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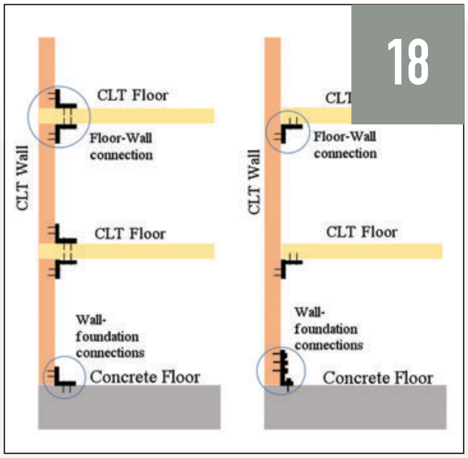

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CANADIAN CIVIL ENGINEER
L'INGÉNIEUR CIVIL CANADIEN

CSCE/SCGC
521-300, rue St-Sacrement
Montreal, Québec H2Y 1X4
Tel.: 514-933-2634, Fax: 514-933-3504
E-mail: mahmoud.lardjane@csce.ca
www.csce.ca

PRESIDENT/PRÉSIDENT
Jim Gilliland, Ph.D., P.Eng., LEED® AP

CANADIAN CIVIL ENGINEER/L'INGÉNIEUR CIVIL CANADIEN

EDITOR/RÉDACTEUR
Doug Salloum, CSCE Executive Director
514-933-2634 ext. 1, doug.salloum@csce.ca

MANAGING EDITOR/ DIRECTEUR DE LA RÉDACTION
Cindy Macdonald
Tel.: 905-713-4338
cmacdonald@annexweb.com

ASSOCIATE EDITOR/ RÉDACTEUR EN CHEF ADJOINT
Bronwen Parsons
Tel.: 416-510-5119
bparsons@ccemag.com

ADVERTISING SALES/ PUBLICITÉ
Maureen Levy
Tel: 416-510-5111
mlevy@ccemag.com

ART DIRECTOR/ COMPOSITION ARTISTIQUE
Lisa Zambri
Tel: 416-442-5600 x3595

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Jim Gilliland, Ph.D., P.Eng., LEED® AP
PRESIDENT, CSCE/PRÉSIDENT SCGC
PRESIDENT@CSCE.CA

Moving the conversation forward

My year as president of CSCE is now well underway, and I continue to be impressed by the level of dedication and expertise throughout the CSCE organization. The calibre of innovation and infrastructure development in Canada is truly world-class and the CSCE will continue to promote and raise awareness of Canada's civil engineering community.

Canadian infrastructure sustainability rating system (ISRS)

Through 2016, CSCE presented the results of the Canadian Infrastructure Report Card across the country in partnership with most of the CSCE local sections. This tour was a great success and focused our attention on the state of infrastructure in Canada.

So what's next? The magnitude of the infrastructure deficit makes correcting the problem economically daunting. A thoughtful approach to support community leaders is required to help prioritize projects and investment. CSCE, with its partners, is providing leadership to develop a Canadian infrastructure sustainability rating system (ISRS) in order "to provide stakeholders with an objective and comprehensive framework to assess how proposed infrastructure projects address the needs of today and anticipate the needs of the future while balancing social and environmental priorities."

CSCE is in a unique position to provide leadership for the development of a Canadian ISRS. Many G20 countries – the European Union, Australia, and the United States – have established infrastructure rating systems. These existing systems have already been reviewed by CSCE members, and an analysis was presented at the 2014 CSCE conference in Halifax.

In particular, the American Envision rating system is an instructive example. The Envision system was developed and implemented by the ASCE, APWA, and ACEC-USA, and is now administered by a joint organization. The CSCE is currently networking with the CPWA and the ACEC-Canada to build a stakeholder group for a Canadian ISRS. Rather than re-inventing the wheel, a Canadian ISRS can draw on the experiences of these existing systems while incorporating innovative Canadian initiatives and requirements – such as the infrastructure resiliency measures recently developed by Engineers Canada.

Now is the time for Canada to implement a system of its own so we can be formally recognized for our expertise and sustainability initiatives.

CSCE corporate partners – an invaluable relationship

In the 2016 summer edition, I discussed a new corporate partnership program. This initiative has now been formally launched and I am pleased to say that we have had very positive feedback and have secured many partners for a five-year commitment. The new program is geared towards providing clear value to companies who are interested in sustainable infrastructure. Many of our CSCE initiatives resonate with corporate members, including connections to engineering student chapters, the opportunity to network with CSCE members and other partners like FCM and CPWA, and providing development opportunities for their employees. In return, corporate partners raise awareness of CSCE, grow our membership, and increase participation in local CSCE events. The value provided to CSCE by our corporate partners is not just about the money! ■

CSCE LEADERSHIP IN SUSTAINABLE INFRASTRUCTURE: FIVE ADVOCACY POSITIONS

- Innovative Procurement Practices
- Long-Term Investment Planning
- Measure Sustainable Performance
- Leverage Asset Management Processes
- Sustainability Education

LE LEADERSHIP DE LA SCGC EN MATIÈRE D'INFRASTRUCTURES DURABLES : CINQ PLAIDOYERS STRATÉGIQUES

- Pratiques d'approvisionnement novatrices
- Planification à long terme des investissements
- Mesurer le rendement durable
- Profiter des processus de gestion des actifs
- Éducation durable

Faire avancer la discussion

Mon année en tant que président de la SCGC est maintenant bien entamée, et je continue d'être impressionné par le niveau d'implication et d'expertise au sein de toute l'organisation de la SCGC. Le calibre de l'innovation et du développement des infrastructures au Canada est véritablement de classe mondiale et la SCGC continuera à promouvoir et à mieux faire connaître la communauté canadienne du génie civil.

Le Système canadien de cotation de la viabilité des infrastructures (SCVI)

Au cours de l'année, la SCGC a présenté les résultats du Bulletin de rendement des infrastructures canadiennes à travers le pays en partenariat avec la plupart des sections locales de la SCGC. Cette tournée fut un véritable succès et a permis d'attirer toute notre attention sur l'état des infrastructures au Canada.

Quelle est la suite ? L'ampleur du déficit en infrastructures rend la solution au problème titanesque d'un point de vue économique. Une approche réfléchie de soutien aux leaders de la communauté est requise pour aider à établir une liste de priorités en matière de projets et d'investissements. Avec ses partenaires, la SCGC procure le leadership visant à élaborer un Système canadien de cotation de la viabilité des infrastructures (SCVI) afin de « fournir aux parties prenantes un cadre objectif et complet permettant d'évaluer la manière dont les projets d'infrastructures proposés comblent les besoins d'aujourd'hui et anticipent les besoins futurs tout en équilibrant les priorités sociales et environnementales. »

La SCGC se trouve dans la position unique de procurer le leadership pour l'élaboration d'un SCVI canadien. Plusieurs pays du G20 - l'Union européenne, l'Australie et les États-Unis - ont mis sur pied des systèmes de cotation de leurs infrastructures. Ces systèmes ont déjà été étudiés par des membres de la SCGC, et une analyse en a été présentée au congrès 2014 de la SCGC, à Halifax.

En particulier, le système de cotation américain Envision est un exemple instructif. Ce système fut élaboré et mis en œuvre par l'ASCE, l'APWA et l'ACEC-USA, et est administré par un organisme mixte. La SCGC est en discussion avec la CPWA et ACEC-Canada afin de mettre sur pied un groupe de parties prenantes pouvant mener à un SCVI canadien. Plutôt que de réinventer la roue, un système canadien peut s'inspirer des expériences des systèmes existants tout en incorporant des initiatives et des exigences canadiennes innovatrices, telles que les mesures de résiliences des infrastructures récemment développées par Ingénieurs Canada.

Le temps est venu pour le Canada de mettre en œuvre un système qui lui est propre, afin que nous puissions être formellement reconnus pour notre expertise et nos initiatives en matière de durabilité.

Les membres d'entreprise de la SCGC - une relation inestimable

Dans mon message estival, je vous ai entretenu d'un nouveau programme de membres d'entreprise qui a été élaboré récemment. Cette initiative a maintenant été formellement lancée et je suis heureux de dire que nous avons obtenu des commentaires très positifs et que nous avons réussi à impliquer plusieurs partenaires pour des engagements de cinq ans. Le nouveau programme vise surtout à procurer une valeur claire aux entreprises qui s'intéressent aux infrastructures durables. Plusieurs des initiatives de la SCGC trouvent écho auprès de nos membres d'entreprise. Elles leur procurent des liens avec les chapitres étudiants, l'occasion de réseauter avec les membres de la SCGC et d'autres partenaires tels que la FCM et la CPWA, ainsi que des opportunités de perfectionnement de leurs employés. En retour, les membres d'entreprise font mieux connaître la SCGC, accroissent le nombre d'adhésions à la Société et augmentent la participation aux événements locaux de la SCGC. La valeur procurée à la SCGC par nos membres d'entreprise n'est pas qu'une question d'argent ! ■

Ontario Region: good news…and the work ahead

By Adrian Munteanu

The Ontario Region is the largest area across Canada serviced by CSCE, with approximately 1900 registered members representing about 38 per cent of all CSCE members.

The good news is that our young professional and student chapters are in good shape and their membership shows significant increase in the last year. In spring 2015, the region got involved with the Ontario National Engineering Month (NEM) organizers to promote CSCE in Ontario, to engage the sections and involve young professionals and students.

