabilitation processes of urban streets.

1) Conventional road design and materials selection are based on the historic use of high quality virgin road materials, and do not directly assess modern-innovative in-place recycled and stabilized road materials and structures.
2) Conventional pavement design methods were developed for new highway construction applications with raised gradelines, not urban field state conditions comprised of relatively level gradelines and curb and gutter constraints.
3) Conventional pavement design criterion used in Saskatchewan were initially calibrated based on the AASHO Road Test in the late 1950's early 1960's and were developed for primary pavement structures and traffic conditions of the period. This has resulted in a high degree of inaccurate empiricism currently used in road design with no ability to properly account for current urban field state conditions in Canadian climates.
4) Conventional pavement design and asset management methods were developed for highway applications, they do not account for slow moving large truck configurations typically experienced in today's urban field state conditions.
5) Conventional road asset management systems do not directly account for the full range of road materials, construction quality, and road structures and therefore are severely limited when attempting to predict the performance of alternate urban road systems, particularly the structural performance of urban roads.

To overcome the limitations of historic pavement design and management methods for implementing cold in-place recycling and full depth strengthening of urban streets, this project drew upon an integrated mechanistic approach to engineer and assess the asset value as opposed to historic empirical based engineering methods. These advanced engineering and management protocols were found to be useful for designing and managing recycled and conventional pavement structures across a wide spectrum of road materials as well as conventional road materials and road structural systems. This project employed a probabilistic vehicle emissions model to compare the emissions generated by conventional street rehabilitation methods as well as cold in-place recycling and full depth strengthening system.

2.0 PROJECT OBJECTIVES

The primary objective of this field demonstration project was to provide more sustainable road rehabilitation and recycling solutions from the perspective of agency fiscal optimization, as well as social and environmental stewardship.

A second objective of this project was to demonstrate the application of advanced mechanistic based engineering design and structural asset management systems that will directly quantify the technical merits as well as the environmental savings associated with in-place road recycling technologies.

3.0 ENVIRONMENTAL BENEFITS OF PROJECT

On December 16, 2002, Canada was the 99th country to ratify the Kyoto Protocol to reduce total greenhouse gas (GHG) emissions to fifteen percent below 1990 levels within the time frame of 2008-2010. Although Kyoto Protocol focuses only on greenhouse gas emissions, such as Carbon Dioxide (CO_2), heavy diesel engines produce other emissions that seriously harm human health: carbon oxide (CO), nitrogen oxides (NOx), hydrocarbons (HC), and particulate matters (PM). Damages resulting from these emissions are divided in three categories: air pollution damages for CO, NOx and HC, fine particle damages for PM, and global warming for CO_2.

To understand how emissions volumes resulting from heavy diesel engines typically employed in road construction could be calculated, four different emissions quantities calculation methods were studied: the Environment Canada methodology, which uses an emission factor for its calculations; the U.S. Environment Protection Agency (USEPA) MOBILE 6 model, based on an conversion emission factor; the Australian life cycle analysis, using a simple equation to find out the performance measure of emissions per distance travelled; and the UC Berkeley fuel-based inventory for heavy-duty diesel truck emissions, using official fuel consumption data.

Significant portions of Canada's urban road infrastructure is experiencing high rates of deterioration and a significant portion of the road system has surpassed a sustainable level of service as expected by most Canadians. Unfortunately, coventional road construction and road rehabilitation methods are highly energy dependent, and they consume significant amounts of non-renewable aggregate resources. Given this background, there are five primary environmental improvement objectives set in this project:

1) Reduction of construction related energy and therefore emissions;
2) Conservation of non-renewable natural aggregate resources in urban areas;
3) Optimized re-use of existing in-place road materials and reduced disposal costs;
4) Improved level of service to road users, therefore reducing vehicle operating costs and energy consumption associated with poor quality roads, as well as time consuming construction methods, and;
5) Reduction in weather related construction delays, therefore reducing construction energy and emissions.

This project successfully demonstrated that recycling urban roads, particularly roads that are in need of full depth structural rehabilitation that contain significant amounts of in-place quality aggregates and asphaltic concrete, is a viable technology and asset management solution. This is a critical environmental issue regarding increasing infrastructure renewal because of the conservation of natural aggregates as well as reduction in emissions associated with processing aggregates and construction. In addition, the elimination of concentrated haul to remove existing road materials and replace them with new materials, eliminated ancillary road damage that typically occurs with conventional road construction.

