Centre d'expertise et de recherche en infrastructures urbaines (CERIU)
Congrès INFRA 2019

Utilisation de matériaux innovants pour accroître la durabilité des ponts

4 décembre 2019

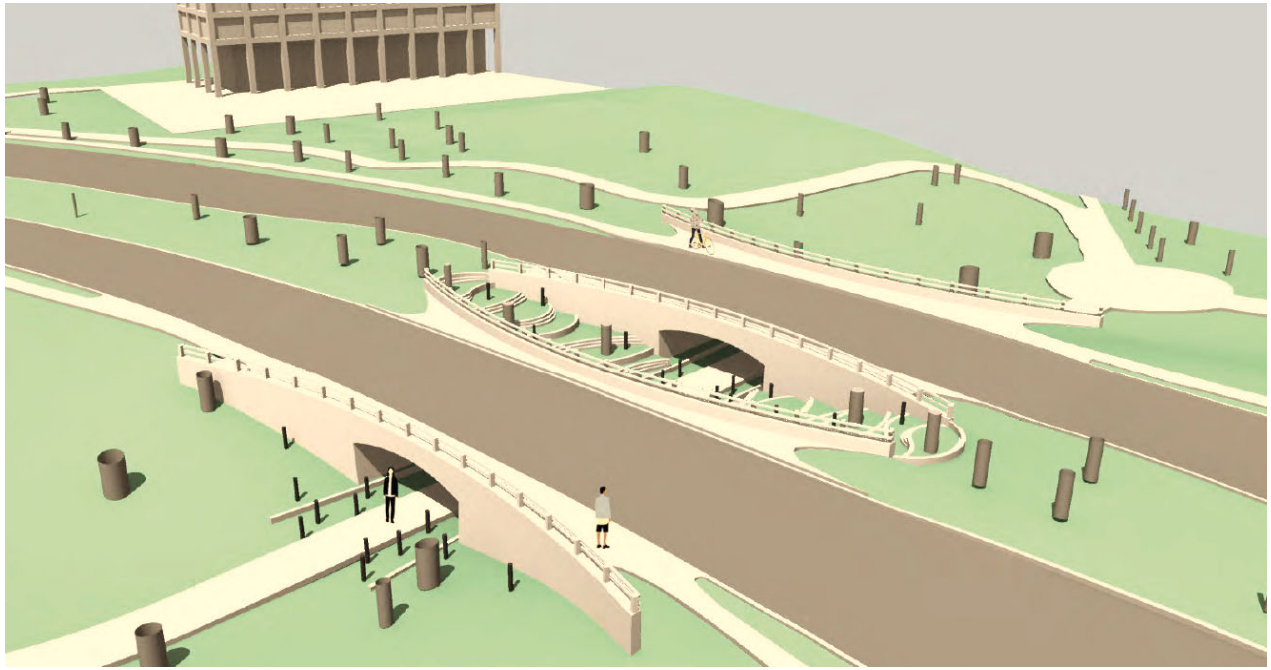
Étienne Cantin Bellemare, ing., PMP, Ass. écologique LEED

Montréal

Ville de Montréal – Section ponts et tunnels

1. Béton avec poudre de verre
2. Barre d’armature en acier inoxydable
3. Passerelle en aluminium
4. Barre d’armature en PRF
5. Béton fibré à ultra-hautes performances