Out of many, many other activities we have supported since then, I will share with you the Canadian experience at the 1st International Interactive Ultra-High Performance Concrete (UHPC) Symposium held in Des Moines, Iowa, in July 2016. The organizers of the conference selected the top 10 teams to participate in the student UHPC Beam Competition. Among those was a very dynamic OttawaU student team led by Prof. Hassan Aoude. The competition was open to all universities around the world, and the OttawaU team (also sup-

The OttawaU team for the 2016 UHPC Beam Student Competition: (left to right) Ahmad Shahroodi, P.Eng., Ph.D. candidate; Corey Guertin-Normoyle and Sarah De Carufel, M.ASc. candidates; Alex Carriere, M.Eng. candidate.
L'équipe de l'Université d'Ottawa participant au concours étudiant de poutre UHPC 2016 : (de gauche à droite) Ahmad Shahroodi, P.Eng., candidat Ph.D.; Corey Guertin-Normoyle et Sarah De Carufel, candidats M.ASc.; Alex Carrière, candidat M.Eng.

Région de l'Ontario : de bonnes nouvelles…et encore du travail

par Adrian Munteanu

La région de l'Ontario est la plus grande région du Canada desservie par la SCGC, avec approximativement 1 900 membres inscrits représentant environ 38 pour cent de la totalité des membres de la SCGC.

La bonne nouvelle est que nos sections de Jeunes professionnels et nos chapitres étudiants sont en bonne santé et que leur nombre d'adhésions a affiché une importante augmentation au cours de la dernière année. Au printemps 2015, la région s'est impliquée auprès des organisateurs du Mois national du génie de l'Ontario (National Engineering Month ou NEM) afin de promouvoir la SCGC en Ontario, et ainsi impliquer les sections, les jeunes professionnels et les étudiants en génie civil.

Parmi les très nombreuses activités dont nous avons été témoins au cours de l'année, je partagerai avec vous l'expérience canadienne au 1er symposium international interactif sur le béton à rendement ultra élevé (Ultra-High Performance Concrete - UHPC) tenu à Des Moines (Iowa) en juillet 2016. Les organisateurs du congrès avaient sélectionné les 10 meilleures équipes afin qu'elles s'affrontent lors du concours étudiant de poutre UHPC. Parmi celles-ci, il y avait la très dynamique équipe étudiante de l'Université d'Ottawa menée par le professeur Hassan Aoude. Le concours était ouvert à toutes les universités du monde, et l'équipe de l'Université d'Ottawa (appuyée et ported and sponsored by CSCE's Ontario Region and National Capital section) admirably represented the Canadian engineering school. The team returned with an award for the best paper of the conference and overall scored third place in the competition – a great success!

More details about the team and competition are available under the News tab on the Student Affairs page: https://csce.ca/committees/student-affairs/#message.

The not-so-good news is that we still have work to do at our section level to better service our members. At the organizational level, we have been working successfully to strengthen our position by focusing on the planning activities related to CSCE's strategic vision, and on membership and corporate membership growth. Externally, we continue to work with other national organizations in programs like the Canadian Infrastructure Report Card and the Sustainability Rating System for Infrastructure. The latest Infrastructure Report Card was released in January 2016 and CSCE presented the results across Canada. We also have several different technical divisions, programs and committees where our members are actively involved covering many engineering fields.

However, the sections are our members' connection to the industry, to the work of our divisions and programs, and to our young engineers. The sections are servicing our members but they are also led by our members. With only three active sections in Ontario, we all have work ahead to improve the situation. Let's get involved! ■

commanditée par la région de l'Ontario et la section de la Capitale nationale) a admirablement bien représenté l'école d'ingénierie canadienne. L'équipe est revenue avec un prix pour le meilleur article du congrès et a terminé troisième au classement général du concours. Tout un succès !

Des détails supplémentaires sur l'équipe et le concours sont disponibles à l'onglet Nouvelles de la page des Affaires étudiantes : https://csce.ca/committees/student-affairs/#message

La moins bonne nouvelle est que nous avons encore du travail à accomplir au niveau de nos sections pour mieux desservir nos membres. Sur le plan organisationnel, nous avons travaillé d'arrache-pied et avons réussi à renforcer notre position en mettant l'accent sur les activités de planification associées à la vision stratégique de la SCGC, ainsi que sur la croissance de nos effectifs, tant pour les membres individuels que pour les membres d'entreprise. À l'externe, nous avons continué à travailler avec d'autres organisations nationales dans des programmes tels que le Bulletin de rendement des infrastructures canadiennes et le Système de notation de la durabilité pour les infrastructures. Le dernier Bulletin de rendement sur les infrastructures a été publié en janvier 2016 et la SCGC a présenté ses résultats partout au Canada. Par ailleurs, nos membres sont activement impliqués dans plusieurs divisions, programmes et comités techniques.

Cependant, les sections constituent le lien entre nos membres et l'industrie, les activités de nos divisions et nos programmes, ainsi que nos jeunes ingénieurs. Les sections sont au service de nos membres, mais elles sont également dirigées par nos membres. Avec seulement trois sections actives en Ontario, nous avons bien du travail devant nous afin d'améliorer la situation. Impliquons-nous ! ■

Canadian civil engineering students shine

Charles-Darwin Annan, Ph.D., P.Eng.
CHAIR, CSCE STUDENT AFFAIRS COMMITTEE

I would like to extend a heartfelt welcome to all civil engineering students across Canada to a new and exciting school year. The 2015/2016 academic year was hugely successful because of our students' resolve to enrich themselves, and the support of our faculty and practising advisors. I envision new opportunities this school year for professional development, and I encourage every student to take advantage of the free student membership this year.

Our students continue to make us proud as they challenge themselves and apply their knowledge to projects outside the classroom. Congratulations to ETS Montreal for flying the Canadian flag at international events. The team was overall champions of two competitions this past spring: the American Society of Civil Engineers (ASCE)/American Institute of Steel Construction (AISC) National Steel Bridge competition and the ASCE National Concrete Canoe Competition. This is a remarkable achievement, to come out on top of more than 150 competing universities from North and South America and beyond!

In another competition, the 1st International Interactive Ultra-High Performance Concrete (UHPC) Student Beam competition held in July 2016 in Iowa, the University of Ottawa student team received the best paper award and overall third place (see page 6).

Congratulations to BCIT (Burnaby, B.C.), winner of the President's Award for Outstanding Student Chapter. UBC Vancouver and UNB Fredericton scooped second and third places, respectively. Waterloo was judged as the most improved chapter and Calgary and Sherbrooke received honourable mentions.

Congratulations also go to Carleton University for winning the National Civil Engineering Capstone Design Competition, and to ETS Montreal for winning both the Canadian National Concrete Canoe and Steel Bridge competitions.

The CSCE Student Affairs committee will continue to offer stimulating programs to provide excellent networking opportunities. We are engaging the CSCE sections to participate and provide support to student chapter activities. ■

Les étudiants canadiens en génie civil brillent

Par Charles-Darwin Annan, Ph.D., P.Eng
PRÉSIDENT, COMITÉ DES AFFAIRES ÉTUDIANTES DE LA SCGC

J'aimerais souhaiter chaleureusement une nouvelle année scolaire des plus excitantes à tous les étudiants et étudiantes en génie civil au Canada. L'année universitaire 2015-2016 fut des plus réussies en raison de la résolution de nos étudiants à s'enrichir de connaissances et du soutien de nos conseillers de faculté et de nos conseillers professionnels. J'anticipe de nouvelles opportunités de perfectionnement professionnel cette année et j'encourage chaque étudiant à tirer avantage de l'adhésion étudiante gratuite.

Nos étudiants et étudiantes continuent de nous rendre fiers alors qu'ils relèvent des défis en mettant en pratique leurs connaissances dans des projets à l'extérieur de la salle de classe. Je félicite l'ÉTS (Montréal) d'avoir fait voler bien haut le drapeau canadien en remportant les honneurs de deux concours le printemps dernier : le Concours national de pont en acier de l'American Society of Civil Engineers (ASCE)/American Institute of Steel Construction (AISC) et le Concours national de canoë de béton. Il s'agit d'un exploit remarquable d'affronter et de battre plus de 150 universités d'Amérique du Nord, d'Amérique du Sud et d'ailleurs !

Lors d'un autre concours, le 1er Concours international étudiant de poutre UHPC tenu en juillet 2016 en Iowa, l'équipe des étudiants de l'Université d'Ottawa a reçu le prix du meilleur article et a terminé troisième au classement général.

Je félicite également l'Institut de technologie de la Colombie-Britannique (BCIT, Burnaby, C.-B.), récipiendaire du prix du président pour le meilleur chapitre étudiant. L'Université de la Colombie-Britannique - Vancouver et l'Université du Nouveau-Brunswick - Fredericton ont terminé respectivement deuxième et troisième. Le chapitre étudiant de Waterloo a été nommé chapitre s'étant le plus amélioré et ceux de Calgary et de Sherbrooke ont également reçu une mention honorable.

Enfin, mes félicitations vont à l'Université Carleton pour avoir remporté le Concours national de conception Capstone en génie civil et à l'ÉTS de Montréal pour ses victoires aux concours de pont en acier et de canoë de béton.

Le comité des affaires étudiantes continuera à offrir des programmes stimulants qui fourniront d'excellentes opportunités de réseautage. Nous demandons par conséquent aux sections de la SCGC de participer à ce réseautage et de fournir un soutien lors des activités des chapitres étudiants. ■

Fresh ideas from the YP committee

By Vincent Tourangeau

I was very enthusiastic when I picked up the phone this summer for my first meeting as a YP committee member. After all, it is not every day that one gets to participate in a conference call with young civil engineers from across the country. The diversity of the members' backgrounds is as impressive as their engagement to the committee and the profession, and I was pleased to hear several excellent ideas and recommendations.