An additional environmental benefit realized from this study is reduced weather exposure during construction. Wet weather conditions can easily double or triple the construction time, therefore construction energy required, and as a result emissions generated. In addition, weather induced construction delays impact significant incremental user costs due to reduced access and poor level of service during construction. An additional benefit of this project was realized through reduced emissions in the workplace for road workers, as well as a significant reduction in the number of workers required to rehabilitate roads.

In summary, the environmental issues addressed within this project are numerous and multifaceted. It is projected that the cummulative benefits to be realized from this field demonstration project are significant for the Canadian environment as determined by the emissions modeling framework illustrated in Figure 1.

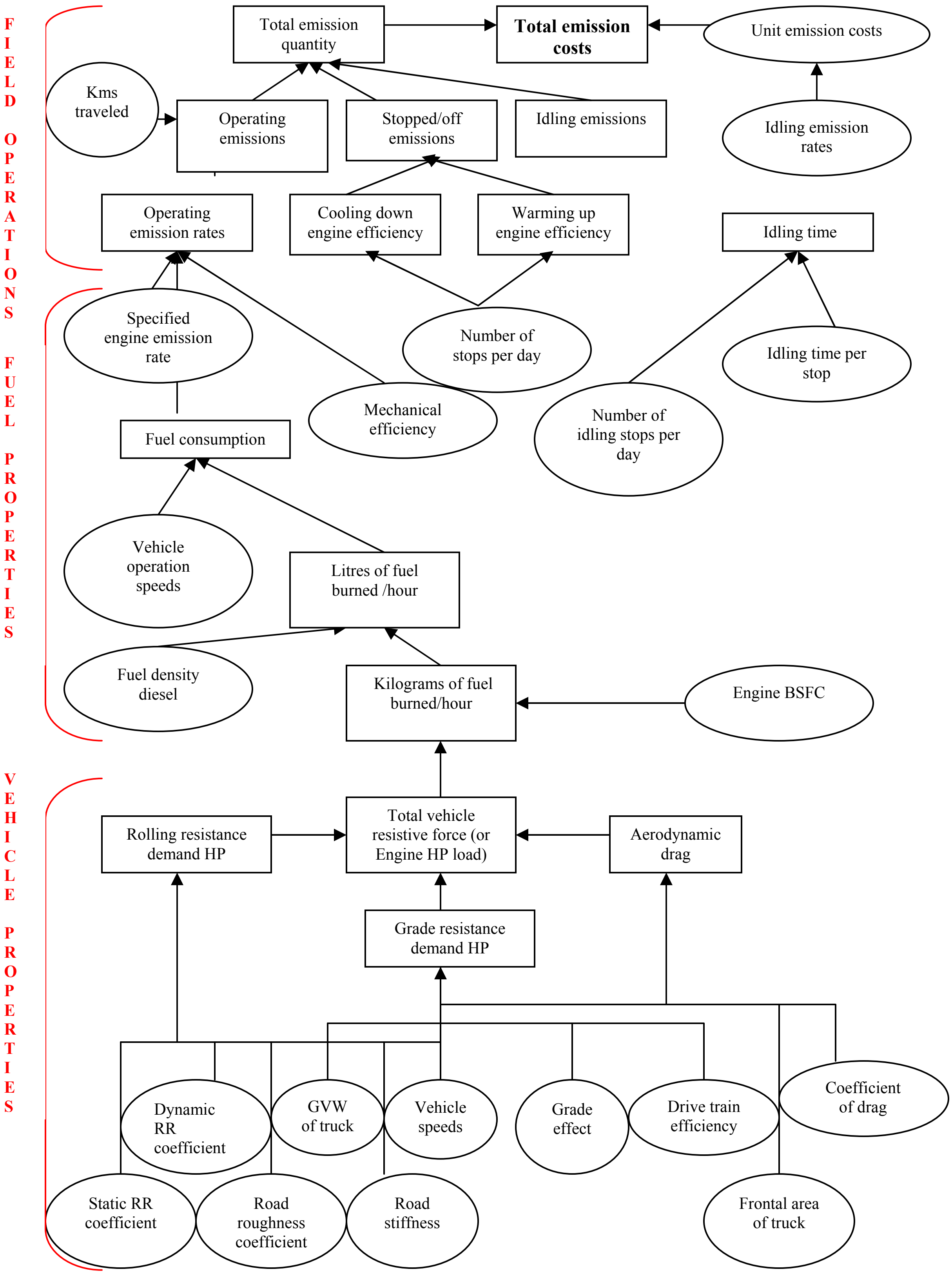

Figure 1: Emissions Model Framework (ref Ms. Amelie Courand Thesis, 2007)

4.0 ENGINEERING METHODOLOGY EMPLOYED IN PROJECT

The approach used in this field demonstration project was comprised of five distinct but integrated project elements.

Element 1: Mechanistic *A Priori* Structural Asset Value Characterization.
Element 2: Mechanistic Materials and Structural Design and Analysis.
Element 3: Road Rehabilitation Options Analysis.
Element 4: Cold In-Place Recycling Construction and Field Quality Control.
Element 5: Post Construction Mechanistic Quality Assurance and Sructural Asset Management Characterization.

All project elements drew upon advanced road engineering technologies in order to document, analyze and prove out the merits of innovative road recycling. To overcome the limitations of histroric engineering methods to reliably implement road recycling methods, this field demonstration project employed an integrated Mechanistic Pavement Structural Design and Asset Managment System that has been developed by PSI Technologies as the central technological system that enabled engineers to design and manage the implementation of these systems.

PSI Technologies have been developing and validating the applied use of advanced engineering mechanics over recent years for road materials engineering and road structural analysis. These technologies are intended for road engineers, managers and road builders to employ innovative road materials and road structural systems.

To be pragmatic for project level design and structural asset evaluation of roads, the mechanistic road engineering framework proposed herein has the flexibility to be applied across all road engineering activities including: *a priori* road structural assessment; materials design, specification, and selection; road structural design options analysis; construction quality control/quality assurance; structural asset management monitoring performance prediction modeling; product, warranty and performance based specifications; contractor bonus and penalty pay factors; primary response based traffic load equivalency analysis, transport policy derivations such as load equivalency analysis and climatic load management; et cetera.

