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civil

Thinking Outside the Transportation Box
Réflexion non conventionnelle en matière de transport

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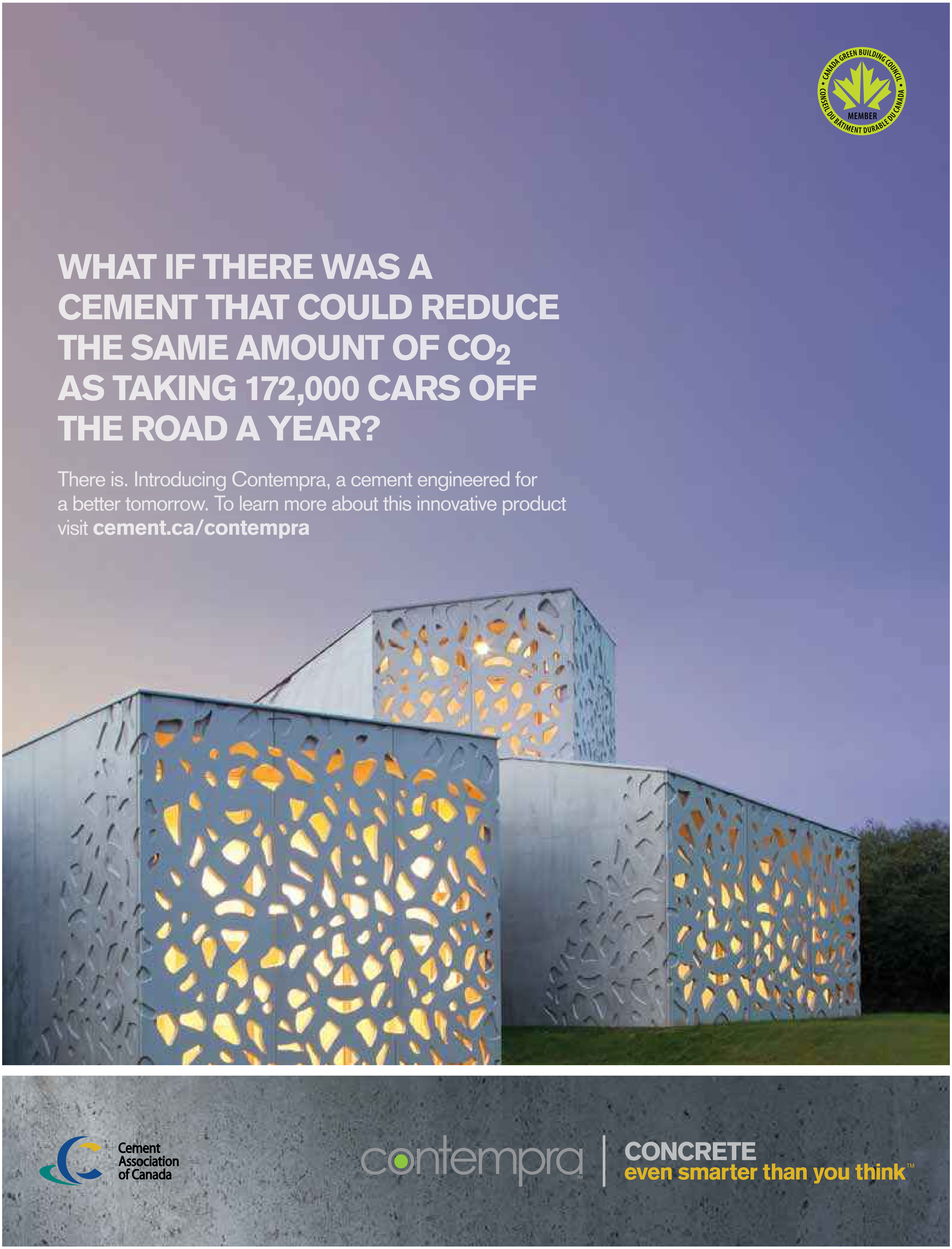
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CSCE / SCGC
4877 Sherbrooke St. W.
Westmount, Québec, H3Z 1G9
Tel: 514-933-2634 Fax: 514-933-3504
E-mail: info@csce.ca
www.csce.ca

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All commentaries and questions about this publication should be forwarded to the Editor:
Pour vos commentaires ou de plus amples informations, contacte la rédactrice :
Louise Newman, louise@csce.ca 514-933-2634 ext. 23

Return Address / Adresse de retour :
The Canadian Society for Civil Engineering
La Société canadienne de génie civil
4877 Sherbrooke St. W., Westmount, Québec H3Z 1G9

FROM THE EDITORS / MOT DES RÉDACTEURS



LOUISE NEWMAN LOUISE@CSCE.CA
DR. SAID M. EASA PH.D., P.ENG., RYERSON UNIVERSITY
DR. CARL HAAS PH.D., P.ENG., UNIVERSITY OF WATERLOO

The theme of this special issue is Thinking Outside the Transportation Box. The issue includes four interesting articles that address various areas of transportation engineering, including planning, operation and management, intelligent systems, and pavement construction.

The article by Preston Schiller, "*Getting Outside the Box of the Automobile*," proposes that engineers who work in urban transportation literally get outside the rectangular solid box of the automobile. The article seriously questions many of the premises guiding the ways that city streets, intended to be shared by many users for many purposes, have been transformed into roads dominated by one user, the private motor vehicle. The author argues that transportation planning is too complex to be dominated by one discipline; that engineers should extend concerns about efficiency and safety to all road and street users, as well as benefiting from collaboration with experts in mobility management, health and fitness, and land use planning. The implementation of new paradigmatic approaches to the whole range of urban transportation challenges is stressed.

Vaziri et al. describe important applications of traffic load data from weigh in motion (WIM) systems in their article, "*Traffic Load Data from Weigh-In-Motion Systems*". WIM has come a long way from its early days. It has become a cost-effective, reliable, and accurate technology for acquiring traffic load data. Such data are essential for life cycle management of road assets and applications such as pavement and bridge design, monitoring for planning purposes, and compliance as well as enforcement. The installation and evaluation of WIM systems in the Region of Waterloo and Highway 401 in collaboration with a number of government and industry partners are described.

Currently, there are very limited efforts to enable remote sharing and integration of ITS infra- and info-structures. To address this issue, El-Darieby and Abdulhai present an innovative platform for intelligent transportation systems in their article, "*ONE-ITS: Intelligent Transportation Systems without Borders.*" The platform enables building ITS research and development applications using the ONE-ITS (Online Network-Enabled Intelligent Transportation Systems) platform. The ONE-ITS technical architecture, implemented using industry-standard collaborative information and Internet technologies, is highlighted.

The article by Abd El Halim and Easa, "*Pavement Recycling: New and Innovative Technologies for Sustainable Roads*," highlights new and innovative technologies for cold in-place recycling (CIR) that are contributing to sustainable road rehabilitation and reconstruction. The authors describe various aspects of the new technologies, including the basic CIR technology, expanded technology using foamed asphalt, design and construction, economic and environmental benefits, and potential compaction technology. Looking ahead, the authors highlight several areas that require attention in the future, including best practices, better education, information on long-term performance, and quality assurance criteria.

While these articles are representative of the range of transportation innovations that promise to change the way we move people and goods in Canada, they are just a very small sample. Universities, government departments, and private enterprise are collaborating on many more innovations that we will all encounter in the years to come. ■

Ce numéro spécial a pour thème la réflexion non conventionnelle en matière de transport. Ce numéro comporte quatre articles portant sur divers aspects du génie des transports : la planification, l'exploitation et la gestion, les systèmes intelligents, et la construction des chaussées.

L'article de Preston Schiller, intitulé « *Getting Outside the Box of the Automobile* », propose que les ingénieurs spécialisés en transport urbain sortent de la pensée conventionnelle axée sur l'automobile. L'article remet en cause nombre d'hypothèses qui régissent la façon dont les rues des villes, conçues pour être partagées par plusieurs utilisateurs et pour plusieurs fins, ont été transformées en voies dominées par un seul utilisateur, qui est l'automobile privée. L'auteur affirme que la planification du transport est trop complexe pour être dominée par une seule discipline, que les ingénieurs devraient appliquer leur souci d'efficacité et de sécurité à l'ensemble des utilisateurs des routes et des rues, et devraient bénéficier d'une collaboration avec des experts en gestion des déplacements, en santé et en condition physique, et en aménagement du territoire. L'article souligne aussi la mise en œuvre de nouvelles démarches paradigmatiques pour l'ensemble des défis en matière de transport urbain.

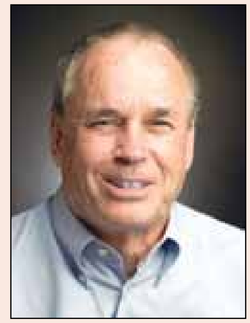
L'article de Vaziri et al., intitulé « *Traffic Load Data from Weigh-In-Motion Systems* », décrit d'importante applications de données sur le volume de trafic tirées des systèmes de données par pesage routier dynamique (WIM). Le pesage routier dynamique (WIM) a fait beaucoup de progrès depuis ses débuts. C'est maintenant une technologie efficace, fiable et précise pour acquérir des données sur les volumes de circulation. Ces données sont essentielles pour la gestion du cycle de vie des actifs routiers et des applications comme la conception de ponts et chaussées, la surveillance pour fins de planification, et le respect des règlements. L'article décrit l'installation et l'évaluation de systèmes WIM dans la région de Waterloo et de l'autoroute 401, en collaboration avec des partenaires publics ou privés.

Il y a présentement peu de travail qui se fait sur le partage et l'intégration à distance des systèmes intelligents de transport dans les infra- et les info-structures. Dans cette perspective, les auteurs El-Darieby et Abdulhai présentent une plate-forme innovatrice pour les systèmes intelligents de transport dans leur article intitulé « *ONE-ITS: Intelligent Transportation Systems without Borders* ». Cette plate-forme permet de créer des applications de recherche et développement in technologie à partir de la plate-forme ONE-ITS (Online Network-Enabled Intelligent Transportation Systems). L'article explique comment l'architecture technique du ONE-ITS est mise en œuvre à l'aide de données standardisées pour l'industrie et de technologies Internet.

L'article de Abd El Halim et Easa intitulé, « *Pavement Recycling : New and Innovative Technologies for Sustainable Roads* », porte sur les technologies nouvelles et novatrices pour le recyclage qui contribuent à une restauration et une reconstruction durable des routes. Les auteurs décrivent divers aspects des nouvelles technologies, comme la technologie de base CIR, la technologie faisant appel à l'asphalte cellulaire, le design et la construction, les avantages économiques et environnementaux, et la technologie du compactage. Pour l'avenir, les auteurs soulignent plusieurs secteurs qui exigeront du travail, comme les meilleures pratiques, une meilleure éducation, des renseignements sur le rendement en longue période et les critères d'assurance qualité.

Bien que ces articles représentent la gamme d'innovations en transport qui annoncent les changements qui viennent en matière de transport des personnes et des biens au Canada, ils n'en mentionnent qu'un faible échantillonnage. Les universités, les ministères des gouvernements et les entreprises privées collaborent à nombre d'autres innovations que nous verrons au cours des années à venir.

SPOTLIGHT ON MEMBERS / MEMBRES EN VEDETTE



Dr. Ian Jordaan was recently named Fellow of the Royal Society of Canada's Academy of Science in recognition of his distinguished work to date. Dr. Jordaan is a University Research Professor and a Professor Emeritus in the Faculty of Engineering and Applied Science at Memorial University, Newfoundland, as well as being a Principal Consultant in Ice Engineering at C-CORE.

Dr. Jordaan is a pre-eminent engineer working on design of offshore structures in harsh environments. The author of more than 200 papers and reports, as well as a book on probabilistic analyses for engineering, *Decisions Under Uncertainty*, he has pioneered the risk-based approach to offshore engineering and estimation of structural loads caused by ice. He has also worked extensively on the mechanics of ice compressive failure, and has developed theories that explain the high local pressures experienced by ships and structures in ice.

Dr. Jordaan has consulted on major Canadian and international projects, including the Terra Nova, White Rose and Hebron developments and the Confederation Bridge.