Contenu

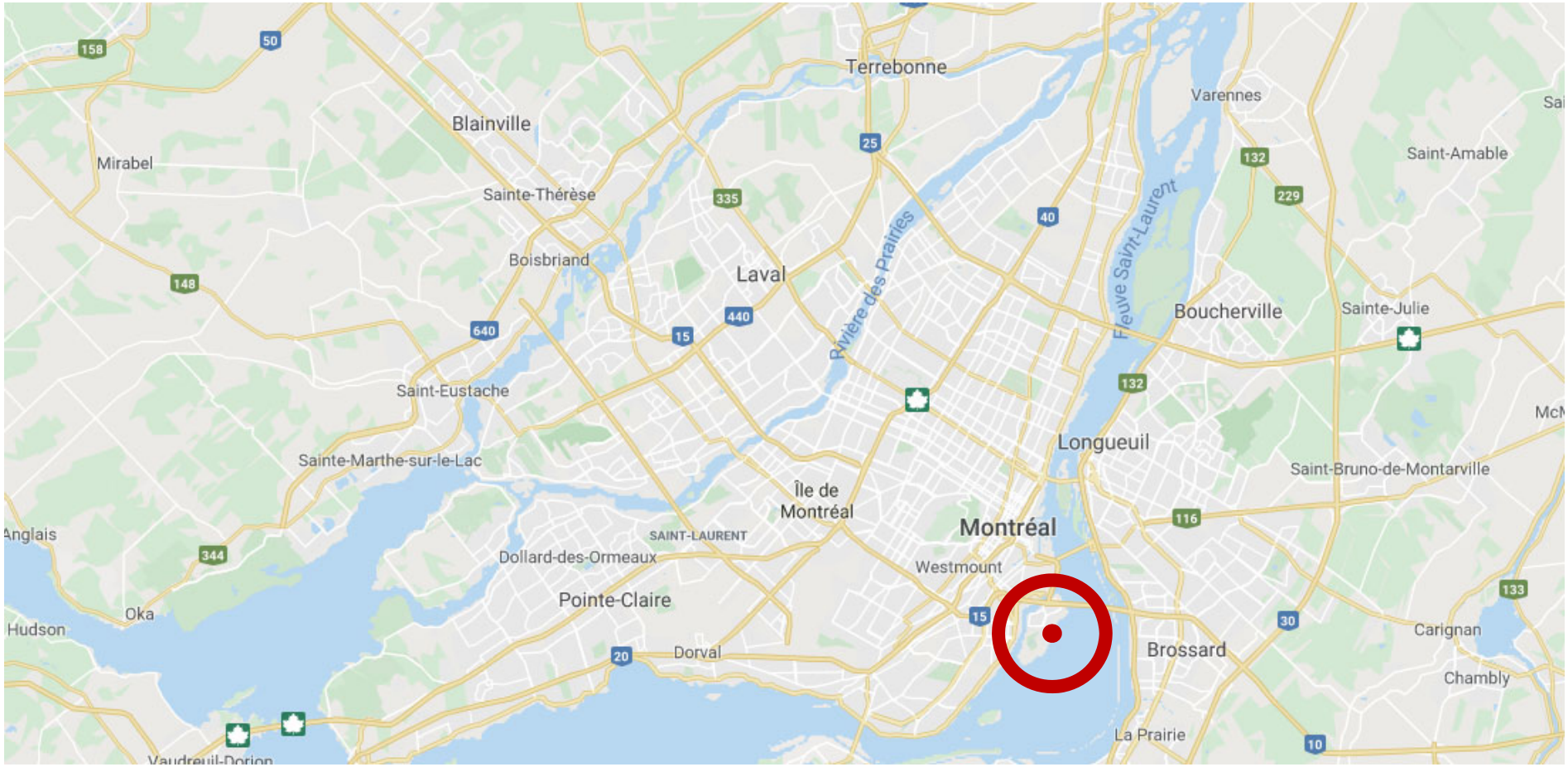


Projet : Construction des ponts West Vancouver

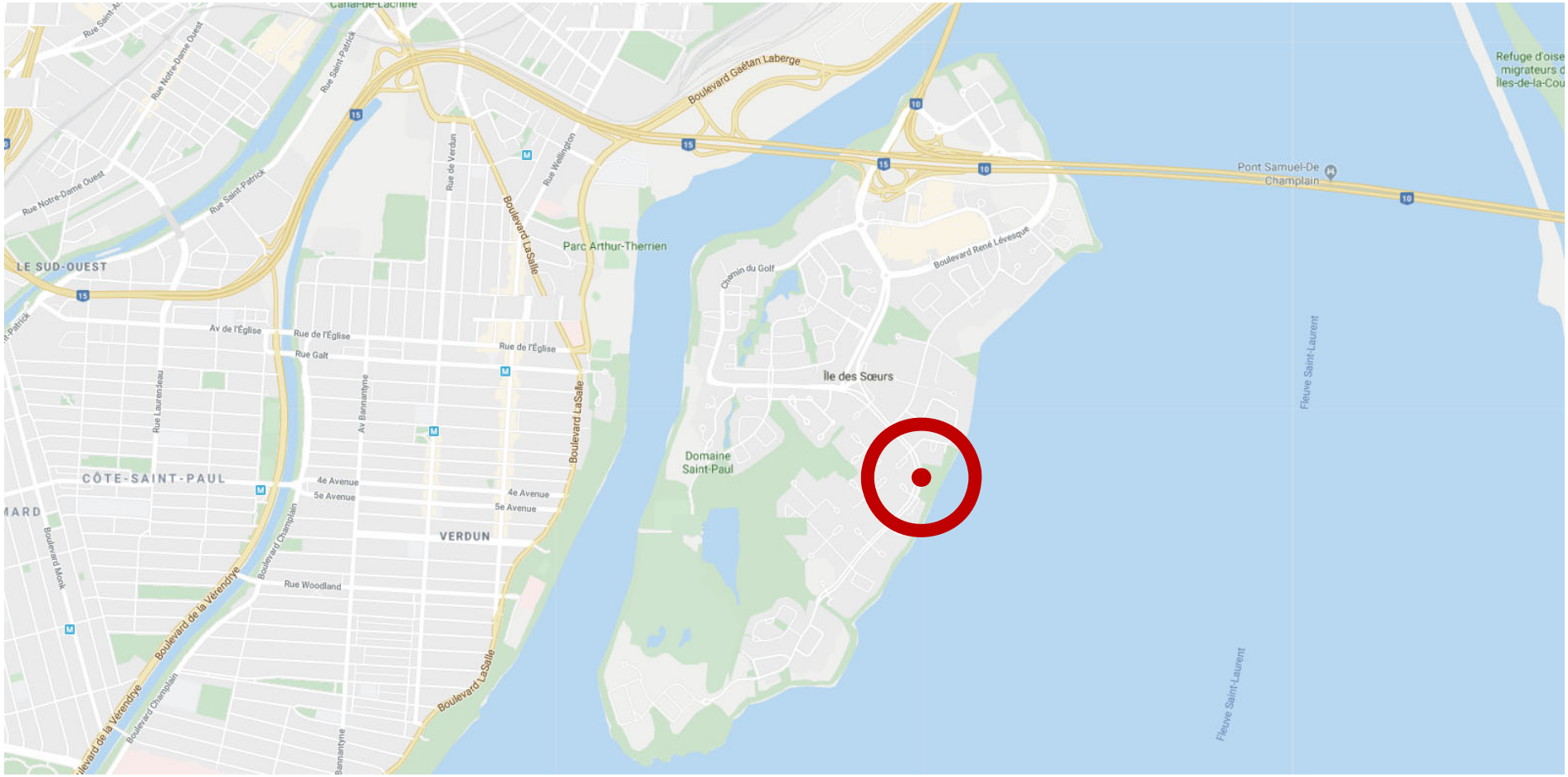
Années : 2020-2021

Conception : Ville de Montréal, Provencher-Roy

1.1 Béton avec poudre de verre