4.1 Element 1: Mechanistic *A Priori* Structural Asset Value Characterization

PSI Technologies have developed integrated ground penetrating radar and falling weight deflection non-destructive road structural characterization methods (Figure 4.1) that quantify the physical and mechanical *in situ* road structural properties and recycleable material quantities under typical field state conditions. The use of ground penetrating radar and falling weight deflection assessment methods have typically been related to structural sustainability and rehabilitation design of existing road assets.

Figure 4.1 PSI Technologies Ground Penetrating Radar and Falling Weight Deflectometer

Given the findings of several pilot project applications of non-destructive structural characterization of Saskatchewan in-service road assets over the past five years, PSI Technologies have developed mechanistic based fundamental primary response structural analysis methods that more accurately characterize the structural integrity and structural performance of Saskatchewan road assets. In addition, PSI Technologies structural assessment methods have the ability to interpret large volumes of field data required to characterize the inherent variability of typical Saskatchewan urban and rural roads in spatial graphical illustrations. This is critical in the context of making decisions to optimize road budget allocations across diverse road systems such as that contained within typical urban road networks.

With the application of integrated non-destructive road structural assessment technologies, *in situ* pavement structural composition and structural integrity of the road structure is known *a priori* on a spatially continuous basis. The data assembled can help optimize project level road rehabilitation decisions based on accurate structural segmentation of roads to result in more uniform end product structural value after construction. This ability is essential to reliably compare conventional and in-place recycling systems (see attached "City of Regina Shannon Road PSI Technologies Structural Assessment and Strengthening Options Analysis" report).

4.2 Element 2: Mechanistic Materials and Structual Design

A fundamental element to mechanistic road engineering and structural asset management is accurate road material constitutive characterization. The material constitutive model must capture the primary structural behaviour and performance prediction of typical road materials across the full spectrum of Saskatchewan field state conditions and typical road structures, within which the conventional or recycled material selected is expected to perform.