"I've always been very focused on my work and take pride in what I do. It is very rewarding to look at something like the Confederation Bridge and know that I helped make it possible," said Dr. Jordaan. "It is a great honour to have my work recognized in this way by my peers."

The Royal Society of Canada is the senior national body of distinguished Canadian scholars, artists and scientists and is Canada's national academy. The primary objective of the RSC is to promote learning and research in the arts and sciences.

Dr. Jordaan was officially inducted in to the Royal Society of Canada at a ceremony in Ottawa in November, entering RSC's Division of Applied Science and Engineering.

RANDY PICKLE P.ENG., FCSCE – PRESIDENT@CSCE.CA

If one thinks back from today, over the span of a little more than two generations, there have been great leaps in the technology that supports the way of life in developed countries. Some of these leaps include the obvious: automobile, air flight, television, refrigeration, water and waste water treatment, and electronic assistants, to name a few.

In 2010, CSCE adopted a new mission statement 'Leadership in Sustainable Infrastructure'. This new direction will see the CSCE, through the President, Board of Directors and members, as more engaging in the discussions and policy making on the state of the Canadian infrastructure. At the Canadian Society for Civil Engineering, we feel that this is the next big leap that we must take and take soon.

CSCE is moving forward to better understand what Sustainable Infrastructure is. A panel of knowledgeable people in the area of infrastructure and sustainable development has been assembled to undertake case studies of two similar bridge infrastructure projects that we feel will help to define what is and what is not sustainable infrastructure. From these templates, we will be able to prepare templates to identify other areas of sustainable infrastructure. The expected deliverables, from the analysis of these case studies, will be Best Practices for the development and selection of sustainable infrastructure alternatives to meet the needs.

Identifying and putting into use the best suited sustainable infrastructure for the need, whether it is a sewer, watermain, road, bridge, treatment plant, transit system, etc., is only the first phase. The life cycle of the infrastructure also needs to be considered. There will be the need during the life of the infrastructure to undertake maintenance and possibly some rehabilitation works. For a typical paved road section, the life cycle will probably include crack sealing within the first 5 to 7 years, place an asphalt overlay perhaps 5 to 7 years later and then, 20 to 25 years after the first traffic has been on the road, major rehabilitation such as partial or full depth pavement removal and replacement. From this point, the cycle can be repeated or it may be time to decide on other improvements to meet the user needs. The timing of these improvements has a number of variables such as but not limited to the quality and performance of the materials used to construct, the workmanship of the contractors, decision making by the owner, which in itself has a number of variables, etc.

In 2010, CSCE adopted a new mission statement 'Leadership in Sustainable Infrastructure'.

A number of years ago, a study was undertaken to assess the condition of the Trans Canada Highway as it passes through our National Parks, from L'Anse aux Meadows to Glacier. Common to all of the parks were the roads and bridges along the route. There were also the unique items such as the sea walls along the Cabot Trail and the snow sheds through Roger's Pass. Apart from providing the owner and operator with a quantitative measure of the infrastructure needs, the study also identified that there is no threshold level as to what the service standard for our infrastructure should be. In Atlantic Canada the focus was on ensuring that bridges were well maintained, which is understandable given the terrain constraints and the fact that those same constraints minimize opportunity for alternative routes should a bridge go out of service. In western Canada the priority was to maintain the roads in good condition, so that potholing was minimized and the risk of claims against the road authority for vehicle damage was mitigated.

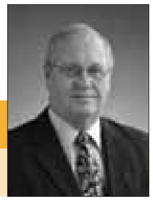
The CSCE will define sustainable infrastructure but it will be necessary for all levels of governance, to come together, hopefully with resources available from CSCE, to establish a national standard for the level of service for our infrastructure. ■

Depuis un peu plus de deux générations, il y a eu de grands progrès dans les technologies qui sous-tendent le mode de vie dans les pays développés. Il y a d'abord les progrès évidents : l'automobile, l'avion, la télévision, la réfrigération, le traitement de l'eau et des eaux usées, et les appareils électroniques.

En 2010, la SCGC a adopté un nouvel énoncé de mission : « Pour un leadership en matière d'infrastructures durables ». Cette nouvelle orientation fera de la SCGC, par son président, son c.a. et ses membres, un organisme plus engagé dans les débats et l'élaboration des politiques touchant à l'état des infrastructures au Canada. À la Société canadienne de génie civil, nous croyons que c'est là le nouveau progrès que nous devons assurer, et ce, le plus tôt possible.

La SCGC commence à mieux comprendre ce que sont des infrastructures durables. Un groupe d'experts en infrastructures et en développement durable a été formé pour procéder à des études de cas sur deux ponts, et nous estimons que ces études nous aideront à définir ce qu'est, et ce que n'est pas, une infrastructure durable. À partir de ces modèles, nous serons en mesure de créer des modèles applicables à d'autres infrastructures durables. Les résultats attendus, à partir de ces analyses de cas, seront les meilleures pratiques à suivre pour l'élaboration et la sélection des moyens adéquats pour obtenir des infrastructures durables qui conviennent aux besoins.

Définir et créer les infrastructures durables les mieux adaptées, qu'il s'agisse d'égouts, d'aqueducs, de routes, de ponts, d'usines de traitement, de systèmes de transport, etc., n'est que la première étape. Il faut aussi se pencher sur le cycle de vie des infrastructures. Il faut tenir compte, pendant la durée de vie des infrastructures, des travaux d'entretien et, peut-être, des travaux de restauration. Dans le cas d'une route pavée, le cycle de vie comprendra probablement le colmatage des fissures au cours des 5 à 7 premières années, la pose d'un revêtement bitumineux de 5 à 7 ans plus tard, et, de 20 à 25 ans après l'inauguration de la route, une restauration importante comme l'enlèvement et le remplacement de



un nouveau cycle de vie ou décider d'autres améliorations pour combler les besoins des usagers. L'échéancier pour ces améliorations comporte diverses variables comme la qualité et la performance des matériaux de construction, la qualité du travail des entrepreneurs, la prise de décisions par le propriétaire, qui comporte à elle seule d'autres variables, etc.

En 2010, la SCGC a adopté un nouvel énoncé de mission : « Pour un leadership en matière d'infrastructures durables ».

Il y a plusieurs années, une étude a été faite pour évaluer l'état de la route Transcanadienne, qui traverse nos parcs nationaux, de l'Anse aux Meadows au parc des Glaciers. Les ponts et les routes étaient de même construction. Il y avait aussi des éléments originaux, comme les murs de protection le long de la piste Cabot, et les galeries paravalanches de Col-Rogers. En plus de fournir au propriétaire et à l'exploitant une façon de quantifier les besoins en infrastructures, l'étude signalait aussi qu'il n'y avait pas de norme minimale pour nos infrastructures. Dans les Maritimes, l'important était de voir à ce que les ponts soient bien entretenus, ce qui se comprend, compte tenu des contraintes naturelles et du fait que ces mêmes contraintes font qu'il y a peu de solutions de remplacement si un pont doit être fermé. Dans l'Ouest du Canada, la priorité consistait à garder les routes en bon état, afin qu'il y ait le moins de nids de poule possible et de minimiser les risques de réclamations pour dommages aux véhicules.

La SCGC entend définir ce que sont des infrastructures durables, mais il sera quand même nécessaire que tous les ordres de gouvernement se retrouvent ensemble, appuyés par les ressources de la SCGC, pour instaurer de nouvelles normes pour assurer la qualité de nos infrastructures.

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GUIDE TO BRIDGE HYDRAULICS

November 29, 2011 – December 2nd, 2011
Vancouver, Calgary, Edmonton, Regina
This course will be presented in western Canada in March/April 2012.
Cette formation est présentée en anglais.

This CSCE-CSA course is based on TAC's Guide to Bridge Hydraulics. It covers planning, design as well as operations and maintenance of bridges relative to their hydraulics. It addresses key topics such as boundary conditions, waterway design, scour protection and channel control as well as hydraulic aspects of construction, inspection and maintenance.

It is presented by **Marcel Chichak, P.Eng.**, who has thirty years experience with bridges and bridge hydraulic performance problems.

The course is aimed at practitioners responsible for addressing bridge hydraulic considerations and issues in the planning, design, operations and maintenance infrastructure lifecycle from consulting, contracting and construction firms, municipal, provincial and federal governments.

AGENDA

1. Overview
2. Bridge Hydraulics
3. Bridge Hydraulics Engineering
4. Bridge Hydrotechnical Planning
5. Bridge Hydrotechnical Design
6. Monitoring and Inspection
7. Cross Selection Case Study

To view the brochure and register, please visit www.csce.ca.

COURSES AT CSCE 2012 ANNUAL CONFERENCE

June 6, 2012
Formations présentées en anglais au congrès annuel 2012 de la SCGC

Winter Road Maintenance— Performance Measurement and Evaluation (WRM)
This short course will introduce the fundamentals of performance measurement for highway winter maintenance operations, including basic concepts, performance measurement framework, alternative performance measures, and data needs, and a new software tool that can be used to automate the performance measurement process. It will illustrate the introduced concepts, processes and methods through the use of case studies.

The course is presented by **Liping Fu, Ph.D.**, Professor and Director of the iTSS Lab at the Department of Civil end Environmental, University of Waterloo.

Infrastructure Asset Management (IAM)
This course introduces the principles of infrastructure management in the practical context of two municipalities: small (Clarence-Rockland, ON) and large (Edmonton, AB). The participants will learn about the principles and key steps in the development of an asset management plan. The presenters will also make linkages between asset management and asset accounting (PS 3150) which plays an important role in municipal reporting.

The course is presented by Guy Félio, Ph.D., P.Eng., President, Infrastructure Strategies & Research Inc. and Konrad Siu, M.Eng, MBA, P.Eng., FCSCE, City of Edmonton.

W.C. (CAL) SEXSMITH M.ENG., P.ENG., FCSCE

On the weekend of October 15 I attended the Annual General Meeting of the Canadian Council for Railway Heritage (CCRH) in Winnipeg. I was attending on behalf of the Saskatchewan Railway Museum, not the CSCE, but I also had a discussion with the CCRH Board on possible joint efforts between the CSCE National History Committee and the CCRH. Most of the CCRH efforts are centred on locomotives and rolling stock, but their members also have impressive knowledge on many railway related civil works such as bridges and tunnels. A number of potential Civil Engineering Historic Sites were suggested to me by the CCRH Board.

The meeting was hosted by the Vintage Locomotive Society (VLS) better known as the operators of the Prairie Dog Central tourist train. The VLS has a number of artefacts from the early days of Canadian railways. The most well known is City of Winnipeg Hydro 4-4-0 steam locomotive number 3. Originally built by Dubs and Company in Glasgow, Scotland as Canadian Pacific number 22, this locomotive was used during the construction and early operation of the CPR. After being renumbered no less than three times in the 1910s (133,63,86) it was sold in 1918 to City of Winnipeg Hydro where it was renumbered once more to City of Winnipeg Hydro number 3. Winnipeg Hydro continued to use number 3 until 1961. In 1967 number 3 was restored to service for the Prairie Dog Central tourist train. The VLS also owns five wooden passenger cars, the youngest of which will be 100 years old in 2012. One of these five cars is the last coach still in its original form built by the Crossen Car Company of Coburg, Ontario.

Railways were the mega projects of the late 1800s and early 1900s and were the first form of mechanized land transport. Because of this, many of the early Civil Engineers in Canada worked for the railways in a variety of activities from surveying rights of ways to designing and building many very impressive bridges.

The CSCE has designated a number of railway projects as National, Regional or International Civil Engineering Historic Sites—from the White Pass & Yukon Railway in the west to the Newfoundland Railway in the east—and include such nation building projects as the Intercolonial Railway and the Canadian Pacific Railway. In fact, Canada as we know it probably would not exist without some of these early railway builders.

PHOTO: Prairie Dog Central Locomotive #3 built in 1882 by Dubs in Scotland and used in the construction of the Canadian Pacific.