I myself have contributed on a range of projects. Having graduated from McGill University in 2013, my first project sent me to La Tuque, Que., where the Hydro-Quebec station was in need of a good overhaul. I then moved to Toronto where I worked on the construction of a new steam cogeneration plant, a complex and compelling

Continued on page 11

Des idées rafraîchissantes du comité JP

par Vincent Tourangeau

J'étais très enthousiaste cet été lorsque j'ai décroché le téléphone pour ma première réunion en tant que membre du comité JP. Après tout, ce n'est pas tous les jours que l'on a la chance de participer à une conférence téléphonique avec de jeunes ingénieurs civils de partout au pays. La diversité du bagage professionnel des membres est aussi impressionnante que leur implication auprès du comité et dans la profession, et j'ai été très heureux d'entendre plusieurs excellentes idées et recommandations.

J'ai moi-même contribué à plusieurs projets. Diplômé de l'Université McGill en 2013, mon premier projet m'a permis de me rendre à La Tuque (QC), où la station d'Hydro-Québec nécessitait une bonne révision. Puis je suis parti à Toronto où j'ai été impliqué dans la construction d'une nouvelle centrale de cogénération à vapeur, un projet complexe et fascinant. Une belle occasion de travailler sur un projet patrimonial dans ma ville natale m'a ramené à Montréal, où je travaille sur le nouveau pont Champlain depuis un peu plus d'une année.

Je suis stimulé par la direction que prend la SCGC et mon but sera de poursuivre le bon travail du comité visant à obtenir davantage de visibilité et d'augmenter le nombre de membres. Le désir de contribuer à améliorer l'expérience des membres est ce qui m'a amené au sein du comité JP, et j'espère que nous obtiendrons autant de succès dans les années à venir que par le passé.

En tant que nouveau membre du comité JP, je suis emballé de constater la prolifération des suggestions émises par les autres membres. Plus tôt cet été, suivant la présentation du Bulletin de rendement des infrastructures canadiennes au Nouveau-Brunswick, la section JP a tenu un événement de réseautage réussi dans un pub local. La section d'Edmonton va organiser un événement de mentorat « express » prévu en début d'année prochaine. De tels événements sont essentiels pour promouvoir la SCGC. Nous travaillerons donc d'arrache-pied pour soutenir toute initiative semblable proposée par les membres du comité.

Je suis disponible pour toute question à propos du comité JP. N'hésitez pas à vous impliquer ! vincent.tourangeau@sslc.ca ■

The link between asset management and sustainable infrastructure systems

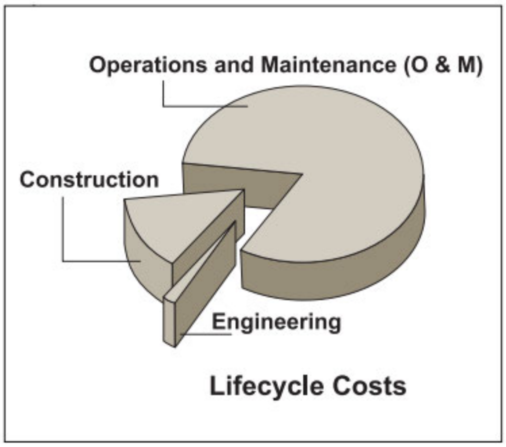
The following is CSCE's feedback to the Ontario Ministry of Infrastructure on the preparation of a new regulation for municipal asset management planning

The Canadian Society for Civil Engineering (CSCE) has prepared this submission to share with the Province of Ontario our collective perspective on the role that asset management (AM) can play to help make our municipal infrastructure systems sustainable.

Since the adoption of our strategic direction of "Leadership in Sustainable Infrastructure", CSCE's sights have been collectively focused on helping our world solve one of the largest problems of our time: how to engineer our infrastructure systems to be sustainable. The CSCE believes that asset management processes within a municipality are the practical mechanism to inform changes to how our infrastructure is planned, designed, procured, operated, maintained and replaced. These AM processes provide the evidence to support staff in making decisions that bring innovation to the infrastructure industry in Ontario.

Background

The Canadian Infrastructure Report Card (CIRC) tells us that a large proportion of our infrastructure systems will need to be renewed over the short to medium term in order to prevent a decline in the quality of life that is supported by the systems. Some $388-billion worth of infrastructure is in fair or poor condition. Governments at all levels in Canada recognize this problem and are taking steps to increase the financial investment in our infrastructure. But, equally as important as financial concerns, the CIRC tells us that there is a widespread lack of maturity in infrastructure asset management-related processes that support informed decision-making related to how our infrastructure systems are renewed. Infrastructure asset management processes provide the tools that will ensure our communities invest now in sustainable infrastructure systems.



Sustainable infrastructure systems will be the foundation of a sustainable future

In 2015, the CSCE Board approved Policy Statement 2015-01: Development of Sustainable Infrastructure. This policy statement was based on the recognition that the civil engineering profession is the steward of Canada's core infrastructure systems. The availability, condition and functionality of public infrastructure systems are widely acknowledged as having a direct impact on the quality of life for all Canadians. We will not have a sustainable future without sustainable infrastructure systems.

What does the CSCE feel should be done to address the infrastructure challenges that are identified in the 2015 CIRC?

In short, our infrastructure systems are not sustainable because we have not engineered them to be sustainable. We have engineered them with other purposes in mind, such as to be cheaper or faster to construct. Data shows that over the life cycle of an infrastructure asset, 80 per cent of the costs are attributed to operations, maintenance and repairs while only 20 per cent of the costs are from the acquisition of the asset: engineering and construction (Infraguide 2006). Unfortunately, public sector agencies and municipalities have focused on the 20 per cent while a sustainable approach would be to concentrate on the 80 per cent - the operational serviced life of the assets.

Civil engineers have the ability to turn our infrastructure challenges into an opportunity – to bring innovation into the next generation of infrastructure systems that will support our future society. The CSCE is providing leadership in the collection of different areas that will need to work together to build the next generation of infrastructure systems: academia, government and the private sector in the disciplines of engineering, public policy and finance.

Here are some areas where the CSCE believes asset management can help transition our infrastructure systems to be sustainable:

- Asset management processes should be able to justify the adoption of innovative ideas and techniques around the planning, design, construction, financing and management of infrastructure systems.
- Asset management processes should inform the restructuring of how our infrastructure is procured by its owners to remove the barriers to innovation that currently exist within our municipal, provincial or federal bureaucracies.
- Asset management processes should be engineered to quantify greenhouse gas emissions of an infrastructure system, to justify the adoption of a new product or construct technique that would result in lower GHG

emissions, and to understand the resilience of an infrastructure system to climate change.

Closing

We would like to thank the Province of Ontario for the opportunity to provide commentary into the proposed Bill 6 regulations. We would be happy to meet with a representative of the Province to further discuss how asset management can help make our infrastructure systems sustainable. ■

Submitted by:
Adrian Munteanu, P.Eng., vice-president, CSCE Ontario Region

Prepared by:
Guy Felio, P.Eng., chair of CSCE's Infrastructure Renewal Committee
Nick Larson, P.Eng., member of CSCE Infrastructure Renewal Committee

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project. The opportunity to work on a legacy project in my home town brought me back to Montreal, where I have been working on the new Champlain bridge for just over a year now.

I am excited about the direction the CSCE is taking, and my goal will be to carry on the good work of the committee towards gaining more visibility and membership. The desire to help improve the member experience is what brought me to the YP committee, and I hope we will achieve as much in the coming years as has been accomplished in the past few.

As a new member of the YP committee, I am thrilled to see the proliferation of suggestions from other members. Earlier this summer, following the presentation of the Canadian Infrastructure Report Card in New Brunswick, the YP section hosted a successful networking mixer. The Edmonton section is already organizing a Speed Mentoring event they plan to hold early next year. Such events are essential in promoting the CSCE; we will work hard to support any such initiative from the committee members.

I am available for any question about the YP committee. Do not hesitate to get involved! vincent.tourangeau@sslc.ca ■

Donadeo Innovative Centre for Engineering–Cladding

A unique façade combining glass and ultra high-performance precast concrete (UHPC) panels was developed for a building at the University of Alberta.

By Gamal Ghoneim P.Eng., M.Sc., Blair Bisson P.Eng., M.Eng.,
Gerry Carson P.Eng., Clark Webber, P.Eng. & Don Zakariasen

At the University of Alberta in Edmonton, the Donadeo Innovative Centre for Engineering, known as the ICE Building, is an approximately 28,000-square metre addition to the Chemical Engineering Materials Building (CEMB). Besides the addition, the project involved replanning, modernizing and renovating the CEMB Building.

The project started in 2012 with DIALOG as prime consultant, and in 2013 DIALOG took on an additional role as specialty engineers for the precast elements of the high performance exterior façade: a triple-glazed curtain wall. The project was completed in 2015.

The CEMB addition is constructed in a sliver of space between the existing CEMB and the Windsor Parkade as an infill building. The floors are constructed with concrete topping on metal deck, supported on a structural steel frame system on 10 x 15 m bays.

The exterior façade of this building combines glass, metal and precast concrete panels. A striking feature is the "fly-by" panels which extend at the corners of the structure, displaying the transparency of the glass and the minimal thickness of the support precast.

Slender UHPC panels

Ultra-high performance precast concrete (UHPC, known as Ductal by Lafarge) is the key element in the precast panels. The 150 MPa material strength provides the capacity to carry gravity and environmental loads while maintaining an unobtrusive shallow thickness. The UHPC mix was blended with polyvinyl alcohol (PVA) fibres instead of steel fibres to avoid rust staining on the façade. In addition, the maintenance requirements are reduced due to UHPC's low porosity, which reduces surface pours making the panels less susceptible to absorption of rain-water and to deterioration. The strength, ductility and moldability of UHPC allow thinner, lighter, and more elegant new designs than when using conventional concrete.