PSI Technologies applied mechanistic based material science and pragmatic laboratory equipment and procedures, as well as improved computational capabilities to characterize the fundamental mechanistic behaviour of all types of conventional virgin road materials as well as recycled road materials. The mechanistic material characterization approach employed by PSI considers non-linear and anisotropic material behaviour of all materials across the spectrum of Saskatchewan field state conditions. These material properties account for the most significant performance complexities to engineer roads, and employ advanced material characterization and road modeling techniques.

PSI Technologies have successfully applied mechanistic materials analysis systems across diverse field state conditions and field applications including:

1) Saskatchewan traffic load spectra;
2) Anisotropic multi-axial stress states representative of various traffic load spectra and spatial positions within the road structure;
3) Traffic load rates representative of various traffic speeds;
4) Construction related material quality control assurance variability;
5) Seasonal climatic states as experienced in Saskatchewan, and;

6) Various cementitious and bituminous recycling and stabilization systems including substructure as well as bituminous surfacing materials.

In summary, the mechanistic material characterization protocols that will be applied in this project can accurately characterize the continuum mechanical behaviour under triaxial stress states and triaxial load frequencies and Saskatchewan field state conditions, which are proving to be the primary driving factors in structural performance of road materials. The materials catalogue generated in this project will provide fundamental material constitutive relations that can be used for future mechanistic primary road response modeling and structural design purposes. In addition, the development of a materials catalogue will enable the system to become increasingly populated and accurate over time across the diversity of road materials in City of Regina (see attached "City of Regina Shannon Road PSI Technologies Structural Assessment and Strengthening Options Analysis" report).

An essential component of employing Mechanistic Surfacing Analysis and Asset Management System is an accurate road structural model. Unfortunately, most road agencies currently employ material equivalencies and/or California Bearing Ratio design nomographs to perform road structural design and analysis. The primary limitations of applying conventional structural design nomographs include:

1) California Bearing Ratio (CBR) values and material equivalencies are empirical based and are limited to quantify all subgrade and aggregate material performance under modern field state conditions.
2) Commercial truck loadings have increased significantly since the original performance validation of the design nomographs in the 1960's.
3) Structural design nomographs were initially developed for structural design of new primary highway pavement structures comprised of high quality materials under historic traffic load spectra from the 1960's.
4) Structural design nomographs do not directly accommodate recycled and stabilized road materials and structures.
5) Structural design nomographs do not account for alternate types of asphaltic concrete mix surfacings, nor do they consider other types of surfacing systems such as engineered asphaltic emulsion based surfacings.

The mechanistic based primary structural response model employed herein provides the ability to accurately assess the primary structural responses spatially within any road structure, conventional or recycled. The mechanistic primary responses of alternate road structures and road materials as they perform in the field, and provide a more direct mapping to field performance of alternate road systems.

The road structural model employed herein is based on numerical road structural algorithms associated with each structural layer. The integration of the layer responses are used to model the primary anisotropic multiaxial stresses and strains within typical Saskatchewan road structures. The mechanistic road model has the ability to encode Saskatchewan commercial truck load spectra, alternative Saskatchewan materials including recycled and stabilized systems, structural design layer thicknesses under Saskatchewan field state conditions. This is essential to direcly compare conventional and recycled road structures.

Other applications of the mechanistic primary road structural response model proposed herein include the ability to quantify structural design equivalencies across alternate traffic load spectra, road structure materials, road structural geometry, and urban roads under specified Saskatchewan field state loading conditions. These primary road structural response predictions can then be used to predict the whole life structural performance of alternative road structures, and can be used to validate primary deflection response measures made in the field using heavy weight deflection measures as part of the structural asset management system.

4.3 Element 3: Road Rehabilitation Options Analysis

When considering recycled road systems, the recycling options are always compared to conventional road rehabilitation systems. The systems considered within this pilot project include conventional full depth road structures that remove the entire road structure and replace it with virgin aggregate materials and hot mix surfacing materials. As well, full depth strengthened systems employing in-place recycling cement strengthening and cement/asphalt emulsion blends, with and without substructure drainage are also considered.

Based on the proposed design segment, Figure 4.2 illustrates the conventional full depth remove and replace strengthening option, Figure 4.3 illustrates the PSI Technologies™ strengthening option, and Figure 4.4 illustrates the full depth PSI Technologies™ strengthening with drainage option proposed for Shannon Road.