Durant la fin de semaine du 15 octobre, j'ai assisté à l'assemblée générale annuelle du Conseil national des musées ferroviaires, à Winnipeg. J'y représentais le « Saskatchewan Railway Museum », et non la SCGC. J'ai cependant eu l'occasion de discuter avec le c.a. du Conseil national des musées ferroviaires de démarches conjointes possibles entre le comité des affaires historiques de la SCGC et le Conseil des musées ferroviaires. Les travaux du Conseil des musées ferroviaires sont axés sur les locomotives et le matériel roulant, mais leurs membres ont un impressionnant bagage de connaissances sur plusieurs ouvrages connexes, comme les ponts et les tunnels. Plusieurs lieux historiques du génie civil m'ont ainsi été suggérés par le c.a. du Conseil des musées ferroviaires.

La réunion se déroulait sous les auspices de la « Vintage Locomotive Society (VLS) », connue comme étant l'exploitant du train touristique « Prairie Dog Central ». La VLS possède des artefacts remontant aux premiers jours des chemins de fer du Canada. Le plus connu est certainement la locomotive à vapeur nº 3 de (Winnipeg Hydro 4-4-0). Construite par Dubs and Company, à Glasgow, en Écosse, ce fut au début la locomotive nº 22 du Canadien Pacific. Cette locomotive a servi lors de la construction et des débuts d'exploitation du CP. Cette locomotive a changé de numéro au moins trois fois dans la décennie 1910 (133,63,86), pour être enfin vendue à Winnipeg Hydro, où elle est devenue la numéro 3. Elle est demeurée en service jusqu'en 1961. En 1967, la numéro 3 a été restaurée pour tirer le train touristique « Prairie Dog Central ». La VLS possède également cinq wagons passagers en bois, dont le plus récent aura 100 ans en 2012. L'un de ces 5 wagons est le dernier wagon construit par la « Crossen Car Company », de Coburg, en Ontario, qui ait conservé son allure originale.

Les chemins de fer furent les méga-projets de la fin du 19e siècle et du début du 20e. Ils furent aussi la première forme de transport mécanisé. Pour cette raison, nombre des premiers ingénieurs civils du Canada ont travaillé sur les chemins de fer à divers titres, pour l'arpentage des emprises ou pour créer et construire nombre de ponts qui demeurent impressionnants.

La SCGC a commémoré de nombreux ouvrages ferroviaires qui sont devenus des lieux nationaux, régionaux ou internationaux du génie civil, depuis le « White Pass & Yukon Railway », dans l'Ouest, au « Newfoundland Railway », dans l'Est. Ces lieux comportent d'importants chantiers qui ont aidé à la création du pays, comme le chemin de fer Intercolonial et le chemin de fer du Canadien Pacifique. En fait, le Canada que nous connaissons aujourd'hui n'existerait pas sans ces pionniers de la construction des chemins de fer.

Dr. Preston L. Schiller

Adjunct Lecturer, School of Urban and Regional Planning, Queen's University, Kingston, Ontario (preston.schiller@queensu.ca)

Getting Outside the Box of the Automobile

I propose that engineers who work in urban transportation get outside the box that most have enclosed themselves in for the past several decades. Literally, I propose getting out of the rectangular solid box of the automobile (or the more inclusive term PMV for private motor vehicle) within which much transportation engineering thinking is trapped. I propose a serious questioning of many of the premises guiding the ways that city streets, intended to be shared by many users for many purposes, have been transformed into roads dominated by one user, the PMV. I believe it is time to review the trajectory that has turned this domain of engineering away from efficiency as a guiding ethic to promoting the multiple inefficiencies of the PMV; away from an ethic of safety for all to an ethic of safety for those inside a PMV; away from balance and equity to an over-privileging of one mode.

Mind you, I am not anti-engineer. I think it is vitally important for engineers to be the authorities on stresses, loads, structural capacities, relations between gradients, curves and velocities and similar phenomena. But I am troubled by the over-reach of the profession when it comes to that basically human phenomenon known as traffic; an area that can be influenced by the physical but involves numerous factors best addressed by the social sciences. This field is much too complex for any one profession, and decision making needs to be shared with planners, public policy experts, elected officials, psychologists, sociologists, anthropologists, economists and the public—especially those who have been traditionally neglected; those who walk, bicycle, have mobility issues, use transit and want safe streets for children and the elderly.

WHAT HAPPENED TO EFFICIENCY?

A memorable film of my 1950s childhood was "Cheaper by the dozen," a biographical account of Frank B. Gilbreth, Sr., a pioneer in time and motion studies in the early twentieth century. The story is told by two of his dozen children. Many aspects of their household and family life were organized according to efficiency principles by Gilbreth Sr. who was generally considered a masterful mechanical engineer despite being self-educated and un-credentialed (Gilbreth and Carey 1948). I grew up believing that engineering was all about efficiency and safety; increasing the ratio of outputs to inputs, making processes speedier and safer for those engaged in them.

Out of environmental concerns in midlife I turned my attention to air pollution which led me to transportation as the much ignored elephant in that room. I discovered that the fuel efficiency of internal combustion engine vehicles was fifteen per cent, likely down to single digits were a complete life cycle analysis undertaken. If all the highly subsidized, un-priced and underpriced infrastructure and service provisions, from fuels and driveways to expressways to parking, planning, operations, maintenance, emergency response and enforcement were to be included I suspect that the fifteen per cent figure would quickly shrink well into negative territory. I came to think of PMV-based transportation as a "black hole" into which we poured endless resources, money and human lives and whose demands and wishes were impossible to satisfy. (Levinson, undated)

The ways in which transportation engineers assess the efficiency of roads and intersections also attracted my attention. It appears that the dominant engineering practice is to evaluate roads and intersections in terms of vehicle throughput versus delay. Keep the traffic moving at a brisk pace and if it slows then speed it up by expanding capacity or fiddling with the traffic signals—the extremity of which is satirically depicted in Figure 1, a sculpture erected to replace an old tree destroyed by motor vehicle pollution (Vivant 1998). Perhaps a better measure would be person throughput? Or the amount of space and time a mode consumes for a trip? Or a combination of these two? In these cases the efficiency winners would be transit, walking and bicycling rather than simply

FIGURE 1: "Traffic Light Tree," Pierre Vivant (sculptor) by permission of Weather Underground, www.wunderground.com

Yavehicular throughput and it would only be fair and proper to give these modes priority; more space, more traffic signal time (Bruun and Vuchic 1996; Bruun and Schiller 1996). Figure 2 indicates the much greater efficiency of walking, bicycling and transit compared to car-based commuting when time-area analysis is done (Bruun and Schiller 1996)

WHAT HAPPENED TO SAFETY?

The engineers' views on safety also attracted my attention as it seemed essentially to be measured in terms of reported traffic incidents and questionable standards and practices; more incidents created more points for interventions. Intersections qualified for an intervention after a certain number of traffic incidents were reported—severe crashes and deaths gained bonus points for an intervention. Urban streets qualified when the average speed was well above that posted or when too many motorists collided with trees in boulevard strips. Curiously it often seemed that the cure for speeding was to raise the speed limit or remove the pedestrian protective trees and boulevard strips rather than slowing the speeders. Or the road was widened despite credible evidence that wider roads were less safe than more narrow ones. (Hauer 2000; Pucher and Buehler 2010) To the contrary, a growing amount of evidence pointed to narrower roads and "skinny streets" as safer than wider ones. (StreetsWiki, undated; Miller 2009; Marohn 2010) Occasionally the cure for a dangerous intersection was to forbid pedestrians from crossing there and directing them to another often uncomfortably distant intersection.

Especially curious was the reporting of crashes using a measure of vehicle kilometres travelled (vkt or vkmt) as the

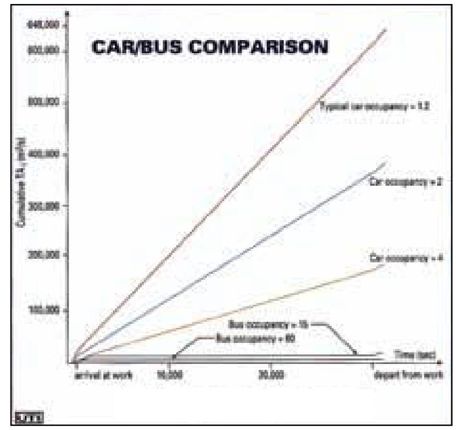

FIGURE 2: Efficiency of walking, bicycling, and transit compared to car-based commuting (used with the permission of *Urban Transport International*

denominator; asserting that the situation of pedestrians and bicyclists was improving because fewer of them were being squashed per 100,000 vkt or vmt. (The National Academies 2002; Richter et al. 2001) Or did these statistics mean that motorists were driving more? Or that motorists had to drive further to find a pedestrian or bicyclist target to squash since most were discouraged from walking and bicycling by the mounting levels of traffic and unsafe walking and cycling conditions?

Part of the problem is that road and intersection standards (Wellar 2010) are not always correct or appropriate. Or they may be correct for rural or limited access/separated roadways but inappropriate for city streets and urban traffic. Drivers on city streets should be attentive, not relaxed. They should be alert for children running into the street, vehicles stopping or veering suddenly. Their caution should be reinforced with lower speed limits and streets designed to enforce slower speeds. Then all street users will be safer.

THE OLD BAU PARADIGM HANGS ON

Despite its many shortcomings and lack of applicability to city streets and urban traffic the dominant paradigm of road expansion as the way to relieve congestion, smooth traffic flow and reduce emissions continued to dominate the field. Traffic was conceptualized as a liquid, and increased flow was accommodated by facility expansion, despite observations that traffic behaved more like a gas; as levels increased it became more dense and compressed and when some street space was reduced it often evaporated (Cairns et al. 2002; European Commission, undated;

Litman 2010). Free right turns and right turns on red were touted as ways of keeping traffic moving and reducing emissions. They were not (Newman et al. 1988; Zador 1984; Preusser et al. 2002). Road expansions were observed to generate traffic unexpectedly stimulating new and longer trips (Noland 2001; SACTRA 1994; Litman 2010), yet the highway expansion machine rolled on. Boulevard strips were eliminated to create more lanes, and stately trees shading sidewalks and houses and protecting pedestrians were removed as "obstacles" to more lanes or traffic or both (Dumbaugh 2005; Wolf and Bratton 2006). Instead of a widespread reflection upon and reconsideration of its mission and paradigm the profession continued on, with a few exceptions, with business as usual (BAU). But recent years have seen the more progressive and reflective elements of the profession articulating the need for a new paradigm.

A NEW PARADIGM OF SUSTAINABLE TRANSPORTATION

Fortunately a new paradigm of sustainable transportation is close at hand. My colleagues Eric Bruun and Jeff Kenworthy and I describe the new paradigm in our recently published book, *An Introduction to Sustainable Transportation* (Schiller et al. 2010, esp. Chapters 7 & 8). The new paradigm stresses several departures from BAU:

- *Accessibility, environment and equity trump increased PMV mobility*—the number of significant destinations that are relatively close and can be reached by walking, bicycling or public transportation is stressed rather than the BAU approach of making any and all destinations available regardless of their environmental or equity consequences.
- *Mobility management* (also known as transportation demand management or TDM) is stressed rather than reflex-like expansions of roads to meet motorists' demands.
- *Multi-modalism and intermodalism*; the provision of an array of transportation options as well as the improvement of connections between them is stressed.
- *Land use planning that supports less need for travel* and more appropriate infrastructure such as sidewalks, cycleways and quality transit that enjoys priority in traffic are stressed.
- *Healthy and safe for all* are among the recent contributions of public health and medical sectors who are recognizing the importance of regular walking, bicycling, or walking to transit as key ingredients of a healthy lifestyle.

Aspects and antecedents of the new paradigm can be traced back several decades, but the growing interest in applying new paradigm approaches to the whole range of urban transportation challenges is relatively new and growing. Many progressive engineers are identifying with new paradigm approaches: will the rest of the profession follow and begin quickly thinking and practicing outside the box of the PMV or will they continue to see transportation only through the windshield of the PMV? ■

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Dr. Shahram Hashemi Vaziri PhD
University of Waterloo, Waterloo, Ontario

Dr. Carl Haas PhD, P.Eng., FCAE
University of Waterloo, Waterloo, Ontario

Dr. Ralph Haas PhD, P.Eng., CM, FRSC, FCAE
University of Waterloo, Waterloo, Ontario

Dr. Leo Rothenburg PhD, P.Eng., FCSCE
University of Waterloo, Waterloo, Ontario

Dr. Joseph Ponniah PhD, P.Eng.
Ministry of Transportation of Ontario

Traffic Load Data from Weigh-In-Motion Systems

INTRODUCTION

Traffic load data is an essential element of life cycle management of road assets. It can consist of gross vehicle weights (GVW), equivalent single axle loads (ESAL) or individual axle and wheel load spectra, depending on the application. In a broad sense, the applications include the following:

- Pavement and bridge design
- Monitoring for planning purposes
- Compliance/enforcement

Life cycle management of road assets involves three distinct but interrelated levels: strategic, network or system wide and project or site specific (Haas 2007), with component systems including pavement management systems (PMS), bridge management systems (BMS), maintenance management systems (MMS), traffic management systems (TMS), and others. Traffic load and vehicle type or composition data is particularly important to all these systems and indeed essential to the structural design and performance modelling of pavements and bridges.