The surface finish of the precast is a custom texture that resembles stone in appearance, developed with the architect's input to generate an appropriate level of shadows while maintaining a surface that would naturally shed dust and grime.

The alignment of joints in the precast in relation to joints in the glazed wall added a challenge to the precast design, with panels spanning across a number of mullions. The precast façade's natural colour and visual depth provide contrast to the glossiness and reflectivity of the glazed wall and contribute to the high-efficiency building envelope.

Structural analyses

Non-linear finite element analysis used in the structural analysis of the panels, and our design experience from previous UHPC work in bridge and building structures, enabled us to create thin panels 17 to 35 mm thick. At the fly-by corners, however, thicker panels were needed. Stone or granite panels of the same dimensions would have been four to five times heavier and much thicker. They also would have required a structural steel support system, which would have been undesirably visible at the fly-by corners.

The stress-strain material model used in the analysis had an upper limit of 100 MPa in compression and 5 MPa in tension, even though 15 MPa flexural strength was observed during testing (associated with large deformations exhibiting ductile behavior). Recent research in concrete materials at Rice University is showing evidence of ductile behavior mechanisms in the cement hydrate that are reminiscent of crystalline alloys and ductile metals.[1] Given that crack growth and strength are inherent properties controlled by nanoscale deformation mechanisms, new findings may open up opportunities and strategies that turn brittle cement hydrate into a ductile material, which will impact the future engineering of concrete structures.

A total of 814 panels (including 190 backer panels at the fly-by corners) of multiple heights (150 to 1100 mm), and lengths (1700

All photos Lafarge

Top left: Fly-by corners. Above: The building façade combines glass, metal, and UHPC panels. Far left: Panel texture resembles stone in appearance. Left: Assortment of UHPC panels after casting.

to 5000 mm) were required. Mountings were designed to allow connection of the panels to the vertical mullions of the curtain wall and installation from the exterior of the building. The fly-by corners use the precast as structural elements to carry gravity, wind and seismic loads, and to transfer these loads to the mullions.

The fly-by design concept was validated by full-scale load and wind pressure testing conducted by a Miami-based company, Construction Research Laboratory. Lafarge conducted load tests to validate the flexural strength of the panels as well as to validate the pull out capacity for the connection inserts.

A key success factor in this project was the strong collaborative efforts of all the key participants including the owner, University of Alberta, and the contractor, EllisDon. The project won the 2015 Award of Excellence - Institutional Buildings from Consulting Engineers of Alberta. ■

Gamal Ghoneim, P.Eng., M.Sc., Blair Bisson, P.Eng., M.Eng., and Gerry Carson, P.Eng., are with DIALOG. Clark Webber, P.Eng., is with Bluerock Engineering. Don Zakariasen is with Lafarge.

[1] *Aug 2016 Rice University news release "Nothing – and something – gives concrete strength, toughness." http://news.rice.edu/2016/08/08/nothing-and-something-give-concrete-strength-toughness-2/ (August 8, 2016)*

OWNERS: University of Alberta
PRIME CONSULTANT & CURTAIN WALL DESIGN: DIALOG (Edmonton, Calgary)
CONTRACTOR: EllisDon
OTHER KEY PLAYERS: Construction Research Laboratory (façade testing); Lafarge (façade testing); Bluerock Engineering (production drawings)

Pier Repairs Using Ultra-High Performance Concrete

Three bridges, two in B.C. and one in Quebec, had issues that called for unique UHPC solutions.

By Gaston Doiron, P.Eng., M.Eng.
LAFARGE CANADA (a member of LafargeHolcim)

The infrastructure sector is under tremendous pressure to find durable solutions to maintain or upgrade existing structures. Following are three examples of Canadian pier repair/retrofit projects using Lafarge's ultra-high performance concrete (UHPC), Ductal. UHPC has a compressive strength in the range of 150 MPa (22,000 psi), high durability and ductility provided by the fibers in the mix. The customized UHPC solutions below were for: pier jacketing, a seismic pier retrofit, and steel bent leg encasements.

CN Rail Bridge, Montreal, Que. - Pier Jacketing

For repair of a rail bridge pier in Montreal, the Canadian National Railway (CN) and consultant AECOM sought an innovative, durable solution that would last at least twice as long as a conventional concrete solution.

The parallelogram pier, spanning a two-lane access ramp to Victoria Bridge, is approximately 800 mm wide x 7 m long x 3.3 m high. Although the existing pier could support the gravity and live loads, the column repair was needed to protect against chloride and freeze/thaw.

The existing concrete showed considerable degradation. A galvanized rebar cage was added after removal of the deteriorated layer, and forms were set to allow casting of the 115-mm (4.5-in.) thick UHPC jacket. The repair, completed in October 2013, was staged to maintain one lane of traffic during construction and required 11 cubic metres of material.

Mission Bridge, Abbotsford, B.C. - Seismic Pier Retrofit

The Mission Bridge, opened in 1973, is a 1,126-m long structure crossing the Fraser River in British Columbia. In June 2014, one of its V-shaped concrete piers (Pier S4) was retrofitted with UHPC jackets, the final step in a series of seismic upgrades to ensure the integrity of this vital link in a high seismic zone.

The soil is "liquefiable sand"; therefore the lightly reinforced rectangular concrete columns were at risk for high displacement or possible collapse due to earthquake activity. The engineering team of Associated Engineering evaluated many options, including traditional thick reinforced concrete jackets, elliptical steel shells, or soil consolidation. Determining that traditional methods were technically viable but visually obtrusive, they chose the UHPC solution, which also proved to be the lower-cost alternative.

(1) Mission Bridge, B.C., seismic retrofit under construction, and (4) pier jackets completed. (2) CN Rail bridge, Montreal, pier jacketing during construction, and (3) repairs completed. (5) Hagwilget Bridge, Hazleton, B.C., forming details and reinforcement for steel bent leg encasements, and (6) UHPC encasements before capping.

The pedestal was widened with conventional concrete to force the plastic hinge at this location under seismic load. Additional steel dowels were imbedded to the existing column. A reinforcing rebar cage was secured to the dowels and new 230-mm thick UHPC jackets were cast to increase and stiffen confinement, on a height of 3 metres. Four truck loads delivered a total of 18 cubic metres of UHPC. To facilitate batching and maintain proper temperature, 100% ice was used instead of water.

In 2015, this project won an American Concrete Institute (ACI) Excellence in Concrete Award (in the Repair & Restoration category).

Hagwilget Bridge, New Hazelton, B.C. - Steel Bent Leg Encasements

The B.C. Ministry of Transportation and Infrastructure is the owner of this single lane suspension bridge, which has a main span of 140 m, 75 m above water.

In 2015, Buckland & Taylor/COWI proposed a UHPC solution to encase 32 steel bent leg bases supporting the approaches of the bridge. The bases had serious corrosion damage.

The objective was to strengthen these weakened zones and mitigate future corrosion. Access limitations and a congested site area meant the project required a very high strength concrete with excellent flowability, virtually no shrinkage, no permeability and good tensile capacity.

The load transfer, facilitated by the use of steel plates bolted to the flanges of the bent leg, helped distribute the vertical load to the top of the UHPC encasement.

Completed in August 2015, the project used 12 cubic metres of material.

Different driving factors

The above cast-in-place applications highlight and demonstrate that each repair/retrofit project is unique. For the CN Rail Bridge, resistance to freeze-thaw and chloride were the main drivers. Ductility, aesthetics and cost savings were important for the Mission Bridge. For the Hagwilget Bridge, confinement and high compressive strength were key concerns. In some situations, UHPC precast elements may be used by grouting them to the existing structure. In other situations, a UHPC shotcrete might be the best solution for difficult access or complex shapes.

Owners, designers, consultants and contractors face ongoing challenges with respect to infrastructure repair, retrofit and rehabilitation. Engineers today are more receptive and aware of the many benefits that UHPC solutions can provide. Owners are also painfully aware of the cost and high number of interventions required to maintain a structure. This is where UHPC solutions offer significant advantages compared to traditional repairs. ■

Gaston Doiron, P.Eng., M.Eng. is project manager, Ductal Repair and Retrofit Markets, Lafarge Canada (a member of LafargeHolcim). E-mail gaston.doiron@lafargeholcim.com

High performance materials/structural systems for sustainable civil infrastructure

By Dr. M. Shahria Alam, P.Eng.

The use of advanced materials and structural systems profiled in this issue provides new opportunities to meet global challenges.

The use of advanced materials in conjunction with innovative structural systems can substantially improve the performance of civil infrastructure against extreme loads like earthquakes. This edition of CIVIL features high performance materials/structural systems for sustainable civil infrastructure. Short articles will explore the use of cross-laminated timber (CLT) in buildings in seismic regions, self-healing engineered cementitious composites (ECC) for repairing and retrofitting, and self-centering structural systems for improved seismic safety of buildings.

More than 40 per cent of Canadian civil infrastructure has passed its service life. Canada's municipal infrastructure deficit has grown to $141 billion and increases at a rate of $2 billion annually. The Canadian Infrastructure Report Card (2016) emphasizes that if immediate measures are not taken to revamp current infrastructure, the cost of replacement may increase many folds.

Deficient infrastructure also poses a threat to the public during natural disasters like earthquakes. Forty per cent of Canadians live in the B.C. and Quebec seismic zones. AIR Worldwide, global experts in catastrophe modelling, predict potential economic losses from an earthquake of $75 billion in B.C and $61 billion in Quebec.