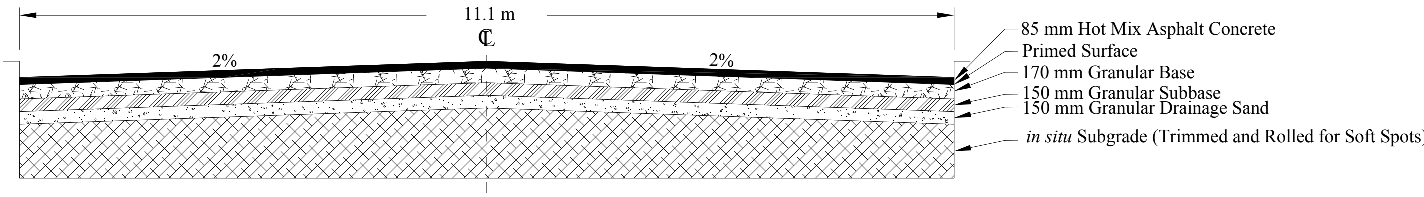

Figure 4.2 Rehabilitation Option A: Conventional Full Depth Remove and Replace with Granular Structure Cross Section

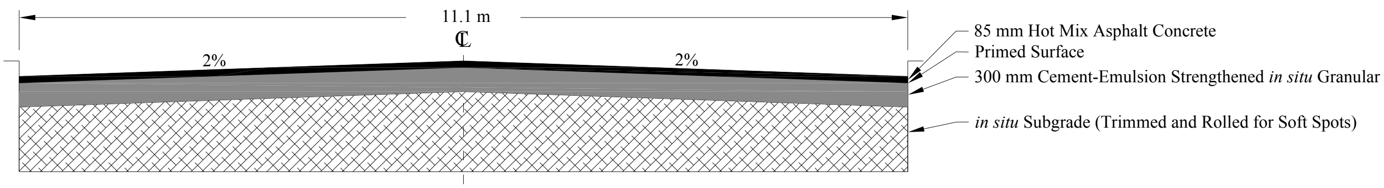

Figure 4.3 Rehabilitation Option B: Full Depth PSI Technologies Strengthening Structure Cross Section

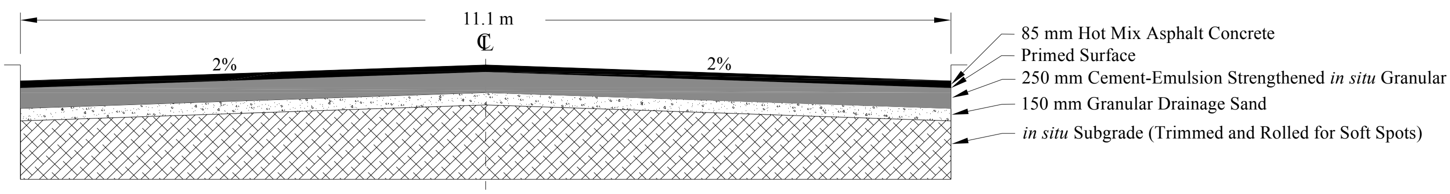

Figure 4.4 Rehabilitation Option C: Full Depth PSI Technologies Strengthening Structure with Granular Drainage Layer Cross Section

The full depth strengthening systems constructed in this field demonstration project significantly improved the climatic and mechanistic performance of the material systems, which will significantly improve the long term performance of the structural system. In addition, full depth strengthening provides the ability to optimize the use of select aggregate materials already in place. The benefits of strengthening Shannon Road with full depth strengthening are significant relative to conventional full depth remove and replace. Given the relatively high *in situ* moisture content of the highly plastic lacustrine clay subgrade, structural Option C is recommended since the drainage sand layer above the *in situ* clay subgrade provides an improved working platform and reduces any future swelling of the street.

Based on preliminary estimated construction costs, there appears to be a potential rehabilitation construction savings of \$8.15/m^2 by implementing a full depth cold in-place strengthening system (Option B) as compared to a conventional rehabilitation system (Option A) and a construction cost saving of \$5.90/m^2 by implementing a full depth cold in-place strengthening system with drainage (Option C). In addition, it is believed that the full depth strengthening option will significantly reduce weather exposure, as well as reduced risk due to increasing construction costs related to construction capacity and energy prices.