Given the need for load data, the issue then becomes one of acquiring the data in a cost-effective way, with reliability or accuracy commensurate with the application; e.g., from high volume major highways to low volume secondary or tertiary roads to research programs such as the Long Term Pavement Performance (LTPP) study in the United States and Canada (FHWA 2010).

For research programs, such as LTPP, site specific data for test sections on a continuous or frequency scheduled basis, with associated quality checks, using weigh-in-motion (WIM) sensors to acquire load spectra, is essential. Traffic counts and composition data with WIM sampling is used by a number of agencies to estimate traffic load accumulations in terms of ESAL's for the higher volume facilities. As well, for these facilities using long life or perpetual pavement designs, and AASHTO's Mechanistic-Empirical Pavement Design Guide's (MEPDG) Level 1 approach (AASHTO < 2008) requires load spectra data. Low-volume roads design can make use of more approximate procedures (TAC 1997 and 2012).

Formation of the University of Waterloo's Centre for Pavement and Transportation Technology (CPATT) in 2002, construction of the CPATT test track at the Region of Waterloo's Waste Management Facility (Tighe, Haas & Kennepohl 2004), and construction of Ontario's long life/perpetual pavement on Hwy. 401 between Kitchener and Woodstock, afforded an opportunity to install and evaluate various types of WIM sensors. In the following sections, the basics of WIM sensor types and features are first summarized, and then the CPATT test track and Hwy. 401 installations and evaluation results are described.

BASICS OF WIM TECHNOLOGY

Weigh-In-Motion is "the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle" (ASTM E 1318 2009). A WIM system should have the capability of continuously measuring axle and vehicle weights, counting their numbers, classifying into weight categories and recording speeds. ASTM groups WIM systems into four types, based on speed ranges, traffic data collection or weight enforcement use and functional performance in terms of 95% probability of ± % conformance with wheel load, axle load, axle group load, gross vehicle weight, speed and axle spacing. As well, WIM systems can be permanent or semi-permanent installations, or portable. Only permanent installations are considered in this article. Considerable research on WIM systems has been carried out in North America, Europe and elsewhere, as summarized in (Hashemi Vaziri 2011).

Operational Components and Applications of WIM Systems

WIM sensors and loop detectors produce, as main outputs, axle weight, axle spacing, axle class numbers, time of passing/speed and presence. Other data, such as wheelbase, length and gross vehicle weight are produced from these main outputs.

Types of WIM Systems

The major types of permanent WIM systems include the following: Bending Plate, Piezoelectric and Load Cell. A number of vendors exist for these systems, including a pioneering Canadian based developer/supplier/installer (see www.IRD.com). Features of the major types of WIM Systems are briefly summarized in Table 1 and in the following descriptions.

Bending Plate WIM Systems consist of steel and rubber plates with strain gauges where the signal generated is proportional to the deflection of the plate under load. They include, as a minimum, one scale and two inductive loops, but normally two scales are used. Bending plate systems have been the technology of choice in the LTPP program to acquire research quality data. Based on a pooled fund program, 28 bending plate sites have provided extensive load spectra data over the United States for over 5 years (see www.fhwa.dot.gov/pavement/ltpp). These systems have a relatively higher initial cost, and there are rigorous requirements for approach and passed smoothness, but the data is expected to be particularly valuable to calibration of AASHTO's MEPDG (AASHTO 2008).

Piezoelectric Systems are based on the transformation of a mechanical input to an electrical output, where the common materials used are quartz crystal or man-made ceramic or polymer sensors. Quartz is naturally piezoelectric and the most stable among all materials. It is not sensitive to temperature change, but has high voltage sensitivity which makes it ideal for use in voltage amplified systems. Ceramic and polymer sensors are less costly and easier to install. However, they are temperature sensitive, more prone to physical damage, subject to intrinsic degradation and require more calibration effort.

Load Cell Systems are placed perpendicular to travel direction and consist of a single load cell with two independent scales. These detect wheel weights and sum them to calculate axle weights. As shown in Table 1, a plus is relatively high accuracy, but they are also substantially higher in cost.

INSTALLATION AND EVALUATION OF WIM SYSTEMS IN WATERLOO AND HIGHWAY 401

The intent of installing and evaluating the three types of piezoelectric sensors at the CPATT Test Track in Waterloo, and quartz and polymer sensors at the Highway 401 site was to investigate the sensitivity or impact of specific climate and traffic variables. A factorial arrangement of variables was employed to enable statistical modelling and recommendations for improving sensors accuracy. Some highlights of the research, which is described in detail in (Hashemi Vaziri 2011) are presented in the following.

Table 1 – Features of Types of WIM Systems

Technology	Permanent or Portable and Speed	Likely Initial Cost Range	Features
Bending Plate	Both, but only low speed for portable	$20K+ per lane single place and $35K+ for double	± 5% error on GVW at highway speed; ± 3-5% error for double plate
Piezoelectric	Both, but only high speed for both	$10K+ per lane	± 10% error on GVW at highway speed
Load Cell (Deep Pit Installation)	Permanent and low and high speeds	$50K+ per lane	± 3% error on GVW at highway speed

NOTES: Likely cost range includes equipment and installation' expected life for all systems ranges from about 8 to 12 years.

FIGURE 1: The Highway 401 Site

Methodology of Field Work and Installations

CPATT has a test van, GVW 2.8t, which was used for installation and manual calibration of all sensors and auto calibration for the polymer and ceramic sensors at the CPATT Test Track. It was also used at the Highway 401 site (Figure 1) for installation and manual calibration of the quartz and polymer sensors.

Calibration of Sensors

Manual calibration is used to find the fixed set of calibration factors for best performance of sensors under a particular set of conditions, and for observing sensors' behaviour under changing conditions. For this purpose, the vendor's automatic calibration algorithm is provided primarily for polymer and ceramic sensors. However, the procedure is not accessible, well documented or validated and cannot be customized to specific site characteristics. Accordingly, all three sensors at the CPATT Test Track underwent manual calibration; as well, the polymer sensors were under the vendor's auto-calibration procedure periodically for experimental purposes.

The results showed that quartz sensors are not sensitive to temperature variations, as compared to the polymer and ceramic sensors which are quite sensitive. Additional results showed:

- No interaction between air temperature and speed.
- Speed has a moderately significant effect on the quartz sensors.
- Transverse location (path of axles) has a significant effect on all sensors.
- Interaction of path run and air temperature factors affects significantly the polarized piezoelectric sensors (polymer and ceramic sensors) and the vendor's auto calibration process.
- 5 km/hr bin size for speed factor seems to be appropriate for all sensors for compensation procedures.

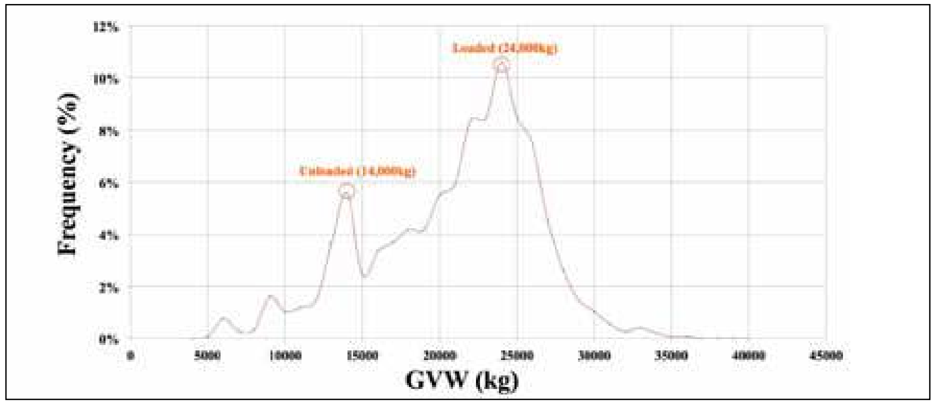

FIGURE 2A: The Load spectra at the Landfill site in July 2008.

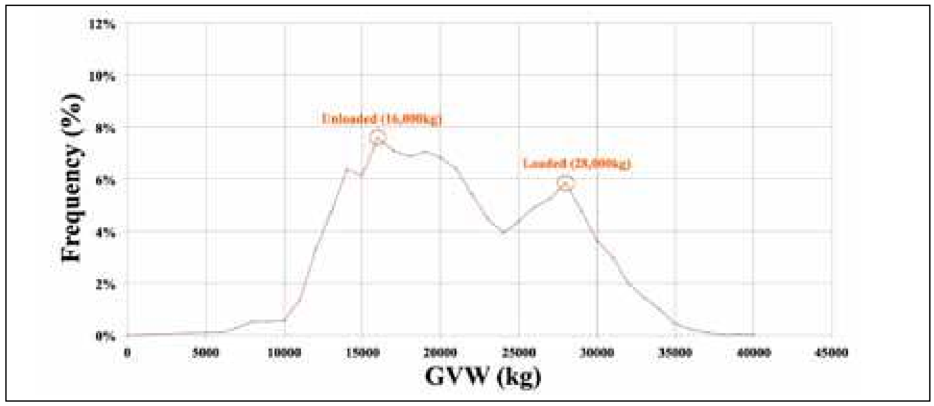

FIGURE 2B: The Load spectra at the Highway 401 site in November 2010.

- 1°C bin size for warm days (5°C to 20°C) and 2°C bin size for cold days (-12°C to 5°C) are appropriate for the polarized piezoelectric sensors (polymer and ceramic sensors).

Acquisition of Load Spectra Data

The sensors afforded the opportunity to acquire load spectra data. An example for the CPATT Test Track GVW's is shown in Figure 2A, and similar example for the Highway 401 site is shown in Figure 2B.

The ASTM definition of Weigh-In-Motion previously stated (estimating static weight from a moving vehicle), was tested with static weigh scale data from the Region of Waterloo's scale at the entrance to their landfill site (upstream). All three sensor installations are only a short distance from the scale and most garbage trucks pass over the sensors.

A straight linear relationship showed increasing variance with increasing GVW's Figure 3. However, a Box and Cox transformation, as described in (Hashemi Vaziri 2011) resulted in a stabilized variance of estimations and a very good relationship, as shown in Figure 4.

CONCLUSIONS

Weigh-In-Motion technology is quite advanced, and various WIM Systems are available and used extensively. However, in order to fulfill their intended purpose of estimating static weights with reasonable accuracy, a number of factors need to be taken in to account. These relate to operational effectiveness, reliability and service life. Proper calibration is essential, and this includes the effects on sensor response of temperature to speed, transverse location of axle loads and other factors.

The University of Waterloo's Centre for Pavement and Transportation Technology, CPATT Test Track and a Highway 401 long life/perpetual pavement, afforded a unique opportunity to install and evaluate three commonly used WIM systems involving quartz, ceramic and polymer sensors. Data from these installations has provided valuable knowledge on sensor performance, on their advantages and limitations, and on future directions for WIM research.