1.2 Localisation



1.2 Localisation

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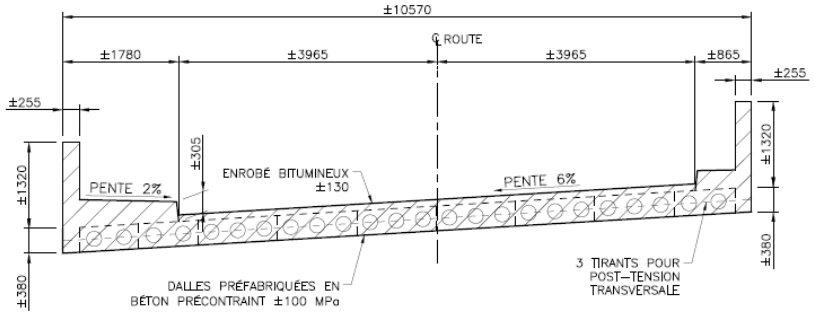
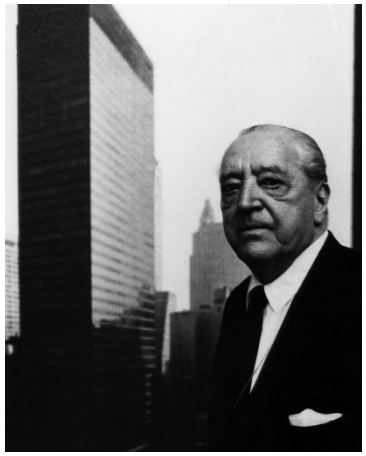
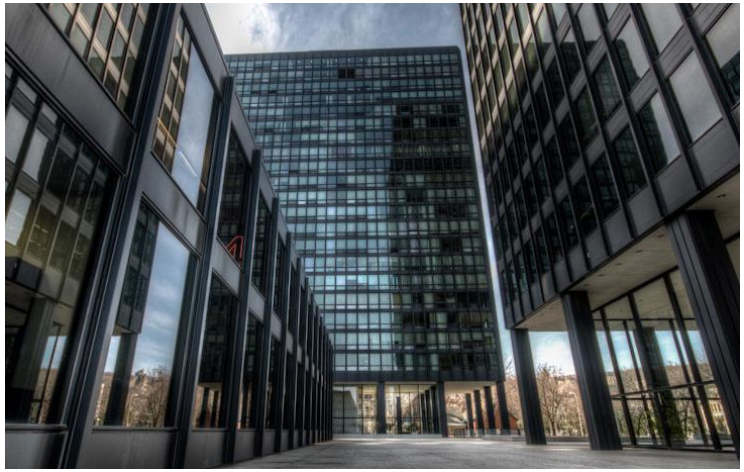
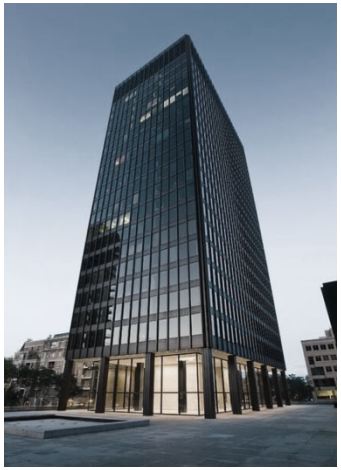