Based on the pilot cold in-place recycling and full depth strengthening projects undertaken in the City of Regina in 2006, the capital costs of the in-place recycling systems were found to be approximately equal to that of conventional full depth remove and replace systems based on 2006 pricing. It must be noted that the 2006 project was undertaken with considerable risk on behalf of the road constructor as well as the City of Regina. However, given the significantly increasing costs related to conventional road materials and construction methods that are being realized in early 2007 tenders, it is expected that conventional construction costs will continue to increase relative to cold in-place recycling systems given the reduction in performance risk of the cold in-place recycling system based on the 2006 pilot projects.

This field demonstration project also selected the best options based on holistic cost analysis. To perform this analysis, this project will employ holistic life cycle economic evaluation across the road infrastructure strengthening options considered. PSI Technologies have developed costing models as well as structural performance models that incorporate the materials characterization, construction processes, user delay costs, and environmental impact costs associated with typical alternate road structural strengthening systems.

Because the mechanistic based engineering and road management system is based on discretized engineering measurements that are directly related to structural performance, it has the ability to employ mechanistic-climatic materials characterization to more accurately quantify the probability of a target road performance in the field. By implementing a performance based selection criterion that incorporates structural and material performance directly, road agencies will be able to implement more optimal road asset management strategies that result in proactive and preventative road infrastructure management as opposed to the current surface based reactive preservation strategies. Road agencies will also be able to quantify performance risk by project element contributing to whole life performance. Once broken down into performance related factors, risk may be characterized based on discretized elements of performance multiplied by the probability of the performance occurring:

Risk ($) = Cost of Detrimental Performance Factor ($) x Probability of Detrimental Performance Factor

In addition, by incorporating holistic economic evaluation criterion, road agencies will be able to move towards more environmentally sustainable road management solutions that better align with national and international environmental stewardship. That is one of the major goals of this field demonstration project. Based on the findings of this project analysis, over a 50 percent decrease in emissions generated and 95 percent decrease in user delay costs was realized with deploying cold in-place recycling relative to conventional road construction methods.

4.4 Element 4: Cold In-Place Recycling Construction and Field Quality Control

A primary objective of this field demonstration project is to apply and evaluate the technical and economic effectiveness of cold in-place recycling and strengthening of urban streets. As a result, this project employed a prequalification process to employ the latest in in-place recycling equipment and construction procedures (Figure 4.5). This project employed the fluid injection feedback control systems that enabled highly accurate injection of asphalt emulsion within the recycled materials as per the specified design requirements.

Figure 4.5 Cold In-Place Recycling and Feedback Stabilization Control System

In addition to state-of-the-art construction equipment, PSI Technologies employed rigorous quality control testing during construction including moisture density master Proctor curves, *in situ* moisture-density measures, and final geometric quality measures. PSI Technologies employ semi-automated test equipment onsite (Figure 4.6) and provided real time quality control measures on a segment by segment basis (see attached "City of Regina Shannon Road Construction Turnover Package").

Figure 4.6 PSI Technologies Quality Control Test Laboratory

PSI Technologies deployed an onsite materials testing laboratory equipped with automated Proctor compaction equipment for accurate Proctor moisture-density characterization of the remixed and strengthened system on the day of construction. PSI Technologies statistical requirements are minimum R^2 of 96 percent on both the dry and wet side of the Proctor moisture-density relationship. A minimum of eight point Proctor curves is recorded for each segment during construction.

PSI Technologies also employs a statistically significant array of full depth nuclear gauge readings (up to 300 mm) in real time during construction. PSI Technologies also recommends daily *in situ* moisture readings to provide the contractor with real time moisture condition assessment in order to ensure efficient compaction. As well, PSI Technologies provides a minimum of three real time moisture correction and validation ground truth measures daily to validate the accuracy of the nuclear gauges.

Based on the field quality control measures and documentation performed during construction, the end product quality measures were used to establish *in situ* variability within the reclaimed material system, as well as, provide the contractor with an indication of the end quality resulting from various construction processes trialed during construction. As seen in the turnover package, significant *in situ* material variability did exist within the road structure, and various construction processes resulted in different levels of *in situ* end product quality. As a result, this project successfully distinguished and determined the optimal construction process that could be implemented for cold in-place recycling and full depth strengthening.