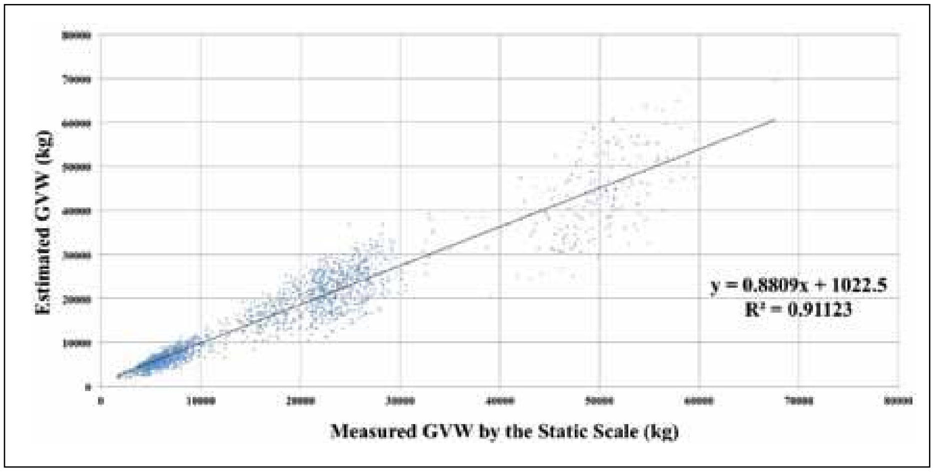

FIGURE 3: Polymer sensor estimations of GVW versus static weight measurements at the Landfill site in July 2008.

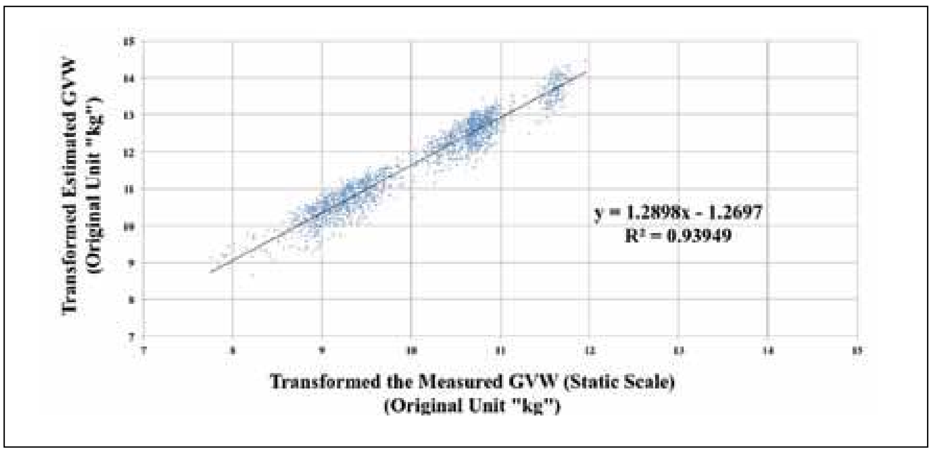

FIGURE 4: Transformations of GVW for the polymer sensor estimations versus static weight measurements at the Landfill site in July 2008.

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ONE-ITS: Intelligent Transportation Systems Without Borders

Dr. Mohamed El-Darieby

Software Systems Engineering
University of Regina, Regina, Saskatchewan

Dr. Baher Abdulhai P.Eng.

Department of Civil Engineering
University of Toronto, Toronto, Ontario

ONE-ITS: A SERVICE-ORIENTED PLATFORM

While ITS creates new opportunities for enhancing transportation, those opportunities come with challenges that require rigorous R&D. The nature of ITS R&D is complex due to a number of reasons including:

- Current ITS solutions are mostly stand-alone systems that are used by a small group of users with little or no support for larger scale collaboration and integration. A vivid example is the incompatible software platforms at different traffic operation centers.
- Advancing ITS applications is typically a labour-intensive and slow process because of using "older" technologies, architectures and programming languages.
- Currently, there are very limited efforts to enable remote sharing and "integration" of ITS infra- and info-structures. ITS applications and services often do not make use of high performance computing technologies for processing and storage of real-time traffic information and services.

The purpose of this article is to introduce how to alleviate the concerns above to enable building ITS R&D applications using the *ONE-ITS* (Online Network-Enabled Intelligent Transportation Systems) Platform. We also introduce *ONE-ITS* to the community and to invite them to start using it.

In general, ITS business operations typically involve the execution of many distributed business processes. Real-life ITS operations often cross the organizational boundaries where business processes enacted by different organization may interact. An operational workflow controls the sequence of execution of these processes. Business workflows orchestrate service interactions in order to perform a specific business operation. Therefore, ITS operations can be divided into two levels, the service/process level and the application level.

At the service/process level, ITS business processes, intelligence, and infrastructure are implemented in *ONE-ITS* as web services. Within *ONE-ITS*, ITS software and ITS deployed infrastructure are viewed as services with open and standard interfaces. Services are modular components that are self-contained with the ability to advertise their capabilities and with well-defined interfaces that enable collaboration with other services. Service-oriented Architecture is a paradigm for designing and implementing business collaborations within and across organizational boundaries. SOA define, build, compose, and orchestrate software services as required by business operations. SOA adopts loose coupling between services in a workflow in order to be able to respond efficiently to changes in business and technology.

Using *ONE-ITS* allows member stakeholders to exchange and share ITS data, information, knowledge, resources, expertise and services. *ONE-ITS* uses the proven principles of IT production, namely, Service-Oriented Architecture (SOA) technologies to build an integrative environment. *ONE-ITS* creates a Virtual Organization (VO) that brings together stakeholders from the academic, private, and public sectors.

On the VO side, *ONE-ITS* enables the exchange of not only information but also of knowledge among ITS stakeholders during the planning, design, and management of ITS systems. This is realized through a dynamic distributed system that allows various organizations to collaborate, providing value and benefit. A VO is established through linking the work processes, product, data and decision makers in various organizations in order to synchronize and integrate the elements of ITS projects. The target range of stakeholders involved includes researchers; government agencies; local operators; vehicle manufacturers; consultants with extensibility all the way down to individual travelers. The roles of ITS stakeholders are customizable with the ability of including more stakeholders as needed. *ONE-ITS* has international members from Canada, the US, and Africa.

On the service-oriented architectural side, *ONE-ITS* depends on SOA to support VO management. The core concept is to allow ITS stakeholders to establish business cases and capture the related business logic in business models through the mother VO or, in the future, through dynamic dissolvable smaller VOs. These business models are realized in the form of ITS foundational, task, and application services. These services integrate ITS data and services provided by different stakeholders. *ONE-ITS* allows VOs and stakeholders to perform these tasks in collaborative efforts of communities of practices and interests.

Combining SOA and VO is the height of what IT promises in terms of flexible application *integration* in response to changes in requirements.

ONE-ITS ARCHITECTURE

The *ONE-ITS* architecture is organized into service layers, depicted in Figure 1, and described below.

Applications Services

Since *ONE-ITS* is based on SOA, it enables stakeholders to build independent as well as "mashup" applications. A mashup application combines *ONE-ITS* services with other services sourced from different parties into a single new service/application. A simple vehicle-routing system, for instance, could be an application that consumes lower applications such as mapping and GIS services, and could be consumed by a higher application that manages traffic across a corridor or a network. To facilitate software interaction, software providers grant access to their services through open Application Programming Interfaces (API). SOA allows ITS applications and mashups to interact through only their API as the functionality of any ITS service is completely conveyed by its API. Mashups exemplify the height of creativity enabled by *ONE-ITS* as it may result in new breed of services that were not necessarily perceived at the time of designing and developing the original ITS services. ITS Mashups allow end users and researchers as well as industrial and government partners to tap into resources and expertise provided by SOA and *ONE-ITS*. A larger community can access these resources and expertise that may have significant transformation on the original services. An example of an application in this layer is multi-agency collaborative or integrated traffic control, where a provincial highway agency interacts with a municipal counterpart to control traffic along a major corridor that includes a freeway, a number of parallel arterials and transit networks. Through web services and mashups, one can easily envision the endless and snowballing potential of *ONE-ITS*.

Foundational Services

This layer includes long-running services that are the basic building blocks of a multi-step ITS operational workflow. Foundational services can also be stitched together to compose other novel foundational services. Examples of foundational services include data aggregation and visualization services, traffic flow models, simulation services, optimization engines and so on. *ONE-ITS* "Foundational Services" are not viewed as only providing software logic but also as providing access to different physical hardware resources, instrumentation, and databases as well. This allows users to link together different infrastructure services with software services in order to build applications mashups.

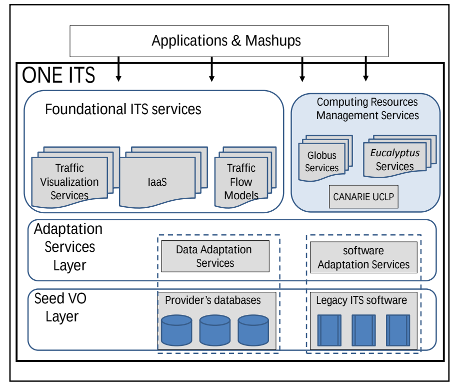

FIGURE 1: A high-level Architecture of ONE-ITS.

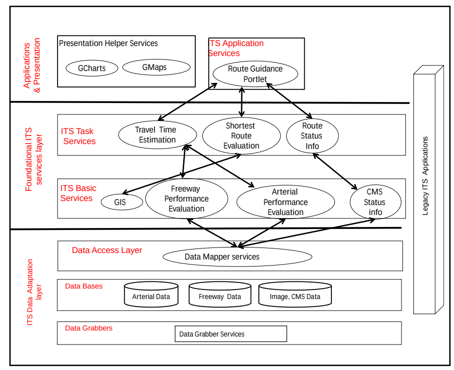

FIGURE 2: ONE-ITS web services involved in the route guidance Application.

Adaptation Services

Adaptation services allow the reuse of already-existing ITS applications and offer a single, consistent point of access to timely, accurate, and integrated data. On one hand, these services enable interactions with existing ITS applications (a.k.a., legacy systems). On the other hand, adaptation services carry out necessary conversions to ITS data in a transparent manner. This provides two major advantages; firstly, local information providers and or users do not need to redesign their data management systems. Secondly, this results in decoupling the consumers from the databases' schemas and locations. Various database and data types can then be accessed through consistent interfaces and will provide data in standard format. An example adaptation service is XML based ITS data administration services and ITS data monitoring services to trace what data is being used and by whom.

Resource Management Services

ONE-ITS relies on resource management services to provide a high performance, high throughput, and flexible environment with high quality-of-service. These services allow

ITS organizations to consolidate IT resources and optimize usage, reducing infrastructure and labor costs and create an interoperable computational platform where resources are automatically augmented or diminished based on business requirements. *ONE-ITS* manages resources including application servers, database servers, grid computing nodes, and networks. This enables, for example, the storage of very large amounts of data on shared resources. Another example is the parallelization of computationally demanding applications such as large-scale multi-modal emergency evacuation models, dynamic road pricing models and network wide traffic control systems.

ONE-ITS MASHUP APPLICATION EXAMPLES

ONE-ITS mashed up applications can range from very simple to extremely complex as we climb up the layers of *ONE-ITS*. A simple mash up could be a routing application, providing travellers and or fleet operators with routing recommendations based on live or predicted traffic conditions. This mashup uses *ONE-ITS* traffic data services and video streaming service and integrates live traffic data within a city like Toronto from multiple sources such as the City of Toronto and the Ministry of Transportation of Ontario and potentially private sector data. The mashup application combines travel time estimates with incident and work zone data provided by MTO and the City of Toronto and weather data provided by Environment Canada and presents the results on a map provided by Google, or a GIS system. By clicking on the generated map, real-time traffic pictures and videos can be shown to the travellers, the fleet manager and to truck drivers. The pictures and videos are tagged with GPS location, time, date and other comments.

A more complex mashup example is an international-award-winning state of art system for emergency evacuation optimization developed at the University of Toronto. The system utilizes *ONE-ITS* data, simulation, optimization, control and grid computing services (all the lower layers) to optimize *when* different evacuees should depart (evacuation temporal profile), *where* they should go (spatial distribution profile) and *how* they get there (dynamic traffic routing and assignment). For evacuees with no cars, transit shuttles are dynamically routed between pick up points and safe shelters to move people out of harms way.

Figure 2 shows how this is implemented in the *ONE-ITS* technical architecture. This example illustrates an ITS business mashup that combines different types of other mashups. The mashup application involves "data mashups" that mix and process data from different sources, internal or external to an enterprise (a freight company). It also involves "service mashups" by interacting with services provided by *ONE-ITS*.