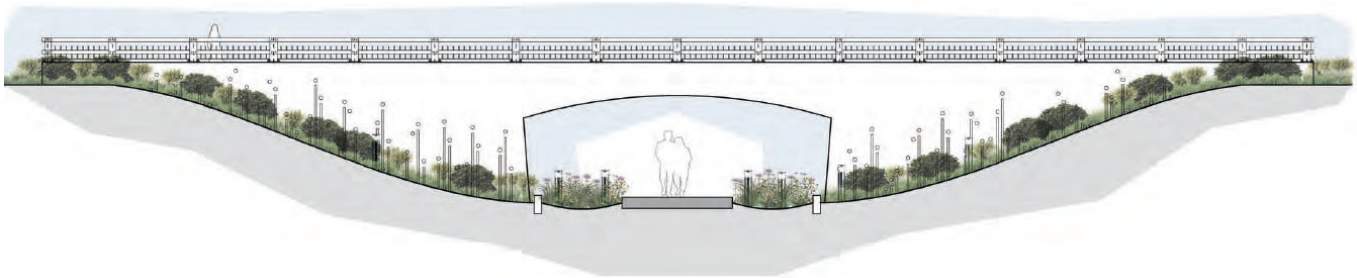
1.3 Ponts existants

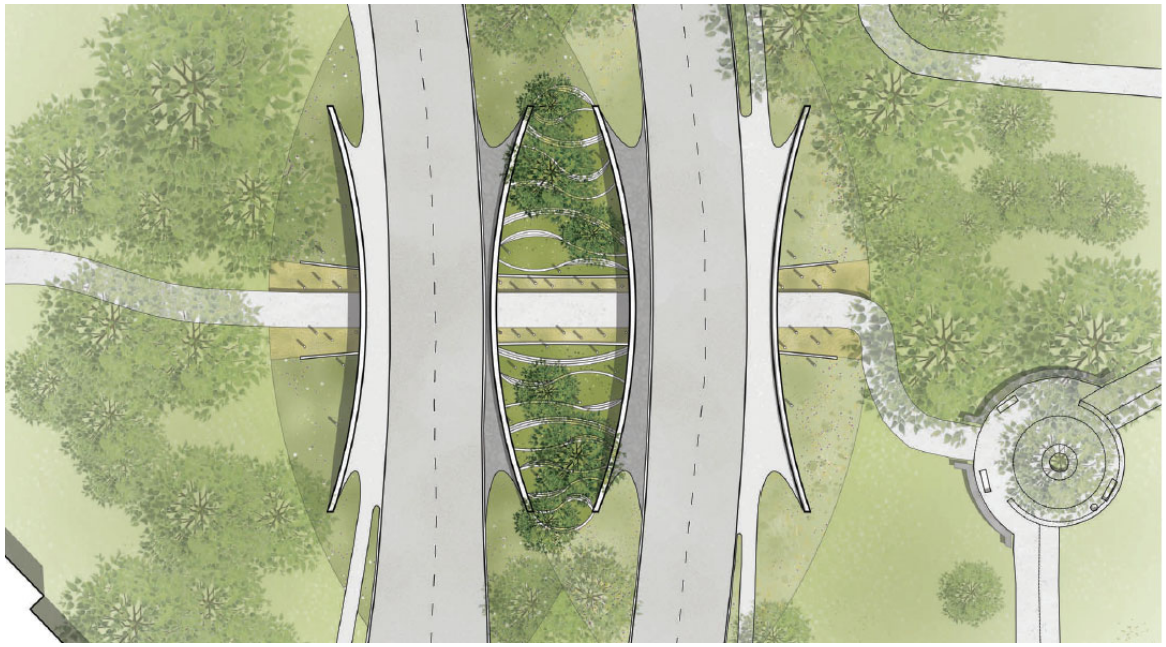
1.4 Tour Corot




1.5 Ludwig Mies Van der Rohe





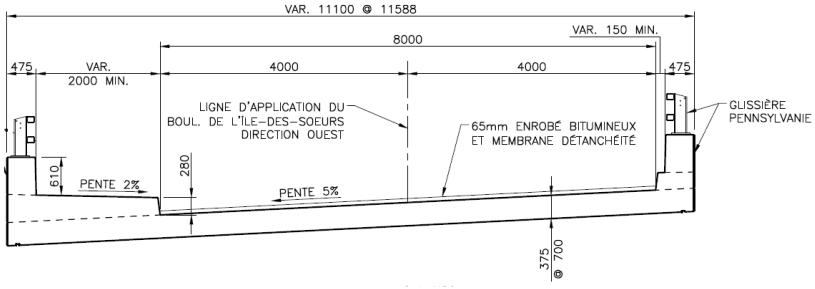
Structure :

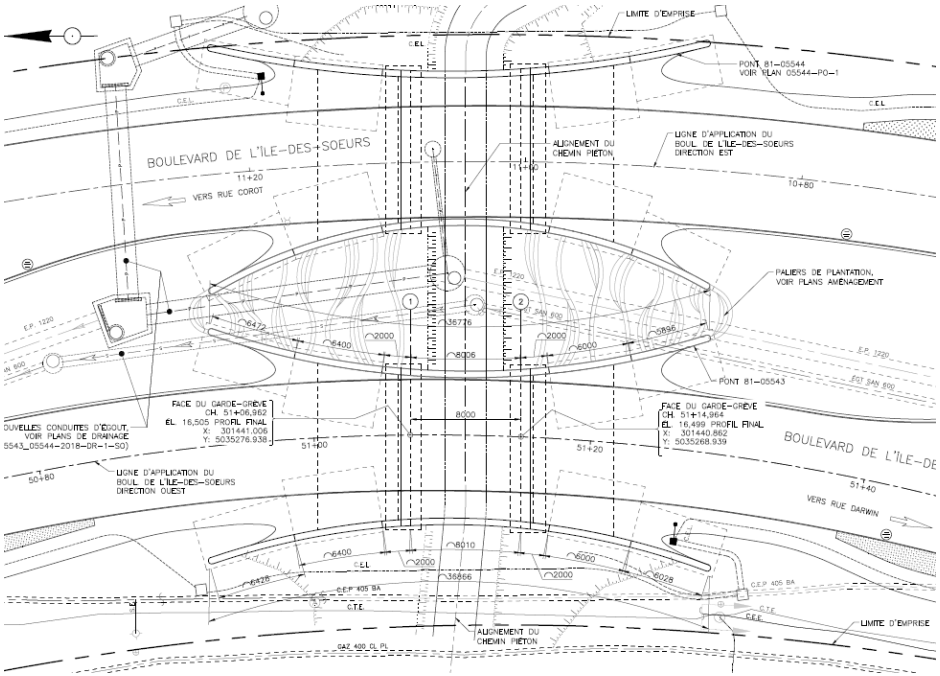
Montréal

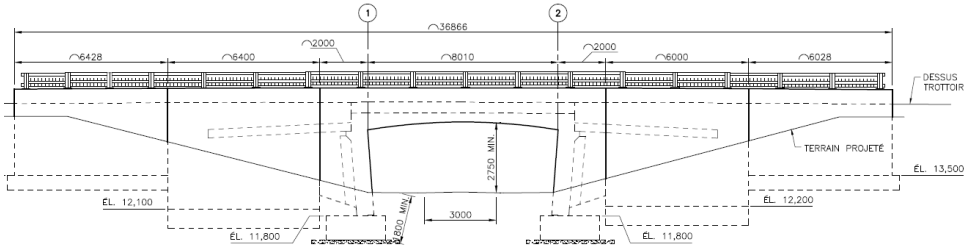
Architecture :

PROVENCHER_ROY

1.6 Ponts West Vancouver





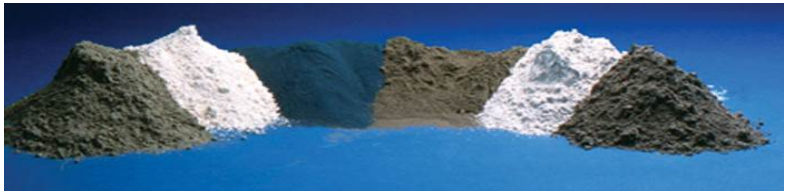


1.6 Ponts West Vancouver

Exigences :

Propriétés d'un type V-S ternaire (C-XL)

Béton blanc



Développement béton blanc :

GU blanc + 10 % métakaolin

GU blanc + 15 % métakaolin

Conclusion :

Non-respect perméabilité (1000 C).