To avoid such scenarios in Canada, immediate measures must be taken to develop and implement innovative structural systems that can be built rapidly, sustainably and durably. Canada has a mandate to reduce GHG emissions by 30 per cent by 2030, compared to 2005 levels (as per Canada's intended contribution to the UNFCCC). Hence, sustainability in construction is critical to help Canada achieve this goal. An easy solution to this problem is to use heavy timber in construction, which has already captured huge amounts of carbon from the atmosphere. Since any new construction project is associated with large emissions, enhancing the service life of structures using advanced materials like ECC can also significantly reduce GHG emissions. For new construction, structural systems possessing self-centering capability can withstand many earthquakes without experiencing major damages – which can help build sustainable infrastructure in Canada requiring no replacement of structures (i.e. zero emission) even after a large magnitude earthquake. ■

M. Shahria Alam is an Associate Professor with the School of Engineering, University of British Columbia, Kelowna, B.C.

Matériaux à haute performance et systèmes structuraux pour des infrastructures civiles durables

par M. Shahria Alam, Ph.D., P.Eng.
PRÉSIDENTE, COMITÉ DE L'ÉDUCATION ET DE LA RECHERCHE, SCGC

L'utilisation de matériaux avancés et de systèmes structuraux présentés dans ce numéro procure des opportunités de faire face aux défis d'ordre mondial.

L'utilisation de matériaux avancés associée à des systèmes structuraux innovateurs peut substantiellement améliorer le rendement des infrastructures civiles lors de charges extrêmes, par exemple les tremblements de terre. Ce numéro de CIVIL met en vedette les systèmes structuraux et les matériaux à haute performance pour des infrastructures civiles durables. De courts articles vont explorer l'utilisation du bois lamellé-croisé (CLT) dans les bâtiments situés dans des régions sismiques, les composites cimentaires fabriqués (ECC) à auto régénération pour les réparations et les remises à neuf, ainsi que les systèmes structuraux à centrage automatique servant à améliorer la sécurité sismique des bâtiments.

Plus de 40 pour cent des infrastructures civiles canadiennes ont dépassé leur durée de vie utile. Le déficit des infrastructures municipales canadiennes s'est accru jusqu'à atteindre 141 milliards de dollars et augmente à un rythme de 2 milliards de dollars par an. Le Bulletin de rendement des infrastructures canadiennes (2016) insiste sur le fait que si des mesures immédiates ne sont pas prises afin de réhabiliter les infrastructures actuelles, le coût de leur remplacement pourrait entraîner plusieurs faillites.

Les infrastructures déficientes constituent également une menace pour le public en cas de désastre naturel tel qu'un tremblement de terre.

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Cross-laminated timber: a high performance sustainable building material

Md Shahnewaz, Ph.D. candidate
DEPARTMENT OF CIVIL ENGINEERING, UBC, VANCOUVER

Thomas Tannert, associate professor
COLLEGE OF SCIENCE AND MANAGEMENT, UNBC, PRINCE GEORGE

M. Shahria Alam, associate professor
SCHOOL OF ENGINEERING, UBC, KELOWNA

Advantages of cross-laminated timber

Cross-laminated timber (CLT) panels consist of several layers of boards stacked crosswise and glued together. A CLT element has usually three to nine glued layers of boards placed orthogonally to each other (90°) to form a solid panel.

CLT offers new design possibilities to architects and engineers, being a light, cost effective and sustainable material. CLT is made of a renewable resource (wood) and is an alternative to replace steel and concrete. It was first developed in the early 1990s in Austria and Germany (Gagnon and Pirvu 2011) and ever since has been gaining popularity in residential and non-residential applications as a wood-based structural solution for a shift towards sustainable densification around the world.

Using CLT panels for pre-fabricated wall and floor panels offers many advantages compared to concrete: the weight of CLT buildings can be one-fourth compared to concrete buildings, which reduces the cost for foundations, transportation and construction (Yates et al. 2008). Since wood is a light material, inertia forces from earthquakes will be relatively lower compared to buildings made of steel, concrete or masonry. The cross-lamination provides improved dimensional stability to the product that allows for prefabrication of long floor slabs and single storey walls. The pre-cut wall and floor panels are assembled on the construction site using various types of screws and steel connectors to form the structural system. Openings for windows and doors can be pre-cut. Quick erection of solid structures is possible even when using non-highly-skilled manpower (Gagnon and Pirvu 2011). The good thermal insulation and a fairly good behaviour in fire are other benefits resulting from the massiveness of the wood structure. Furthermore, it is a clean product to work with resulting in less waste and dust produced on site which is better in terms of health and safety. CLT is a sustainable building material with a low carbon footprint, because panels do not require much energy to be produced and the wood stores carbon during its lifespan (Gagnon and Pirvu 2011).

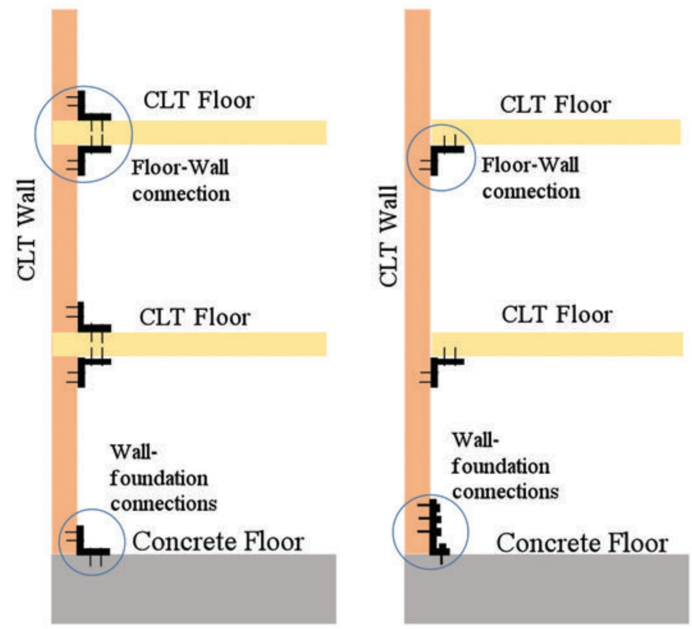

Figure 1: Platform type (left) and balloon type (right) CLT construction.

Use in structural systems

CLT panels provide high in-plane (Shahnewaz et al. 2016) and out-of-plane (Breneman 2014) stiffness and strength which make them a suitable product for building walls and slabs. The cross lamination provides strength in both orthogonal directions and thus offers a two-way load-carrying action like reinforced concrete slab. CLT buildings can be constructed in several ways depending on how the loads are being transferred to the main lateral load-resisting elements as platform- and balloon-type construction (Fig. 1).

Platform construction, where the floor panels are resting directly on top of the wall panels at each storey, is the most common type of structural system for CLT buildings. The advantages of this system are: i) a stable flat platform for erection of the upper storey; ii) usually faster erection time, iii) use of simple connections. The main disadvantage is related to the accumulation of the compression perpendicular to grain stresses on the CLT floor panels which can limit the number of storeys. The current edition of the Canadian Design Standard for Engineering with Wood (CSA086 2016) includes a section on platform-type CLT construction.

CLT walls are effective in resisting lateral forces resulting from seismic and wind loads, and can be the primary lateral force-resisting system in a building. Test results under cyclic loading proved the effectiveness of CLT shear walls to dissipate energy (e.g. Ceccotti et al. 2006 and

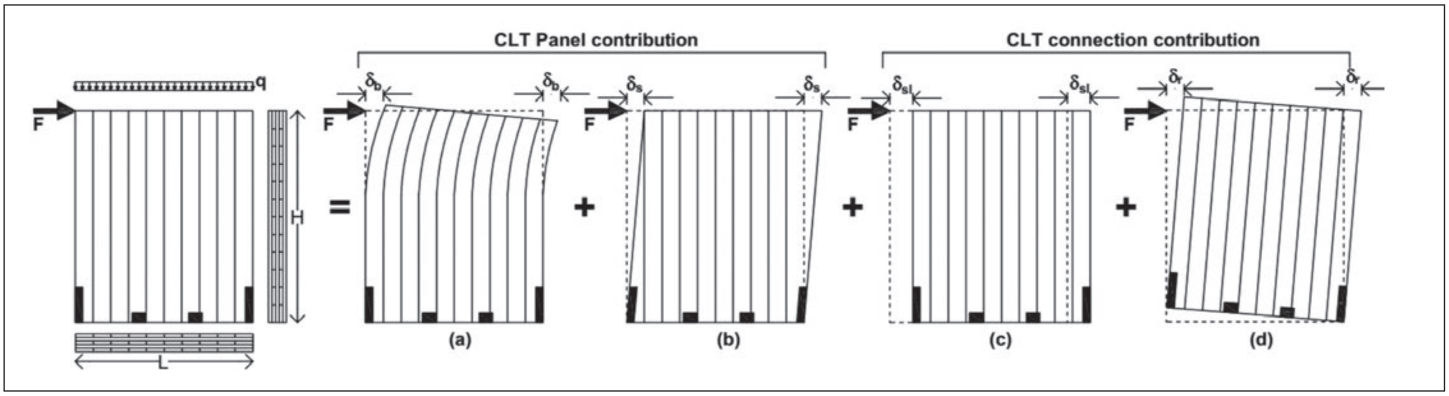

Figure 2: Behavior of CLT shear wall

Popovski et al. 2010). The total deformation of CLT walls coming from panels (bending and shear deformations) and connections (sliding and uplifting) is presented in Fig. 2. Shake table tests on a seven-storey CLT building (Ceccotti et al. 2013) and a two-storey CLT box-type building (Popovski et al. 2014) indicated that the CLT buildings can withstand strong earthquake excitations without significant damages.

Summary

The high-performance, lightweight, cost effective and sustainable material properties of CLT open new design possibilities for using wood to architects and engineers. Also, in seismic zones, CLT can be an alternative structural material due to its energy dissipating capacity along with high in-plane and out-of-plane stiffness and strength.