In conclusion, ITS experts and stakeholders are holding their breath for all the possibilities that "connected vehicles" will bring in the near future. Now imagine what "connected vehicles, infrastructure, info-structure, data, systems, computers, travellers, operators and stakeholders" can do! Welcome to *ONE-ITS* (www.one-its.net). ■

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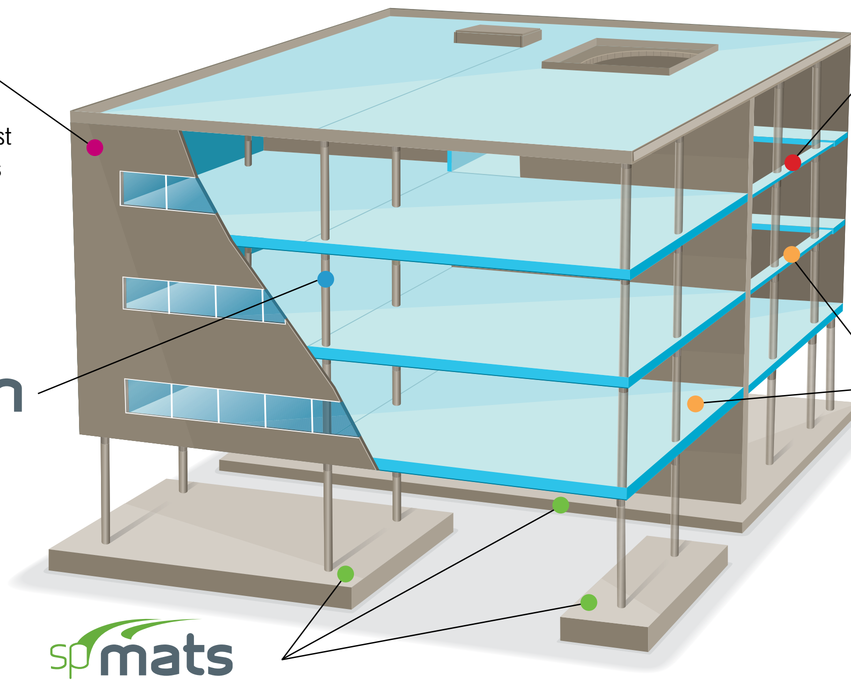

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Dr. A.O. Abd El Halim P.Eng., FCSCE, FCAE
Department of Civil and Environmental Engineering
Carleton University, Ottawa, Ontario

Dr Said M. Easa P.Eng., FCSCE, FCAE
Department of Civil Engineering
Ryerson University, Toronto, Ontario

Pavement Recycling: New and Innovative Technologies for Sustainable Roads

Pavement distresses can lead to significant reduction in the service life of the asphalt pavements, while compromising the safety and comfort of road users. They also require increased expenditures to mitigate them. These factors have led to development of innovative methods to rehabilitate existing pavements in more economical and effective ways.

The traditional method of asphalt pavement rehabilitation and reconstruction is hot in-place recycling. The process uses a specialized train to heat the surface of the pavement which allows a specified portion of the existing layer to be scarified, rejuvenated, remixed, and replaced in a multi-step on-site process. The disadvantage of this method is that heating the existing asphalt materials can cause release of gases emission which is not environment friendly, besides the additional cost of heating the asphalt. As a result, during the past decade cold in-place recycling (CIR) has been introduced as a new innovative method for restoring deteriorated asphalt pavements. The reported field success of several CIR projects has attracted significant interest from provincial governments and municipalities.

This article highlights various aspects of CIR, including basic technology, expanded technology using foamed asphalt, design and construction, benefits, and potential

compaction technology. Before describing these aspects, it is useful to describe the traditional process of milling and grinding.

THE PROCESS OF MILLING AND GRINDING

Cold Milling is the automatically controlled removal of pavement to a desired depth with specially designed equipment, and restoration of the surface to a specified grade or slope, free of humps, ruts, and other imperfections. The resulting milled surface can be used as a driving surface until it is overlaid with a layer of hot asphalt mix. *Grinding* is generally used with rebating which is the grinding along the pavement edges where concrete curb or sidewalk meets an asphalt edge. Grinding or rebating is done to ensure that there is no lip between surfaces that can be a trip hazard or unsightly. In this process, the existing asphalt layers are only milled and loaded to a truck to be either stockpiled away or on-site for future processing.

PAVEMENT STRUCTURE BEFORE AND AFTER CIR

A cross section of a typical existing asphalt concrete pavement layout is shown in Figure 1a. The layout includes four components: Asphalt Concrete (AC), granular base, subbase, and subgrade. The CIR process involves cold milling of one third to two thirds of depth of the pavement surface material and remixing it with the addition of emulsified asphalt or foamed asphalt, followed by placing and laying of the reprocessed material and completing the operation by compacting in one continuous operation. The bottom portion of the milled existing asphalt concrete remains untouched throughout the rehabilitation process. The new asphalt overlay is added to provide a smooth riding surface for vehicles. The existing untouched asphalt concrete and the CIR asphalt layer become two binder courses for the new pavement (Figure 1b).

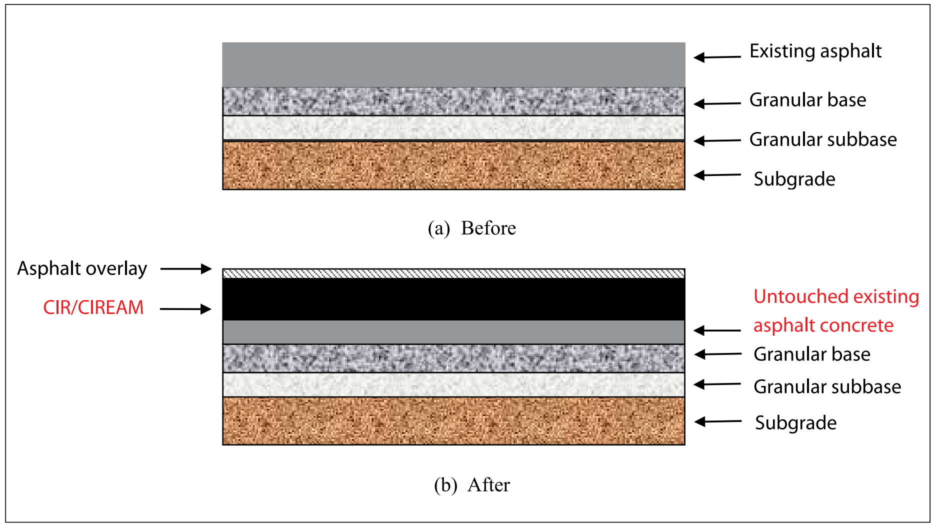

FIGURE 1: Pavement layout before and after CIR/CIREAM rehabilitation.

CIR TECHNOLOGY

The CIR process consists of mixing a recycled crushed asphalt pavement with emulsified asphalt and water. The asphalt emulsion plays a significant role in adhering the asphalt pavement components as it is applied at normal temperatures. In this process, a portion of the existing asphalt concrete is milled, screened for oversize, and asphalt emulsion is added and mixed. The new mixture is placed and spread on the roadway as a base using conventional paving and compaction equipment to form a consistent, stabilized base. The CIR is generally used as a rehabilitation procedure to strengthen the pavement structure as a base layer, during this process additives including Portland cement, quick lime, and fly ash may be added prior to mixing as needed. A new layer of hot mix asphalt or thin surfacing is then applied as the riding asphalt surface (Salomon and Newcomb 2000).

Figure 2 illustrates the steps using a 'train' of equipment to complete the CIR operation. The CIR train consists of a milling machine and mobile screenings/crushing deck. The train then feeds the reclaimed asphalt pavement (RAP) into a paver that adds the emulsion and places the material. The material is then conveyed into a heavy duty paver with dual tamping bars. The milling process is only one of several simultaneous tasks for completing the entire job. Note also that in the CIR operation, asphalt is added as a binder while the entire operation is running (i.e. without delay due to transporting the recycled material off-site).

It should be noted that CIR is often used on low traffic volume roads or secondary roads where a central hot mix plant may not be convenient for obtaining new hot mix asphalt (HMA) overlay (FHWA 2003). The technology can also be used on high volume roadways as a mitigation layer for cracking in conjunction with HMA overlay. The CIR asphalt layer can be opened to regular traffic shortly after compaction. In Iowa Department of Transportation projects (and in many U.S. states), the CIR layer is used as the driving surface during the period of time between the CIR rehabilitation and placing of the HMA overlay. In fact, previous successful CIR projects with traffic on the CIR layer carried up to 400 trucks per day, and a number of states apply the CIR technology on heavy truck routes (Heitzman 2007).

CIREAM TECHNOLOGY

A recent development in CIR is cold in-place recycled expanded asphalt mix (CIREAM). The technology uses expanded (foamed)

FIGURE 2A: Cold In-place Recycling (CIR) train (Chan et al. 2009).

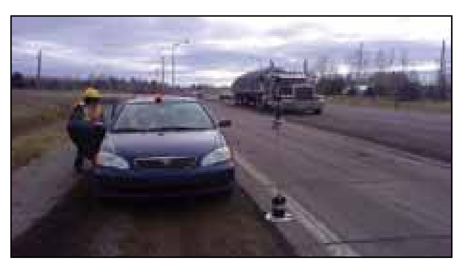

FIGURE 2B: Cold In-place Recycling. Finished CIR asphalt pavement (Abd El Halim et al. 2011).

FIGURE 3A: Cold-In-Place Recycling with Expanded Asphalt (CIREAM).
CIREAM train (Lane and Kazmierowski 2005b).

FIGURE 3B: Cold-In-Place Recycling with Expanded Asphalt (CIREAM).
Placing and compacting of CIREAM (Lane 2011).

asphalt instead of emulsified asphalt to bind the mix. Foamed asphalt is formed by injecting small quantities of cold atomized water (1%) under pressure into hot asphalt binder which is pumped through an expansion chamber installed on top of the cold recycling unit. On contact with the binder, the water becomes steam and creates a large number of tiny bubbles within the hot asphalt cement causing it to rapidly expand, producing a compound termed "asphalt foam" which is mixed with pulverized asphalt pavement materials on the job site. As the mix cools, the steam evaporates leaving the binder-coated aggregates in place as a stabilized base course. Because its surface area is greater than that of regular emulsified asphalt, foamed asphalt mixes are more easily used with recycled pavement materials (Maloney 2009).

Foamed asphalt is commonly used with cold in-place recycling and partial depth reclamation of asphalt pavements. The process involves pulverizing, reprocessing and re-compacting existing pavements at the end of their service life to create a new base course rather than completely removing the old material. As with conventional CIR, the material is then profiled and compacted to form a binder course layer.

Similar to the CIR train, the CIREAM train (Fig. 3) consists of a milling machine and mobile screenings/crushing deck. However, in this case, the CIREAM train feeds the processed RAP into an on-board pug mill, where the expanded asphalt is added and mixed. The material is then conveyed into a heavy duty paver with dual tamping bars in the screed (Lane and Kazmierowski 2005b). The construction of CIREAM rehabilitated pavement involves the following steps (Lane and Kazmierowski 2005): (a) setup road closure and traffic protection, (b) cold milling the existing pavement and sizing, mixing, and laying of the CIREAM asphalt mix, followed by compaction, (c) cure CIREAM asphalt layer for a minimum of two days, (d) sweep and clean the cured surface, (e) provide tack coat to CIREAM asphalt layer to enhance adhesion, and (f) provide new asphalt overlay and compaction of final surface.

DESIGN AND CONSTRUCTION CONSIDERATIONS

The design of CIR mixes is generally performed using Marshall or Hveem design methods with optimizing the water content and the emulsion (Asphalt Institute 2009). The CIR mix specimens may be evaluated using indirect tensile strength or resilient modulus testing methods (Das 2005). Other mix design methods are proposed by different states in the U.S., such as California, Kansas, and New Mexico, which are variations of the basic bituminous mix design procedures. Superpave-based mix design protocol has also been developed for CIR (FHWA 2002). The amount of emulsion to be added is calculated from the water to bitumen proportion in the emulsion.