Découverte de la poudre de verre…

1.7 Béton

Chaire SAQ de valorisation du verre dans les matériaux

Partenaires : SAQ, Ville de Montréal, Équiterre, Permacon, Béton génial

En collaboration avec :

Prof. Arezki Tagnit-Hamou, ing., Ph.D.

UNIVERSITÉ DE SHERBROOKE

Ville de Montréal 2015-2018 :
22 000 m^3 béton trottoir

1.8 Chaire SAQ

LA PRESSE .CA

À la recherche de la solution miracle pour mieux recycler le verre

La Communauté métropolitaine de Montréal (CMM) débute aujourd'hui une large consultation publique pour repenser le recyclage et la consigne. En janvier, elle estimait que le verre n'avait plus sa place dans le bac de recyclage.

Mis à jour le 17 mai 2019 à 9h24

LA PRESSE .CA

La bataille du recyclage du verre

ISABELLE GRIGNON-FRANCKE
LA PRESSE

Mis à jour le 26 février 2019 à 18h20
Publié le 26 février 2019 à 8h24

À la consigne ou dans le bac de recyclage ? Un rapport qui sera rendu public aujourd'hui démontre qu'il est possible d'obtenir à grande échelle du verre très peu contaminé et de lui donner une deuxième vie en améliorant les opérations des centres de tri existants. Une avancée critiquée par les partisans de la consigne qui souhaitent agir au-delà d'une seule réutilisation. Explications.

LA PRESSE .CA

Recyclage du verre : la SAQ prête à appuyer une consigne

La Société des alcools du Québec (SAQ) est maintenant prête à appuyer la consignation des bouteilles de verre, après s'y être opposée vigoureusement pendant des années.

Publié le 12 août 2019 à 15h01

LA PRESSE .CA

Recycler le verre... pour vrai

PHOTO HUGO-SÉBASTIEN AUBERT, LA PRESSE

1.9 Enjeux liés au verre

Utilisation : 2e matière la plus utilisée dans le monde (5 milliards m^3 / année)

Production : Très énergivore

Approvisionnement : Pénurie d'ajouts cimentaires (cendres volantes)

1.10 Enjeux liés au béton

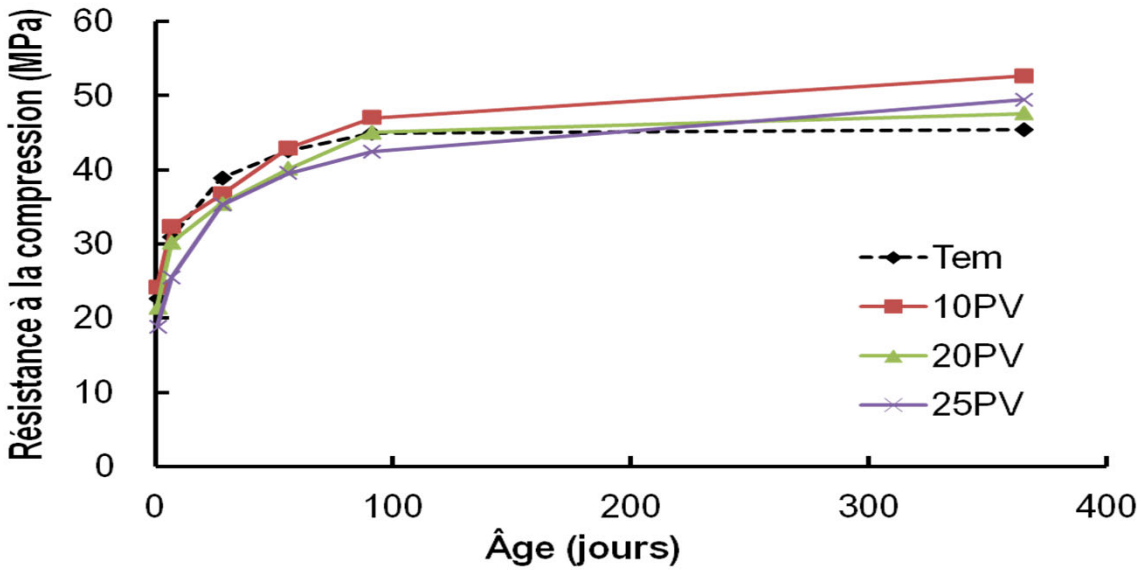
Depuis 2019 :
La poudre de verre est un ajout cimentaire nouvellement normalisée par la norme CSA-A3000-18.