4.5 Element 5: Post Construction Mechanistic Quality Assurance and Structural Asset Management Characterization

The underlying objective of this field demonstration project is to validate the cost effectiveness of road recycling solutions. A critical component to assessing the whole life economics of alternate road strengthening systems is reliable end value quality assurance measures in the field.

The PSI Technologies mechanistic quality assurance and structural asset management approach employed the ground penetrating radar and falling weight deflection measures to provide direct primary road structural responses of the structural system under actual Saskatchewan field state conditions. Direct structural performance measures in the field have been shown to significantly improve the quality and predictive accuracy of structural deterioration, as well as surface distress initiation and propagation of distresses that are related to the strain state profiles within the road structure.

The field performance quality validation of the test sections proposed to be constructed in this field demonstration project will involve the following tasks:

1) Ground penetrating radar survey profiles including dielectric permittivity profiles, layer thickness, and relative moisture profile calculations;
2) Falling weight deflection non-linear structural asset value profiles (Figure 4.7 and Figure 4.8);
3) Digital photo log;
4) Semi-automated surface distress assessment using ground penetrating radar, and;
5) Targeted gradehole sampling and laboratory characterization.

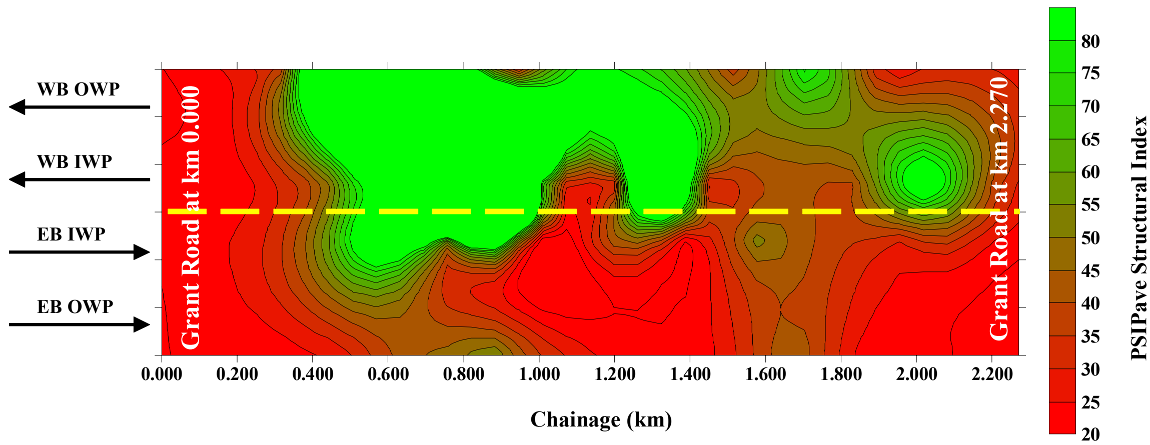

Figure 4.7 Pre-Construction PSIPave Structural Index Contour Profile

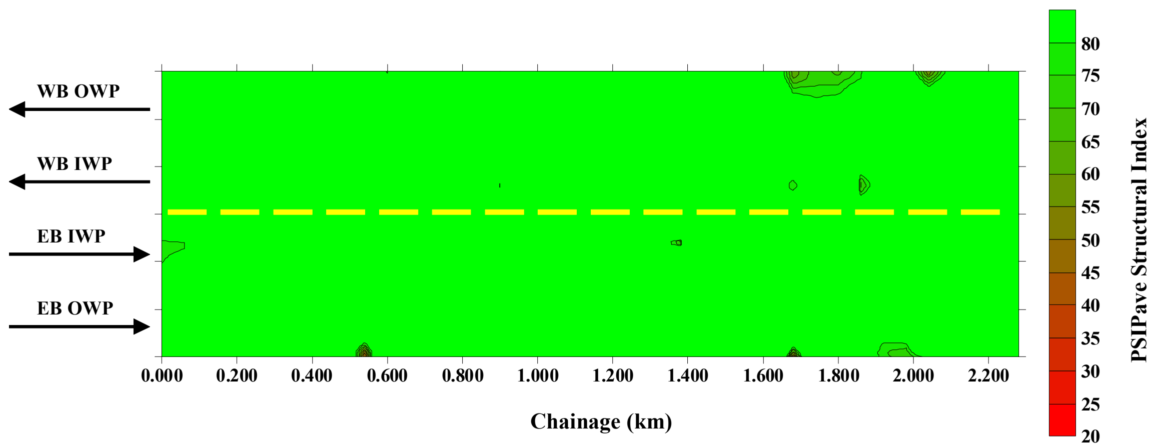

Figure 4.8 Post-Construction PSIPave Structural Index Contour Profile

Mechanistic performance transfer function models based on the non-linear structural primary responses as collected using structural asset management field protocols provide road agencies with more accurate road performance profiles relative to conventional "aggregated" surface performance measures. The mechanistic system proposed herein provides a direct performance validation approach to quantify mechanistic based road structural performance sensitivity analysis across the range of typical Saskatchewan field state conditions.

Structural primary response based performance models is hoped to improve the reliability of pavement performance predictions could significantly improve the value of preservation treatments considered, and help shift road agencies from reactive road management strategies to more proactive road management strategies, particularly with regards to structural health monitoring.

A critical element to employing mechanistic based performance prediction models is a fundamental understanding of the initiation and propagation of specific structural distresses as they occur in Saskatchewan road materials, structures, and field state conditions. The Mechanistic Pavement Structural Analysis and Structural Asset Management System employed herein sets the framework to employ with the latest in advanced material damage mechanics to predict damage mechanisms across diverse road materials and road structures.

5.0 SUMMARY