Since the CIR mix is more viscous than conventional hot-mix, heavier rollers are required. A successful CIR operation will require more compaction than the placement and finishing of a conventional hot asphalt mixture. The use of one heavy pneumatic roller combined with one double drum vibratory roller is generally sufficient to achieve the desired compaction. The minimum compaction requirement specified by the Ministry of Transportation of Ontario (MTO) is generally 96% of the Marshall density using field specimens. Generally, about two weeks of curing time is required during favorable weather conditions after which a suitable seal coat or hot mix overlay is applied for traffic (Abd El Halim et al. 2011).

BENEFITS OF CIR AND CIREAM TECHNOLOGIES

Conventional methods for rehabilitation and reconstruction of existing pavements can generate a significant amount of waste. Aged asphalt pavement rehabilitation is traditionally accomplished by milling the aged cracked asphalt layers resulting in stockpiling the milled material which could be added it to the hot mix or be used as a granular base. CIR has changed this costly practice by allowing new layers to be obtained from old distressed materials and therefore reducing the use of new materials. Thus, the process is environment friendly. In addition, the economic benefits of CIR arise from the savings resulting from the reuse of materials of the existing pavement, the reduced cost associated with transporting new material to the site, and the payments for disposal fees (Martinez et al. 2007). It has been estimated that pavement recycling could decrease the road maintenance costs by almost half when compared to conventional methods.

Note that the achieved benefits of CIR are not realized at the expense of structural performance. The CIR layers have been reported to exhibit satisfactory to excellent structural behaviour especially when constructed properly. However, their mechanical characteristics and behaviour differ from those of conventional hot mix asphalt structures. Their elastic modulus is smaller than that of most hot bituminous mixtures, but their fracture is more of plastic and ductile, allowing the movement of existing cracks in the underlying pavement to be partially absorbed (Martinez et al. 2007). Also, another benefit of CIR is its relative lower stiffness during construction which reduces the amount of construction induced cracks in the surface layer (Luter and Abd El Halim 1998). For CIRCREAM, the major advantage is that a new HMA surface can be applied following a two-day curing period.

POTENTIAL COMPACTION TECHNOLOGY

One of the main concerns with realizing the full potential of CIR and CIREAM technologies is the curing time required before applying the overlay. One possible solution is to examine the potential of using the compaction method known as Asphalt Multi-Integrated Roller (AMIR) which was developed at Carleton University in the early 1990's (Abd El Halim and Haas 2004 and 1995, Abd El Halim et al. 1993, Abd El Halim and Easa 1998). The use of AMIR may provide a tight texture that protects the compacted CIR or CIREAM and achieves a layer with higher density. In addition, the AMIR compaction technology has been effective in substantially reducing pavement cracks for newly constructed asphalt pavements and it is expected to achieve the same benefits for the CIR/CIREAM pavements.

Aged asphalt pavement rehabilitation is traditionally accomplished by milling the aged cracked asphalt layers resulting in stockpiling the milled material which could be added it to the hot mix or be used as a granular base. CIR has changed this costly practice by allowing new layers to be obtained from old distressed materials and therefore reducing the use of new materials.

LOOKING AHEAD

Despite the benefits and the advances in the CIR/CIREAM technology in Europe and elsewhere, its use is still relatively new to Canada and the United States. A number of areas require attention in the future. First, there is a need to establish best practices for provincial and municipal governments on what makes CIR/CREAM valuable to them and what actions taken that made a difference in using the process, making it work, and having the industry as a partner. Second, there is a need for better education that targets pavement designers/consultants, and decision makers, for nationwide synthesis of past research and information on long-term performance, for results on CIR uses on higher volume roads, better documentation on performance of surface treatments over CIR, and for development of design, curing time, and moisture content specifications for these new technologies. Third, quality control and quality assurance criterion specifically intended for the presented pavement recycling technologies are required. Finally, field tests are needed to evaluate the effect of the use of the AMIR compaction technology on the curing period of the CIR/CIREAM mixes. ■

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CHANDAN PUJAPANDA AND SHERIF KINAWY, DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF TORONTO

CSCE University of Toronto's Student Delegation to Hong Kong—Summer 2011

A CSCE chapter in Hong Kong: it came as a surprise to us as two Civil Engineering graduate students in Toronto. However, we soon realized the nature of the industry in Hong Kong promoted a significant level of professional and academic exchange with Canada. For one, many of the new graduates who work in Hong Kong have completed their degrees from Canadian universities. As we also found out later, several of the professors at Hong Kong universities had spent some time engaged in academic and professional work in Canada. Additionally, many of the current students consider Canada for postgraduate research.

This exchange started when Bill Jin from Hong Kong University for Science and Technology (HKUST) approached Professor Shamim Sheikh to invite the University of Toronto among other Canadian universities to join them for an exchange forum in June in Hong Kong. This led to two students accepting the invitation on behalf of the University of Toronto to join Ryerson University in representing CSCE's local Canadian chapters. Chandan is currently studying towards his MEng degree and brings four years of practical civil engineering experience to the table. Sherif is currently working on his PhD thesis in construction management.

In a manner typical of many inquisitive civil engineers traveling to Hong Kong for the first time, our goal was to tap into the ingenuity behind the fast paced infrastructure projects in Hong Kong, a form of practice necessary to establish a balance between the growing population and limited space for land development. The focus on innovative design and low impact implementation techniques is evident in Hong Kong Island where facilities such as water reservoirs and waste water treatment plants are cleverly concealed within the natural landscape to preserve valuable space for residential and commercial development.

Our delegation was overwhelmed by the density of massive construction projects in the heart of downtown Hong Kong, orchestrated by joint partnerships between the Hong Kong Government and international General Contractors. During visits to construction sites we had the opportunity to experience first-hand a few unique techniques and disciplines of civil engineering, such as dredging, land reclamation, slope stability, tunnel engineering, and deep excavation.

In addition, our role was to showcase advancements in the Canadian civil engineering practice and to participate in facilitating the exchange of knowledge and ideas with HKUST, the Institute of Vocational Education (IVE) and the ASCE Chapter from Tsinghua University, Beijing, all important contributors to this exchange forum. We successfully provided an overview of our practices to promote the chapter to our students on campus and the various events and competitions we regularly hold. Finally, we parted with promises to take our collaboration further, motivated by the shared belief that students who become engaged in CSCE at an early stage would eventually develop to become more successful professionals upon graduation.

We look forward to future opportunities for collaboration and strongly recommend similar events to other student chapters. We would like to thank the Department of Civil Engineering at HKUST for their invitation and hosting us during our stay in Hong Kong. ■

FIGURE 1: Picture taken at Hong Kong Institute of Engineers (HKIE).
People in picture from left to right—Kemoo El Sayed (Ryerson University), Sherif Kinway (U of T), George Cheng (President of HKIE), Chandan Pujapanda (U of T), Ahmad Hussein (Ryerson University).

FIGURE 2: Picture was taken on a Tram.
People in picture from right to left—Anthony Leung (HKUST), Sherif Kinway (U of T), Antonio Ni (HKUST), Chandan Pujapanda (U of T), Ada Chung (HKUST), Bill Jin (HKUST), 3 members from Tsinghua University (Beijing, China).

Délégation étudiante de l'Université de Toronto à Hong Kong—été 2011

Une section de la SCGC à Hong Kong : pour nous, deux étudiants en génie civil de Toronto, c'était toute une surprise. Nous nous sommes cependant vite rendu compte que l'industrie à Hong Kong justifiait un niveau élevé d'échanges professionnels et universitaires avec le Canada. Ainsi, nombre de récents diplômés oeuvrant à Hong Kong avaient obtenu leur diplôme d'une université canadienne. Plus tard, nous avons aussi découvert que plusieurs professeurs des universités de Hong Kong avaient passé une partie de leur carrière professionnelle ou universitaire au Canada. En fait, nombre d'étudiants songent à aller faire des recherches de troisième cycle au Canada.

Cet échange a débuté lorsque Bill Jin, de la « Hong Kong University for Science and Technology (HKUST) » a demandé au professeur Shamim Sheikh d'inviter l'Université de Toronto, entre autres universités canadiennes, à faire partie d'un forum d'échange, en juin, à Hong Kong. Ainsi, deux étudiants ont accepté l'invitation, au nom de l'Université de Toronto, à se joindre à l'Université Ryerson pour représenter les sections locales de la SCGC au Canada. Chandan Pujapanda est présentement inscrit pour obtenir une maîtrise en génie, et il compte quatre années d'expérience en génie civil. Sherif Kinawy rédige présentement sa thèse de doctorat en gestion de la construction.

Comme bien d'autres ingénieurs civils qui visitent Hong Kong pour la première fois, notre but était d'étudier l'ingéniosité qui se cache derrière la construction rapide d'infrastructures à Hong Kong, une forme de pratique nécessaire pour trouver un équilibre entre la croissance de la population et la quantité limitée de terrain pour le développement. L'importance d'un design novateur et de techniques de réalisation à faible impact est évidente sur les îles de Hong Kong, où des installations comme les réservoirs d'eau et des usines de traitement des eaux usées sont subtilement dissimulés dans le paysage afin de préserver l'espace disponible pour des fins résidentielles et commerciales.

Notre délégation a été impressionnée par la densité des chantiers énormes au centre-ville de Hong Kong, orchestrés par des partenariats entre le Gouvernement de Hong Kong et des entrepreneurs généraux internationaux. Lors des visites de chantiers, nous avons pu découvrir quelques nouvelles techniques et disciplines du génie civil, notamment en matière de dragage, de remise en état des terrains, de consolidation des talus, de tunnels et d'excavation en profondeur.

En outre, notre rôle était de souligner les avancées dans la pratique du génie civil canadien et de participer à l'échange d'idées et de connaissances avec le HKUST, l'« Institute of Vocational Education (IVE) » et le chapitre de l'ASCE de l'Université Tsinghua, à Beijing, qui sont d'importants joueurs dans ce forum d'échange. Nous avons réussi à présenter un aperçu de nos pratiques pour faire la promotion de nos élèves sur notre campus ainsi que des diverses activités et concours que nous organisons périodiquement. Enfin, nous nous sommes quittés en nous promettant de pousser notre collaboration, motivés par la conviction que des étudiants engagés très tôt dans la SCGC deviennent de meilleurs professionnels lorsqu'ils obtiennent leur diplôme.

Nous anticipons de futures occasions de collaborer ainsi et nous recommandons fortement aux autres sections étudiantes de participer à de telles activités. Nous remercions le département de génie civil de la HKUST de nous avoir invités et de nous avoir accueillis pendant notre séjour à Hong Kong. ■

DOUG SALLOUM BSC, MBA, PMP, EXECUTIVE DIRECTOR / DIRECTEUR EXÉCUTIF

There are two items I would like to update you on: the progress we are making on Vision 2020 and recent initiatives to support students and Young Professionals in CSCE.

CSCE Executives at all levels have been working on a new vision for our Society, which we refer to as Vision 2020—Leadership in Sustainable Infrastructure. Your representatives at the Section, Regional, National Committees and Board levels have been discussing, drafting and reviewing the Vision 2020 and its associated Business Plan for much of the last year. This is a complex process with far-reaching implications so everyone involved has tried to be attentive to as many comments and suggestions as possible. We hope to communicate the results of this process early in the New Year, in a manner that will inform, interest and inspire all members of CSCE.

In the meantime, I know that there are some members who worry, as we move into new areas of activity, that we will abandon or reduce emphasis on services they have come to value and expect from CSCE. I want to respond clearly to this concern. Your Board of Directors, National Committees and Division Chairs, Regional VPs and Section Chairs will never let that happen.

CSCE is a learned society and will always be a learned society. CSCE will always provide technical and professional services to its members, including; technically oriented conferences, Section level presentations and networking opportunities, professional development courses, national lecture tours, CIVIL magazine, awards and fellowships and participation in the Canadian Journal of Civil Engineering. Vision 2020 will not take anything away from these services. Vision 2020 will instead add a number of new initiatives to what CSCE already does. These additional activities will provide CSCE members, if they are so inclined, with opportunities to contribute to the larger Canadian society.

The goal of Vision 2020 is to influence how public infrastructure is built in this country. $400 billion must be invested in infrastructure over the next generation. This time this huge investment must result in sustainable infrastructure—long lived, adaptable, inexpensive to maintain and sensitive to the social and natural environments in which it will operate. The Executives of CSCE are excited about this vision and the opportunities it will offer our members. I hope you will be excited by what we communicate further to this vision in the New Year.