1.11 Norme CSA

Résistance à 28 jours : légèrement inférieure

Résistance à 91 jours : similaire

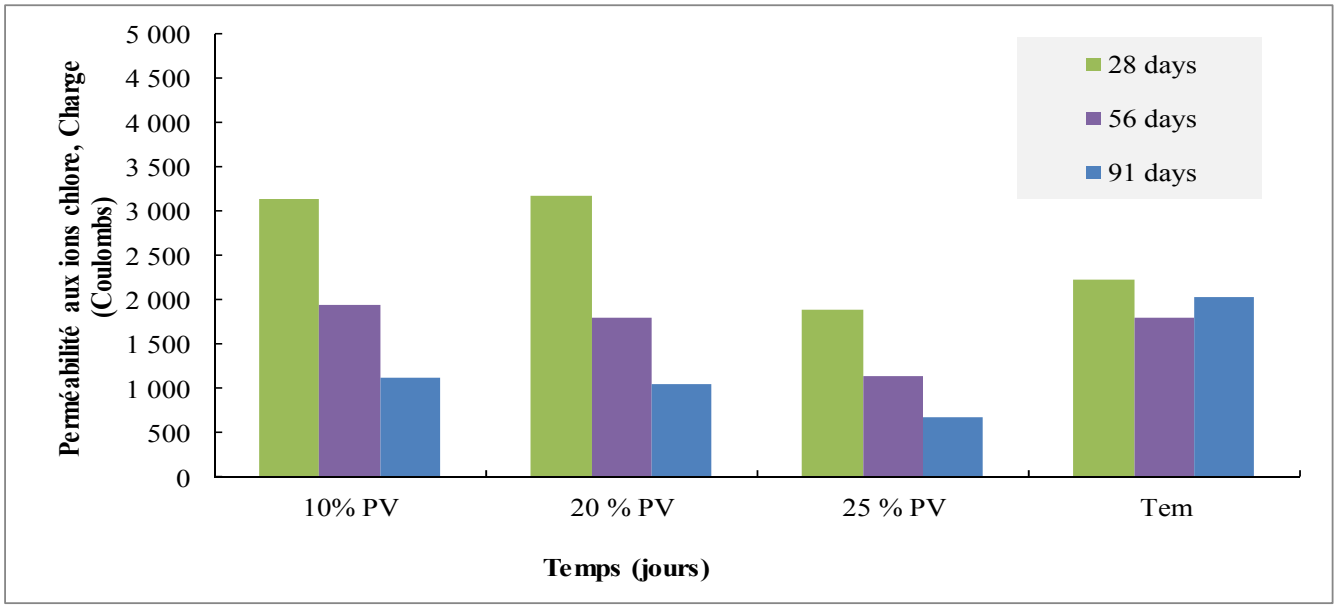
Résistance à 365 jours : légèrement supérieure



1.12 Résistance à la compression

Perméabilité à 28 jours : supérieure

Perméabilité à 91 jours : inférieure



1.13 Perméabilité aux ions chlore

Innovation :
Premier pont avec poudre de verre au monde

Béton :
Type V-S ternaire (norme 3101 MTQ)
35 MPa
GUb-S/SF (90 %)
Poudre de verre (10 %)

Programme de suivi :
Installation de jauges de déformation durant 1 an.
Carottage à tous les ans pendant 10 ans.
Mesure des propriétés modales à 0 an, puis au 5 ans.

1.14 Projet pilote

Adjuvant compensateur de retrait :
Conex (6 % poids liant)

Fibre synthétique :
Taux 2,3 kg/m^3

Contrôle de la température :
Bétonnage de soir ou de nuit

Décoffrage hâtif :
7 MPa (±12h)
Maturométrie

Cure à l'eau :
7 jours

*Collaboration étroite entre ingénieurs matériaux et structure

1.15 Stratégies de réduction du retrait

Béton avec PV = 1000 m^3

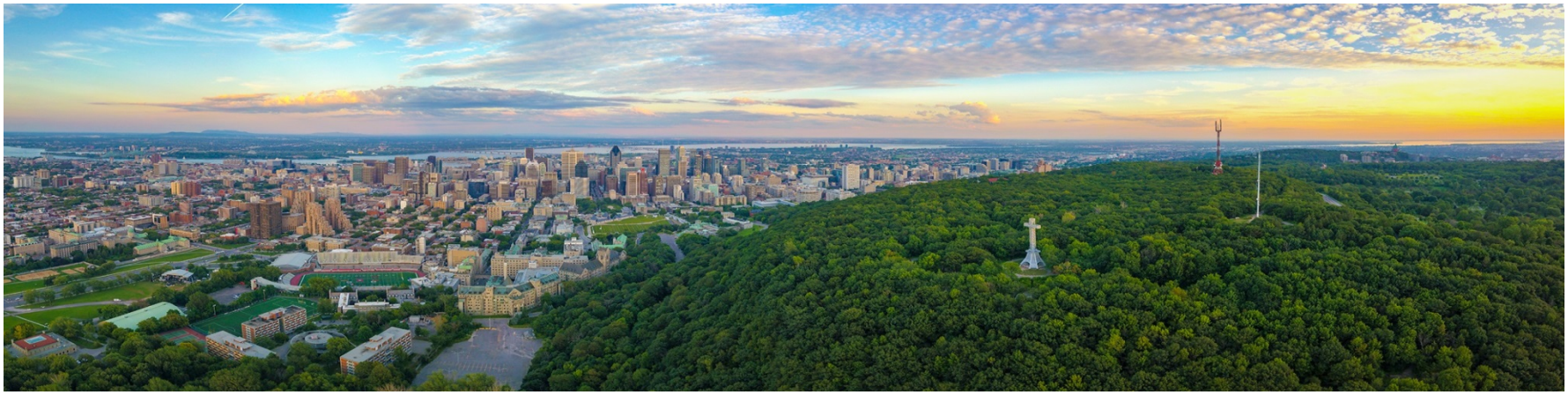
Ciment remplacé par PV = 1000 m^3 * 400 kg/m^3 * 10% = 40 000 kg (40 T)