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MATÉRIAUX À HAUTE PERFORMANCE,

suite de la page 16

Quarante pour cent des Canadiens vivent dans les zones sismiques de la Colombie Britannique et du Québec. AIR Worldwide, les experts mondiaux en modélisation des catastrophes, prédit de potentielles pertes économiques suite à un tremblement de terre de l'ordre de 75 milliards de dollars en Colombie Britannique et de 61 milliards de dollars au Québec.

Afin d'éviter un tel scénario, des mesures immédiates doivent être prises afin de développer et de mettre en œuvre des systèmes structuraux innovateurs pouvant être construits rapidement et de manière durable. Le Canada a le mandat de réduire ses émissions de GES de 30 pour cent d'ici 2030, par rapport aux niveaux de 2005 (en vertu de la contribution canadienne prévue à la CCNUCC). Par conséquent, la durabilité en matière de construction est essentielle afin d'aider le Canada à atteindre cet objectif. Une solution aisée à ce problème est d'utiliser en construction du gros bois d'œuvre qui a déjà emmagasiné une grande quantité de carbone retrouvé dans l'atmosphère. Puisque tout nouveau projet de construction est associé à d'importantes émissions, améliorer la durée de vie utile des structures en utilisant des matériaux avancés (ex. : ECC) peut également considérablement réduire les émissions de GES. Lors de nouvelles constructions, les systèmes structuraux ayant une capacité de centrage automatique peuvent faire face à plusieurs tremblements de terre sans subir de dommages importants, ce qui peut contribuer à développer des infrastructures durables au Canada ne nécessitant pas de remplacement des structures (donc, aucune émission supplémentaire), même après un séisme d'amplitude élevée. ■

M. Shahria Alam est professeur associé au département de génie civil de l'Université de Colombie-Britannique, à Kelowna (C.-B.).

High performance concrete composites with robust self-healing capability

M.A.A. Sherir, Ph.D. candidate

K.M.A. Hossain, Ph.D., P.Eng., associate professor
DEPARTMENT OF CIVIL ENGINEERING, RYERSON UNIVERSITY

M. Lachemi, Ph.D., P.Eng., president and vice-chancellor
RYERSON UNIVERSITY

Figure 2: 15 month natural/field curing.

Discovering new cement-based materials characterized with higher durability and longer service life is crucial for sustainable infrastructure. Engineered cementitious composite (ECC) with high potential of micro-crack healing can enhance ductility/durability of concrete structures (Herbert and Li, 2013). However, low water-to-cement ratio in the ECC matrix, in addition to the lack of cementitious properties of newly formed healing products in micro cracks, could be an obstacle to implement continuous hydration to stimulate self-healing and stop re-opening of old healed micro-cracks during re-loading. An MgO-type expansive agent (MEA), widely used to effectively compensate autogenuous shrinkage in mass concrete, can be used to eliminate such obstacles and to induce self-healing (Du, 2005; Mo et al., 2014).

Figure 1: Loaded beams inducing micro-cracks.

An ECC-MgO self-healing system can be developed by combining enhanced strain hardening and multiple cracking behaviors (featured with tight crack width less than 60 µm) of ECC with micro-structure enhancing capability (through producing cohesive cementitious-based materials at later ages featured with low water demand) of MEA. Such an ECC-MgO self-healing system can be successfully implemented to promote self-healing phenomenon in structural elements through crack-healing and developing post-healed cracks at new locations upon reloading.

Research program

For the last few years, resarchers at Ryerson University have studied the self-healing capability of MEA in ECC and developed ECC-MgO systems through an extensive experiemental investigation. Ongoing research suggested “900°C-2 hours of holding time-45 µm particle size” as the best calcination system based on higher MEA hydration in the MgO powder state. Additionally, 5% lightly burnt MgO combined with low calcium class-F-fly ash (as 55% cement replacement) was found to be a better choice in designing a self-healing ECC-MgO system in terms of lower expansion effect of MEA. Consequently, an ECC-MgO system with 5% MgO and 55% class-F-fly ash (in combination with Portland cement, micro-silica sand and polyvinyl alcohol fiber) was proposed.

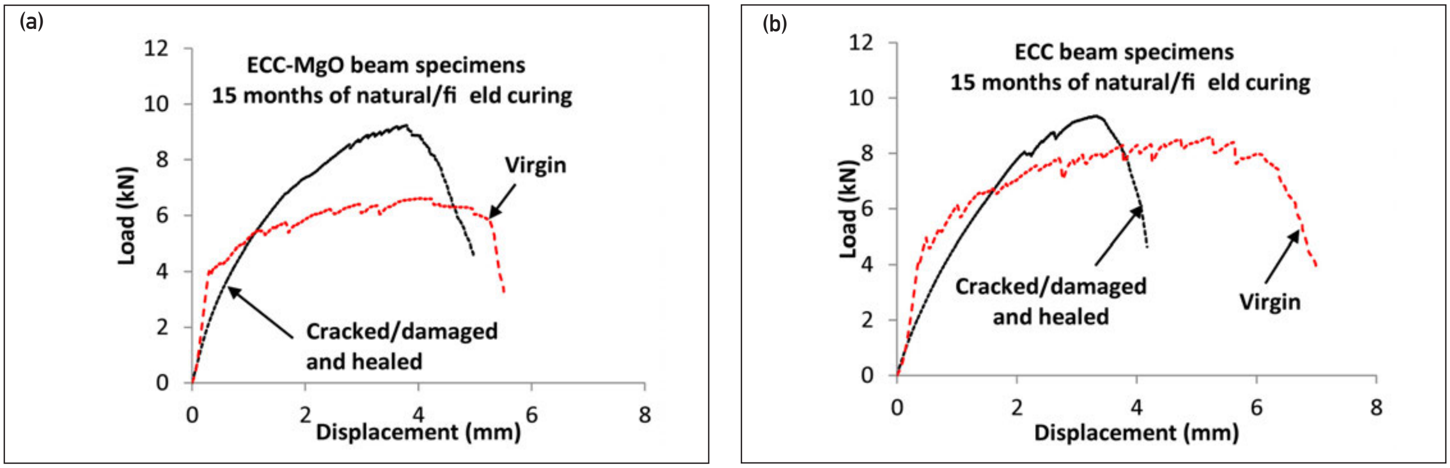

Figure 3: Load-displacement responses of ECC and ECC-MgO beam specimens.

The long-term self-healing capability of the developed ECC-MgO system was then investigated through development/recovery of mechanical/durability properties, crack healing characteristics and micro-structural characterization of cracked/damaged self-healed ECC/ECC-MgO specimens cured under natural/field curing condition compared to their virgin (un-cracked) counterparts.

Self-healing characteristics of ECC-MgO system

The self-healing capability of the ECC-MgO system is discussed based on flexural strength development/recovery, transport property (sorptivity/water absorption characteristics) and scanning electron microscopic (SEM) analysis of matrix and healing products in crack walls.

Long term strength development/recovery of ECC-MgO specimens

ECC and ECC-MgO beam specimens (50 x 76 x 355 mm) were cracked/damaged after 7 days of lab curing (by pre-loading as shown in Fig. 1) and then natural/field cured for 15 months (as shown in Fig. 2) before being loaded to failure under flexure. For comparison, 15-month natural cured ECC and ECC-MgO virgin (un-cracked) beam specimens were also tested to failure under flexural loading. Figure 3 (a-b) shows the flexural load-displacement responses of crack-healed and virgin ECC and ECC-MgO specimens, respectively.

Generally, crack-healed specimens exhibited reduction in stiffness and deflection capacities compared to virgin specimens. During 15 months of natural/field curing (healing), both crack-healed ECC and ECC-MgO specimens recovered the strength of their virgin counterparts (Fig. 3). However, the ability of ECC-MgO specimens in strength recovery was higher than their ECC counterparts. This was evident from 9% and 41% higher strength development of crack-healed ECC and ECC-MgO specimens, respectively compared to their virgin counterparts.

Crack healing and micro-structural characterization of ECC-MgO system

Figure 4 shows the results of SEM analysis conducted on ECC-MgO samples from beam specimens after 15 months of natural curing. SEM graphs show the presence of condensed and cohesive cementitious material presence within the ECC-MgO matrix. The surface texture of this material is similar to a cement glue-like material which might help combine the ECC-MgO matrix together and reduce significantly the surface cracking.

Figure 4 also shows that the crack cavity was self-healed and filled/closed completely with healing products and upon re-loading new cracks formed. Figure 4 (b) shows that the chemical composition of the self-healed materials consisted of magnesium and calcium hydration products with a percentage of 19.9% and 11.5%, respectively.