Now—on to my second topic. National Office has hired Peter George to work on student and Young Professional member activities. Peter will support Lynne Cowe-Falls and Amie Therrien (Chairs of Student Affairs and Young Professional Committees respectively). This position is a major new commitment on the part of National Office. Members have been saying for years that attracting and retaining younger members is essential to the future of CSCE. We are investing in that future.

Peter is working on a growing number of projects, including the following:

- Site visits for the Montreal Student Chapters
- Creation of a Student Activities Funds
- Young Professional Workshops
- Certification of National Student Competitions

I know I can count on your support for these and other younger civil engineer initiatives that Amie, Lynne and Peter will be rolling out over the next year.

Any comments or questions?

Voici les toutes dernières nouvelles sur deux sujets importants : nous faisons des progrès dans le dossier Vision 2020, et nous avons pris des initiatives pour aider les étudiants et les jeunes professionnels à la SCGC.

À tous les niveaux, les dirigeants de la SCGC s'emploient à créer une nouvelle SCGC, basée sur « Vision 2020—Pour un leadership en matière d'infrastructures durables ». Vos représentants au niveau des sections, des régions, des comités nationaux et du c.a. ont étudié durant une bonne partie de l'année et sous toutes les coutures le document Vision 2020 et le plan d'affaires qui y est associé. Il s'agit d'une démarche complexe qui aura d'importantes répercussions. C'est pourquoi tous les participants ont porté attention aux commentaires et aux suggestions formulées. Nous espérons vous communiquer les résultats de cette démarche au début de l'an prochain, d'une façon qui renseignera, intéressera et inspirera tous les membres de la SCGC.

D'ici là, je sais que certains membres vont s'inquiéter et craindre que nous nous lancions dans de nouveaux domaines et que nous abandonnions ou réduisions des services existants fort appréciés et généralement associés à la SCGC. Je tiens à vous rassurer : votre c.a., vos comités nationaux, vos présidents de divisions, vos vice-présidents régionaux et vos présidents de sections ne permettront pas que cela se produise.

La SCGC est une société savante et entend le demeurer. La SCGC va toujours fournir des services techniques et professionnels à ses membres, dont des congrès axés sur les techniques, des exposés et des possibilités de réseautage au niveau des sections, des cours de perfectionnement, des tournées nationales de conférences, la revue L'ICC, des prix et des titres de « fellow », et une participation à la Revue canadienne de génie civil. Vision 2020 n'enlèvera rien à ces services. Vision 2020 va plutôt ajouter des initiatives nouvelles à ce que fait déjà la SCGC. Ces activités additionnelles donneront aux membres de la SCGC qui s'y intéresseront des occasions de contribuer à la vie de la société canadienne.

Le but de Vision 2020 est d'influencer la construction des infrastructures dans ce pays. 400 milliards de dollars seront dépensés dans les infrastructures au cours de la prochaine génération. Cette fois-ci, cet énorme investissement devra produire des infrastructures durables, qui auront une vie prolongée, qui seront adaptables, peu coûteux à l'entretien, tenant compte de l'environnement social et naturel. La direction de la SCGC se réjouit de cet idéal et des occasions qu'il offrira aux membres. J'espère que vous aussi serez séduits par ce que nous vous annoncerons à ce sujet au début de l'an prochain.

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SECTION NEWS

BY LISA R. FELDMAN NLT COORDINATOR

Coast-to-Coast Tsunami Hits Canada!

The Fall 2011 National Lecture Tour featured Dr. Ioan Nistor, Associate Professor of Hydraulic and Coastal Engineering at the University of Ottawa, presenting "Engineering Significance and Lessons of the March 11, 2011 Tsunami in Japan: Tsunami Impacts on Infrastructure." The lecture highlighted the performance and damage of infrastructure caused by the massive tsunami waves that resulted from the magnitude 9.0 earthquake that occurred along Japan's Sanriku Coast the afternoon of March 11, 2011. Dr. Nistor was part of a team that conducted reconnaissance investigations of the affected areas four weeks after the event on behalf of the American Society of Civil Engineers (ASCE).

The National Lecture Tour was presented in eleven cities over a ten-day period. A total of 525 attended from coast (Victoria, BC) to coast (St. John's, NF). Pictured, from left to right, at the Regina, SK tour stop on September 21, 2011 are: Dr. Jim Kells, CSCE President-Elect and Professor & Department Head, Department of Civil and Geological Engineering, University of Saskatchewan; Dr. Ioan Nistor, NLT Lecturer and Associate Professor of Hydraulic and Coastal Engineering, University of Ottawa; Dr. Lisa Feldman, CSCE NLT Coordinator and Assistant Professor, Department of Civil and Geological Engineering, University of Saskatchewan; and Mr. Harold Retzlaff, CSCE Prairie Region Vice-President, and Chair, CSCE Regina Section.

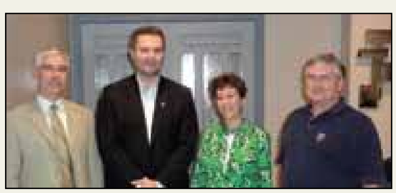

PHOTO (L–R): Jim Kells, President-Elect; Ioan Nistor, NLT Speaker; Lisa Feldman, NLT Coordinator; Harold Retzlaff, Prairie Region VP.

COMING EVENTS / CALENDRIER DES ACTIVITÉS

Domestic Venues

ACMBS-VI
Kingston, ON
May 22–25, 2012
http://www.acmbs2012.ca

2012 CSCE Annual General Meeting and Conference
Edmonton, AB
June 6–9, 2012
http://www.csce2012.ca

15th International Specialty Conference on Cold Regions Engineering
Quebec City
August 19–22, 2012
http://www.csce.ca/2012/iccre

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Voici maintenant ce que j'ai à dire sur mon deuxième sujet : la permanence de la SCGC a embauché Peter George pour s'occuper des activités à l'intention des étudiants et des jeunes professionnels. Peter George appuiera les travaux de Lynne Cowe-Falls et Amie Therrien (respectivement présidente du comité des affaires étudiantes et présidente du comité des jeunes professionnels). La création de ce poste constitue un engagement important de la part de la permanence. Les membres répètent depuis des années qu'il faut absolument attirer et conserver de jeunes membres pour assurer l'avenir de la SCGC. Nous faisons des investissements pour assurer cet avenir.

Peter George travaille sur un nombre croissant de dossiers, dont les suivants :

- Des visites de chantiers pour les chapitres étudiants de Montréal
- La création d'un fonds pour les activités étudiantes
- Des ateliers pour les jeunes professionnels
- La certification des concours nationaux pour les étudiants

Je sais que je peux compter sur votre appui pour ces initiatives ou pour tout autre projet à l'intention des jeunes ingénieurs civils que Amie, Lynne et Peter élaboreront au cours de l'année qui vient.

Faites-nous parvenir vos commentaires ou vos questions!

ERRATUM

On page 17 of Issue 28.4 of CIVIL, Fig. 5 reference was given as [11], which is incorrect. The correct reference should have been: [15] Gan, G. Simulation of buoyancy-induced flow in open cavities for natural ventilation, Energy and Buildings, 38:410–420, 2006. We regret this error.

MAJOR PARTNERS / ASSOCIÉS PRINCIPAUX

PARTNERS / ASSOCIÉS

AFFILIATES / AFFILIÉS

CSCE SECTIONS SCGC

Newfoundland
Contact: Bing Chen, MCSCE
T: 709-864-8958 F: 709-864-4042
E-mail: bchen@mun.ca

Nova Scotia
Contact: To be determined

East New Brunswick and P.E.I. (Moncton)
Contact: Luc DeGrâce
T: 506-856-9601
E-mail: luc.degrace@valron.ca

West New Brunswick
Contact: Andy Small, MCSCE
T: 506-458-1000 F: 506-450-0829
E-mail: andy.small@amec.com

Montréal
Contact: Stéphane Marcouiller, MSCGC
T: 450-967-1260, ext. 3636 F: 450-639-8737
E-mail: stephane.marcouiller@tecsult.com

Sherbrooke
Contact: Eric St-Georges, MCSCE
T: 819-791-5744, ext. 103
F: 819-791-2271

Québec
Contact: Francis Labrecque, AMSCGC
T: 418-623-3373, ext. 192
F: 418-623-3321
Courriel: Francis.Labrecque@cima.ca

Capital Section (Ottawa-Gatineau)
Contact: Gary Holowach, MCSCE
T: 613-739-3255
E-mail: gholowach@morrisonhershfield.com

Toronto
Contact: Cameron Blair
T: 905-803-6357
E-mail: cblair@ellisdon.com

Hamilton/Niagara
Contact: Ben Hunter, MCSCE
T: 905-335-2353 ext. 269 F: 905-335-1414
E-mail: ben.hunter@amec.com

Northwestern Ontario
Contact: Gerry Buckrell, MCSCE
T: 807-623-3449 F: 807-623-5925
E-mail: gbuckrell@enl-tbay.com

Durham/Northumberland
Contact: Brandon Robinson
T: 905-668-4113 ext. 3439
E-mail: brandonrobinsoncsce-dn@live.com

London & District
Contact: Thomas Mara, MCSCE
E-mail: tmara3@uwo.ca

Manitoba
Contact: Dagmar Svecova, MCSCE
T: 204-474-9180 F: 204-474-7513
E-mail: svecovad@cc.umanitoba.ca

South Saskatchewan
Contact: Harold Retzlaff, MCSCE
T: 306-787-5642 F: 306-787-4910
E-mail: harold.retzlaff@gov.sk.ca

Saskatoon
Contact: Mike Hnatiuk, MCSCE
T: 306-477-0655 F: 306-477-1995
E-mail: m.hnatiuk@robb-kullman.com

Calgary
Contact: Dan Dankewich, MCSCE
E-mail: ddanke2@telus.net

Edmonton
Contact: Andrew Neilson
T: 780-917-4669
E-mail: ANeilson@designdialog.ca

Vancouver
Contact: Lacey Hirtle
T: 604-871-6392
E-mail: lacey.hirtle@gmail.com

Vancouver Island
Contact: Kevin Baskin, FCSCE
E-mail: kevin.baskin@gov.bc.ca

CSCE Hong Kong Branch
Contact: Moe M.S. Cheung, FCSCE
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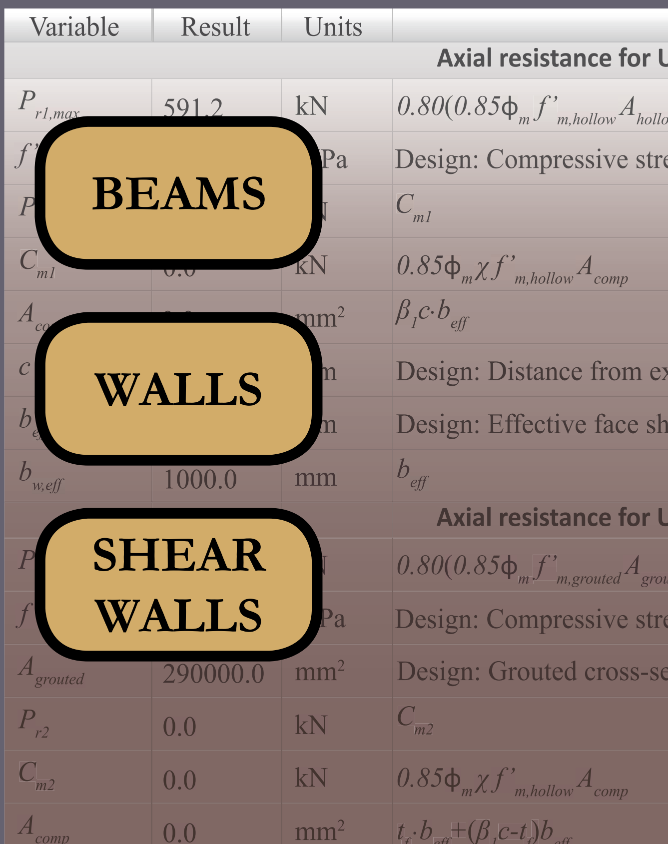

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NMDP would like to thank the following organizations for their significant contributions to the development of MASS™

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