Bouteilles de vin valorisées = 120 000 bouteilles

1 T de ciment → 1 T de CO_2

40 T de ciment → 40 T de CO_2

CO_2 produit par voiture 200 000 km

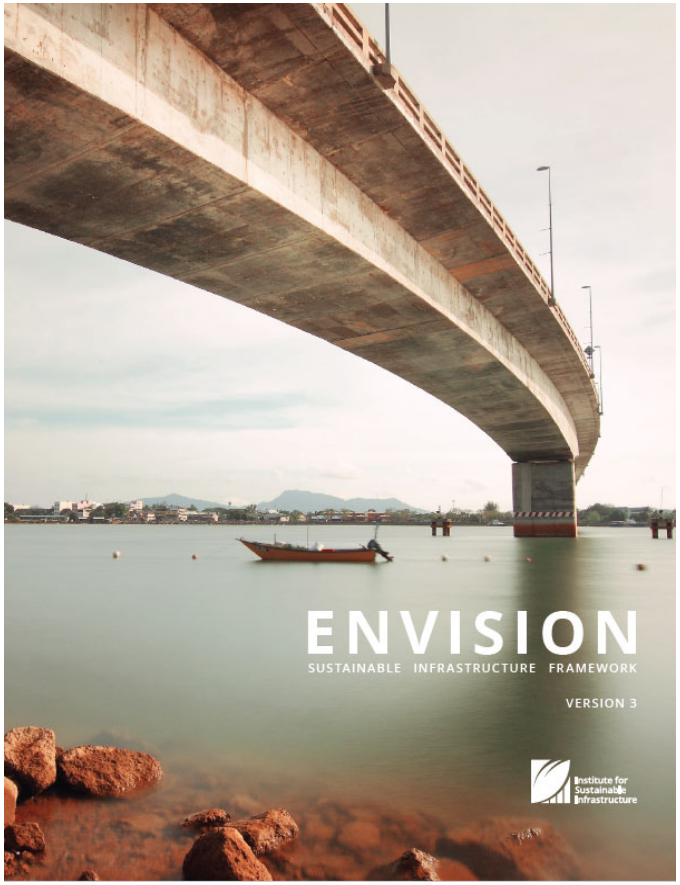


1.16 Empreinte environnementale

Développé par :

Harvard University
American Society of Civil Engineers

Energy	Water	Waste	Transportation	Landscape	Information
Distribution	Treatment	Solid waste	Airports	Public Realm	Telecom
Hydroelectric	Distribution	Recycling	Roads / Highways	Parks	Cables
Coal	Capture / Storage	Hazardous	Bikes / Pedestrians	Ecosystem Services	Internet
Natural Gas	Stormwater	Waste	Railways	Natural Infrastructure	Phones
Wind	Flood Control	Collection & Transfer	Transit	Environmental Remediation	Data Centers
Solar	Nutrient Management		Ports		Sensors
Biomass			Waterways		



1.17 Certification environnementale Envision

Coût béton seulement :
Sans PV : XXX $/m^3
Avec PV : XXX $/m^3 (+15 %)

Coût béton, coffrage, mise en place et cure :
Sans PV : XXX $/m^3
Avec PV : XXX $/m^3 (+5 %)

Coût projet :
Sans PV : XXX $
Avec PV : XXX $ (+1,5 %)

1.17 Coût

Projet : Construction des ponts West Vancouver

Années : 2020-2021

Conception : Ville de Montréal, Provencher-Roy

2.1 Barre d’armature en acier inoxydable

Acier au carbone

Acier au carbone recouvert d'époxy

Acier au carbone galvanisé

Acier au chrome (MMFX)

Acier inoxydable

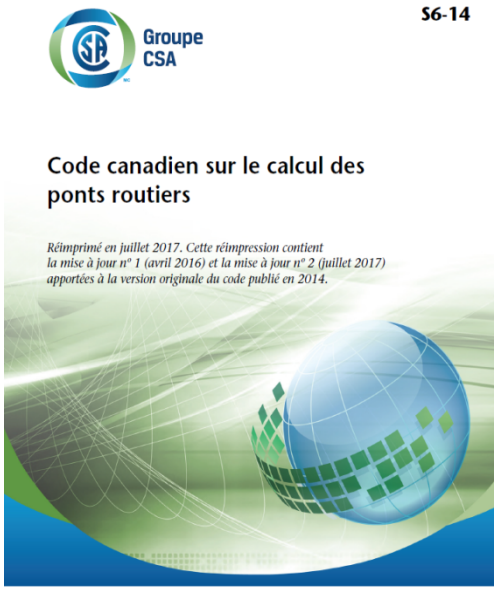
Polymère renforcé de fibre

2.2 Types d'armature

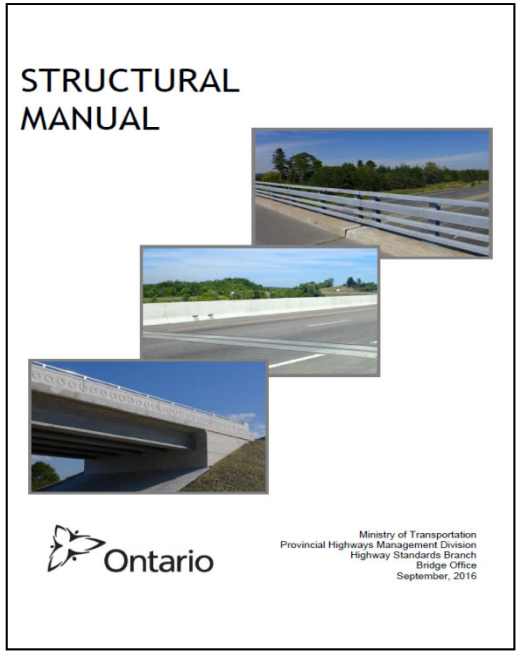
Barres d’armature en acier inoxydable absentes de :