This field demonstration project constructed three urban full depth strengthened roads as registered cold in-place recyled test sections within the City of Regina. These sections will provide the essential field test sites to validate cold in-place recycling of urban streets across various strengthening systems over time, under Saskatchewan field state conditions.

A second result of this field demonstration project was a significant breakthrough in the application of a mechanistic approach to engineering urban recycled pavements. To illustrate, this field application study helped engineers overcome the considerable sensitivity that road materials have to urban field state conditions. This ability to directly characterize the sensitivity that urban roads have to load rate, field stress state, and material quality as typically experienced in urban field state conditions can significantly change the structural capacity of the pavement design. These conditions are known to lead to more rapid deterioration of urban infrastructure assets, however, until now, could not be reliably quantified.

In summary, the expected benefits of the in-place recycling and full depth strengthening field demonstration project in the City of Regina included the following.

1) Reduced environmental emissions to structurally rehabilitate urban streets (up to 75 percent reduction in construction vehicle emissions).
2) Reduced road user delays and residence inconvenience.
3) More sustainable and less volatile road rehabilitation costs due to reduced reliance on energy and conventional road materials.
4) Optimal reuse of *in situ* road materials, particularly select granular materials.
5) Reduced use of high quality non-renewable aggregate resources.
6) Reduced need for re-grading and excavation of existing roads.

7) Improved drainage within established curb lines.
8) Preservation of in-place aggregate materials due to reduced moisture infiltration from strengthened subgrades.
9) Reduced road damage resulting from concentrated aggregate haul.
10) Reshaping, drying and reuse of marginal substructure materials.
11) Improved mechanical performance of road substructure materials.
12) Improved climatic durability of road substructure materials.
13) More efficient road rehabilitation construction productivity.
14) Reduced construction risk due to poor weather.
15) An effective road strengthening system that can be used in conjunction with other road management/strengthening strategies.
16) Ability to employ modern road reclaimers that efficiently incorporate chemical and/or mechanical stabilizers that improve the performance of *in situ* road soils.

Additional environmental benefits could be realized from the reduction in emissions resulting from the application of warm mix surfacing systems placed directly on the in-place recycled and strengthened system. Additional environmental emissions reductions that could be realized from engineered warm mix bituminous surfacing systems are estimated to add an additional 25 percent in the overall reduction in emissions related to street rehabilitation.

In summary, this technology could result in a total of 75 percent reduction in emissions to rehabilitate urban streets. This field demonstration project will be published in the 2007 annual TAC meeting, including the emissions reductions resulting from this technology.