Conclusions

MEA was found to be effective in producing ECC-MgO system with self-healing capability as confirmed from the strength recovery, better transport property and superior crack healing characteristics. This was attributed to the MEA's ability to densification of microstructure through producing magnesium silicate hydrates (M-S-H) at later ages (characterized by cohesive cementitious properties) supplementing the formation of C-S-H products at early ages as confirmed from the SEM analysis. In addition, magnesium products also supplement the formation of $CaCO_3$ and C-S-H products formed within the crack openings enhancing the strength of already healed cracks especially when loadings are reapplied. All these findings should provide inspiration/justification to employ MEA as a self-healing agent in the production of an ECC-MgO self-healing system for sustainable crack-free construction. ■

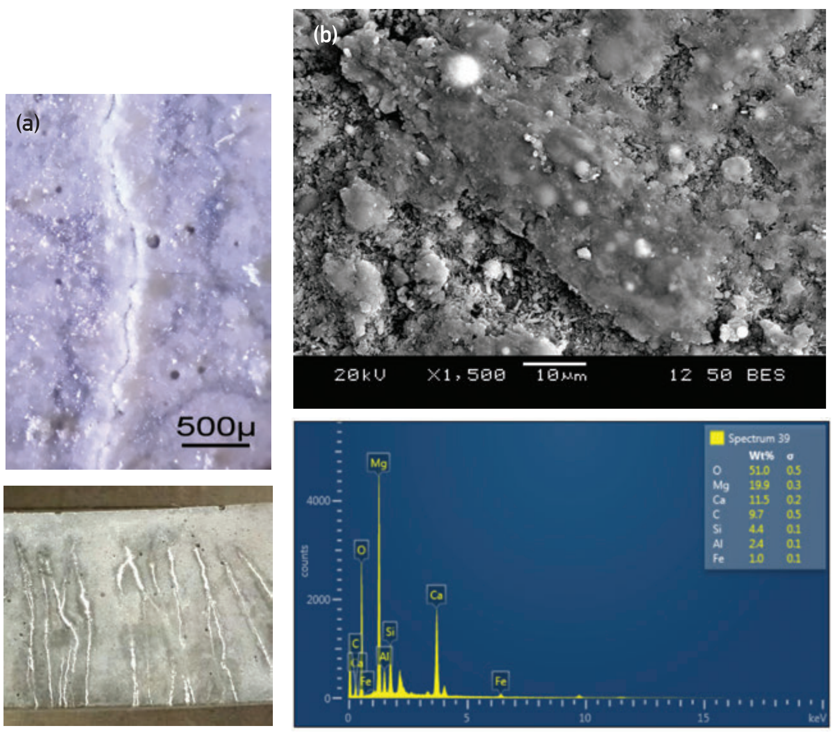

Figure 4: (a) Crack healing and its products, and (b) SEM-microstructure of the ECC-MgO matrix.

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Advanced structural steel systems for enhanced seismic performance

Robert Tremblay, Ph.D., professor
DEPT. OF CIVIL, GEOLOGICAL & MINING ENGINEERING, ÉCOLE POLYTECHNIQUE, MONTREAL

Current seismic design provisions for building structures exploit their capacity to withstand earthquake effects through ductile inelastic deformations. Reduced seismic loads are therefore permitted to be used for systems proportioned and detailed to achieve minimum ductility. This traditional approach generally results in robust and cost-effective solutions; however, these structures are expected to sustain structural damage and residual lateral deformations in case of a strong earthquake, which can lead to high repair or replacement costs and detrimental downtime periods. More recently, alternative design approaches and structural systems have been proposed to achieve enhanced seismic performance and lower overall lifetime costs. Among those, damped moment frames, self-centering moment and braced frames, and controlled rocking braced frames are structural steel systems that have high potential for effectively minimizing seismic-induced structural damage and permanent deformations.

Damped moment frames: Damped moment frames are flexible steel moment frames (MFs) used in parallel with diagonal steel bracing incorporating energy dissipation (ED) systems or dampers. The frame is proportioned to carry the gravity loads and develop minimal lateral stiffness to overcome P-delta effects and provide re-centering response while the brace-ED assemblies are sized to control the lateral displacements. Various ED systems exploiting frictional, hysteretic or viscous response are now available. Viscous dampers can be linear or nonlinear, the second one offering higher energy dissipation capacity. The MF and ED assemblies are designed concurrently so that the structure peak lateral displacements can be accommodated by the frame in the elastic range; the structure then remains free of damage and centering capacity is maintained during the earthquake.

The frame stiffness and elastic deformation capacity can be adjusted by varying member sizes, the orientation of the columns, and the number of moment resisting bays. Minimum lateral strength may also be provided for enhanced robustness. The brace-ED assemblies need not be located in the moment frame bays. In multi-storey structures, they can be positioned strategically to reduce beam axial loads and brace induced loads in columns and foundations. The design can be performed using response spectrum analysis assuming effective linear properties and equivalent damping ratio, as described in Chapter 18 of ASCE 7-10 (ASCE 2010). The solution is then validated using nonlinear response history (NLRH) analysis under site representative seismic ground motions.

Self-centering moment and braced steel frames: Self-centering moment frames (SC-MF) are built with special beam-to-column connections that exhibit re-centering capacity. This behaviour is achieved by using post-tensioned horizontal tendons inducing compression at beam-to-column interfaces (Fig. 1). The connections also include ED mechanisms to improve the system response. Hysteretic (Ricles et al. 2001; Christopoulos et al. 2002) or friction (Rojas et al. 2005; Kim and Christopoulos 2008) ED systems have been studied. The activation moment $M_{c,a}$ is the total moment from post-tensioning and ED systems. Once this moment is exceeded, the joint exhibits a post-ac-

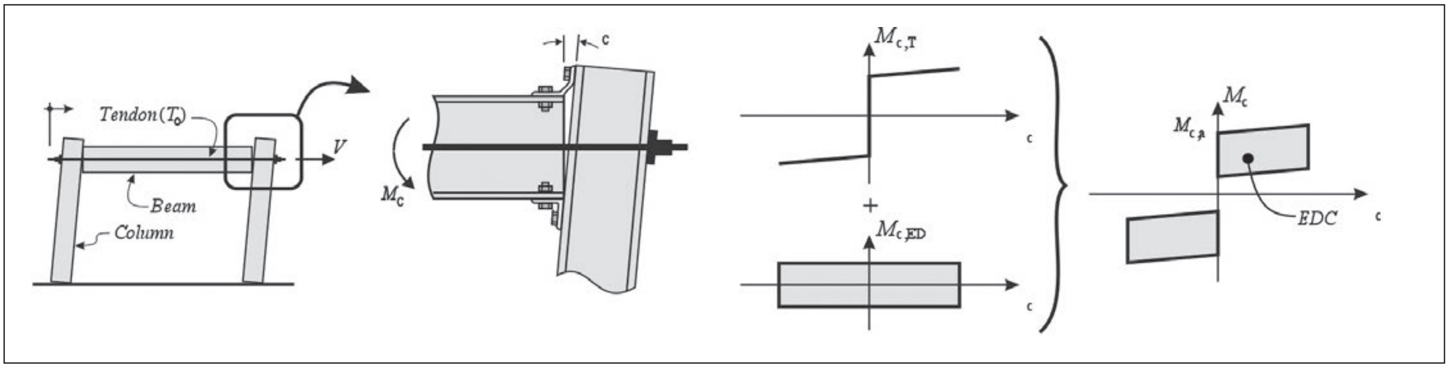

Fig. 1 Self-centering moment frame with post-tensioned connections including hysteretic ED.

tivation stiffness due to elongation of the tensioning elements and, possibility, the ED mechanism. Full re-centering response is reached if the moment from post-tension equals or exceeds the moment from ED. In SC frames, gap opening in connections causes lateral expansion of the frame, which may induce tension in floor slabs, additional compression in beams, and moments in the columns. This behaviour must be considered in design. Analysis methods and means of mitigating these effects have been proposed (Garlock et al. 2007; Kim and Christopoulos 2009; Dowden and Bruneau 2011).

Recent research has also led to the development of special bracing members that exhibit re-centering response in both tension and compression, without structural damage. The concept for one such SC brace is illustrated in Fig. 2a. The brace includes a pair of tubular (HSS) members and pre-tensioned elastic tendons designed to reposition the pieces to their original configuration after the brace has been axially deformed in either direction. The brace also includes built-in ED to better control the lateral displacements. Friction is shown in Fig. 2a but steel yielding can also be used (e.g. Braconi et al. 2012; Miller et al. 2012). Pre-tension and ED combine to give the brace activation load F_a. Alternatively, the tendons can be fabricated from shape-memory alloy (SMA) material combining re-centering and energy dissipation capabilities (Dolce et al. 2000; Alam et al. 2007). SC braces with SMA bars have been examined in several studies (Zhu and Zhang 2008; Walter Yang et al. 2010; Miller et al. 2012; Haque and Alam 2015). An example is depicted in Fig. 2b.

Although SC-MFs or SC braces can be employed in damped MFs to enhance their re-centering capacity, SC-MFs are intended to be constructed without supplemental EDs and SC braces are used to form self-centering braced frames (SC-BFs) without parallel moment frames. For both systems, preliminary design can be carried out using force-based procedures specified in current building codes. In SC-MFs, design activation moments are the moments from factored gravity plus seismic loads and, following capacity design principles, beams and columns are designed to resist combined axial forces and moments that will develop when the connections reach their peak rotations. Beams and columns must also be chosen to satisfy drift limits. Hence, member sizes in SC-MFs are expected to be similar to or larger than those of MFs designed for ductile inelastic response, and markedly larger than those required for damped MFs. Similarly, for the braces of SC-BFs, design activation loads are the factored axial forces from gravity and seismic loads and brace connections, beams, and columns will have to resist gravity loads plus maximum anticipated brace forces. Force-based designs for SC-MFs and SC-BFs are then validated and refined using NLRH analysis of the structure.

Controlled-rocking braced steel frames: By using braced steel frames designed to rock at their bases by allowing columns to uplift, rocking response can limit seismic induced forces, and frame members can then be designed to remain essentially elastic. Similar to beam-column joints in SC-MFs, compression from gravity loads and/or post-tensioned vertical tendons provides the re-centering rotational capacity at the base of controlled rocking braced frames (CR-BFs). The amplitude of base rocking and resulting lateral displacements can be controlled by the base decompression moment and vertical ED elements linking the column bases and the foundation. Viscous, friction, and hysteretic dissipative systems can be used for this purpose (Tremblay et al. 2008, Eatherton et al. 2014, Wiebe et al. 2013). Viscous is potentially more effective as it offers lower resistance to re-centering. In low-rise buildings, gravity loads may provide sufficient overturning capacity without post-tensioning elements. In taller frames, post-tensioned tendons are generally needed. In design, CR-BFs can be isolated from the structure gravity framing to prevent damage due to floor vertical displacements due to column uplift. This response requires special connections capable of transferring lateral loads while allowing vertical movements. Friction bearings placed between the gravity and CR-BF columns may be used for this purpose while also providing for ED upon rocking (Sause et al. 2010).

In design, the required base moment capacity can be determined using force-based seismic design methods and appropriate ductility factors. Member forces can be estimated using response spectrum analysis where only the first-mode contribution is reduced to reflect the expected base overturning moment resistance. This approach, as well as techniques to account for additional rocking interfaces and

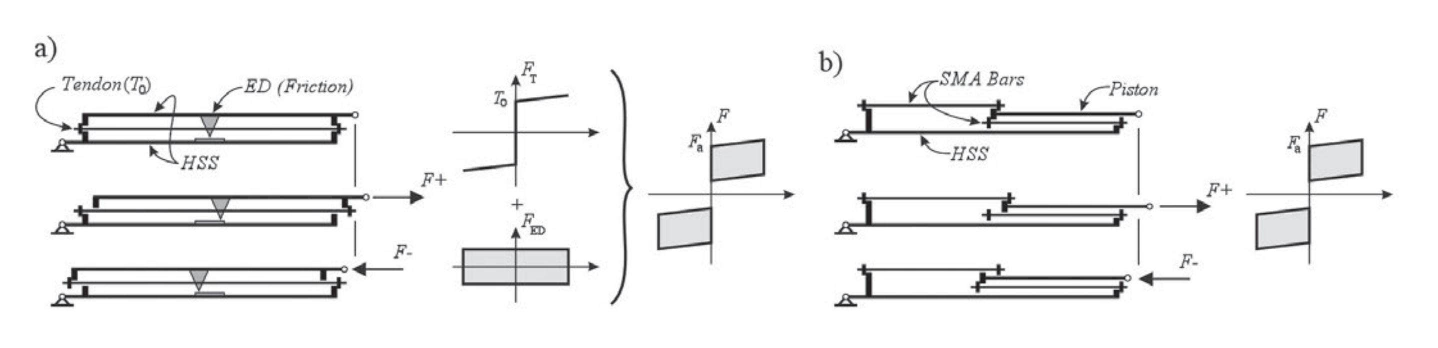

Fig. 2 Self-centering braces with: a) Elastic tendons and friction ED (Christopoulos et al. 2008);
b) Shape-memory alloy tendons (Haque and Alam 2015).

base shear fuses, are presented in Wiebe and Christopoulos (2014). As for other systems, NLRH analysis is used for validation and possible refinement of the design solution.

Concluding remarks

The structural steel systems described herein represent highly promising avenues to achieve superior seismic performance for building structures compared to seismic force resisting systems described in current Canadian codes. All new systems can be designed to avoid structural damage and control lateral displacements. They also possess re-centering capacity to minimize residual deformations. That behaviour also eliminates progressive drifting due to P-delta effects observed for traditional yielding structures subjected to seismic ground motions.

Rocking steel braced frames have already been adopted for three new buildings ranging from 3 to 15 storeys in New Zealand (Wiebe 2015). In the aftermath of the 2010-2011 earthquakes in Christchurch, it is expected that this and other similar advanced steel systems will be used in the future. CR-BFs are also suitable for the seismic retrofit of existent deficient structures in view of the fact that forces imposed to the foundation can be controlled by rocking (Tremblay et al. 2016).

In Canada, systems as described in this article have not been adopted in practice. Design complexity and absence of codified design procedures have probably contributed to this situation. Simplified design procedures have already been proposed for some of the systems and others are continually being developed to achieve more cost-effective and reliable solutions. Guidance on NLRH analysis has been significantly improved in the 2015 NBCC, which should ease this phase of the design. Performance-based seismic design methods have recently become available to develop design solutions that meet project-specific performance objectives. In Canada, performance-based seismic design has been introduced for bridge structures in CSA S6 standard (CSA 2014) and it is expected the approach will be implemented for building structures in 2020. This should provide a reference framework for engineers. ■

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Science camp introduces youth to engineering

CSCE past-president Cathy Lynn Borbely was busy in early August guiding young girls through hands-on activities related to science, engineering, and technology during a camp at the University of Regina called Educating Youth through Engineering and Science (EYES).

"It was a real treat to be approached for this opportunity," Borbely says. "I know what it's like to aspire to be an engineer in a world where many jobs have been gendered. I appreciate the effect a program like this has on young girls. It really opens their eyes to new possibilities and helps guide them to their goals."

While EYES is available to all children from grades 4 to 9, Borbely participated in the All Girls EYES Junior Program. This program is made up of all-female staff and campers. A female mentor who works within engineering, science or technology is also approached to participate. Throughout the camp, the campers participate in a science story adventure where they are faced with a problem to solve.

"I was so impressed with the program and the format and how enthusiastic all the girls were. They were really excited to know how to build strong structures," Borbely explains. "I am telling everyone I know about it because it is such a great program for children who are interested in science, engineering and technology."

EYES camps are held during July and August. Information about EYES camps can be found at: http://eyes.uregina.ca/camps/ ■

Cathy Lynn Borbely with the young girls attending the EYES camp.

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MAJOR PARTNERS / ASSOCIÉS PRINCIPAUX

PARTNERS / ASSOCIÉS

AFFILIATES / AFFILIÉS

CSCE SECTIONS SCGC

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

Nova Scotia
Contact: Haibo Niu
E-mail: haibo.niu@dal.ca

East New Brunswick and P.E.I. (Moncton)
Contact: Samuel Richard
T. 506-857-3164
E-mail: samuel.richard@canamgroupinc.com

West New Brunswick
Contact: Brandon Searle
T. 506-260-3947
E-mail: Brandon.searle@opusinternational.ca

Montréal
Contact: Frédéric Brunet, MASCGC
T. 514-583-4632
E-mail : frederic.brunet@hotmail.ca

Sherbrooke
Contact: Jean-Gabriel Lebel
T. 514-502-7368,
Courriel: jg.lebel@usherbrooke.ca

Québec
Contact: Kim Lajoie
T. 418-650-7193
Courriel: scgc-sectionquebec@outlook.com

Capital Section (Ottawa-Gatineau)
To be announced

Toronto
Contact: Nigel Parker, AMCSCE
T. 647-463-5002
E-mail: nparker@rjc.ca

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

Northwestern Ontario
Contact: Gerry Buckrell, MCSCE
T. 807-625-8705/807-623-3449
E-mail: gerald.buckrell@hatchmott.com

Durham/Northumberland
Contact: Robbie Larocque
T. 905-576-8500
E-mail: robbie.larocque@dgbiddle.com

London & District
Contact: Stephanie Dalo
T. 519-673-0510
E-mail: stephanie.dalo@aecom.com

Manitoba
Contact: Tricia Stadnyk
T. 204-474-8704
E-mail: Tricia.Stadnyk@umanitoba.ca

South Saskatchewan
Contact: Harold Retzlaff, MCSCE
T. 306-787-4758
E-mail: harold.retzlaff@gov.sk.ca

Saskatoon
Contact: Ehren Gadzella
T. 306-343-7280
E-mail: e.gadzella@cwce.ca

Calgary
Contact: Kris Karvinen
T. 403-716-1489
E-mail: cscecalgarychapter@gmail.com

Edmonton
Contact: Mark A. Scanlon, MCSCE
T. 780-801-6115
E-mail: mark.scanlon@arrowonline.ca

Vancouver
Contact: Graham Walker
T. 780-496-5695
E-mail: graham.walker2@aecom.com

Vancouver Island
Contact: Jonathan Reiter
T. 250-590-4133
E-mail: jreiter@seng.ca

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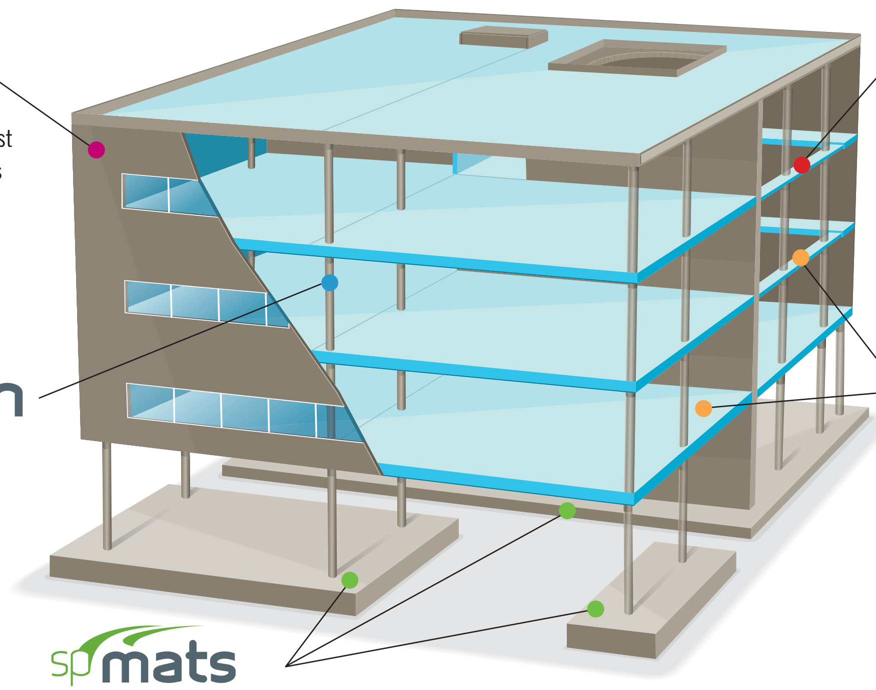

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