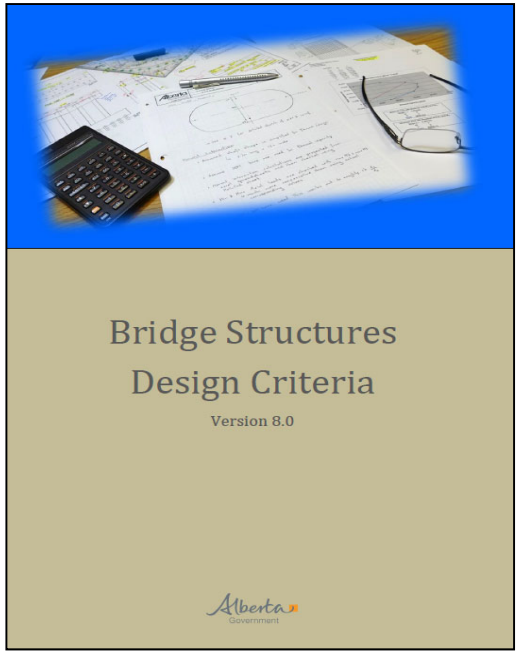
<u>Codes :</u>
Code canadien sur le calcul des ponts routier (CAN/CSA-S6-14)
Calcul des ouvrages en béton (CSA-A23.3-19)
AASHTO LRFD Bridge Design Specifications 2017

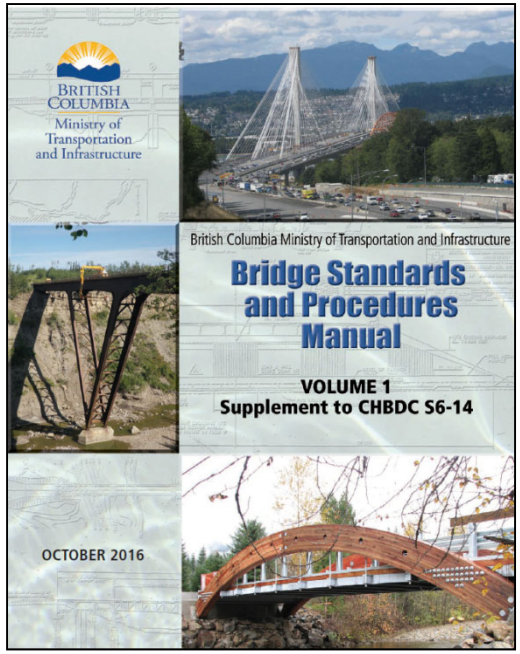
<u>Manuels :</u>
Manuel de conception des structures (MTQ)
Tome III Ouvrages d’art (MTQ)
Tome VIII Matériaux (MTQ)



2.3 Codes et manuels de conception







Applications : Dalles de tablier et glissières.

2.4 Au Canada

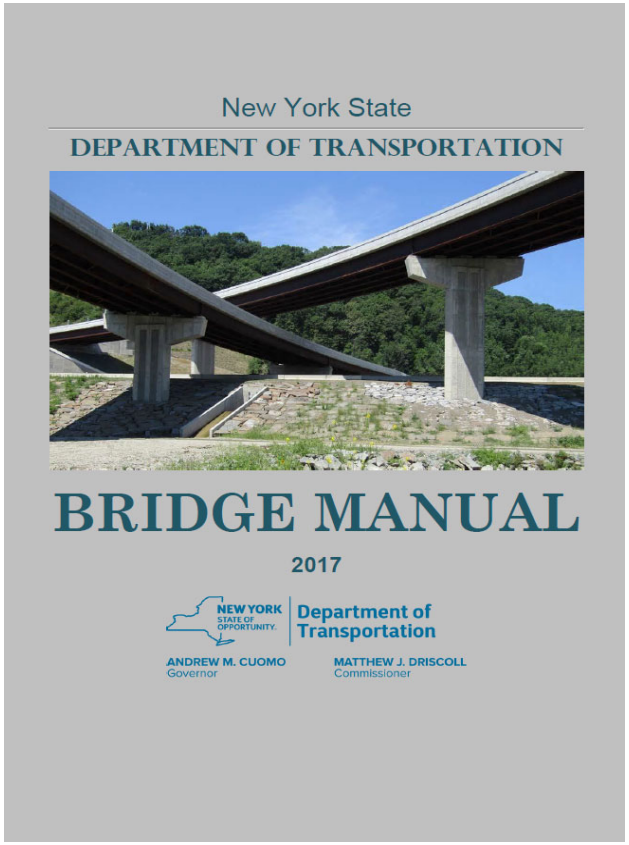
Couramment utilisé :

New York
Virginia
Pennsylvanie
Oregon
Florida
Arizona

Projets pilotes :

Maryland
Delaware
Iowa
Kentucky

Applications : Dalles de tablier et glissières.



2.5 Aux États-Unis

Progreso Pier :

Yucatan, Mexique

2,1 km

1941 (78 ans)

Type 304

2.6 Ailleurs dans le monde

ASTM A955M-19
Deformed and Plain Stainless Steel Bars for Concrete Reinforcement

BS 6744:2016
Stainless steel bars. Reinforcement of concrete. Requirements and test methods

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: A955/A955M – 19

Standard Specification for Deformed and Plain Stainless Steel Bars for Concrete Reinforcement[1]

This standard is issued under the fixed designation A955/A955M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers deformed and plain stainless steel bars for concrete reinforcement in cut lengths and coils used in applications requiring resistance to corrosion or controlled magnetic permeability. The standard sizes and dimensions of deformed bars and their numerical designation shall be those listed in Table 1.

1.1.1 A supplementary requirement (S1) is provided for use where a controlled magnetic permeability product is required by the purchaser. Supplementary requirement (S1) applies only when specified in the purchase order.

1.2 The chemical composition of the stainless steel alloy shall be selected for suitability to the application involved by agreement between the manufacturer and the purchaser. This is an important consideration in achieving the desired corrosion resistance or controlled magnetic permeability, or both, because these properties are not provided by all stainless steels.

1.3 Corrosion Resistance requirements are contained in Section 11 and Annex A1 and the test procedures options are Annex A2 (Rapid Macrocell Test) or Annex A3 (Cracked Beam Test).

1.4 The requirements for introduction of new alloys into a mandatory chemical composition requirements table in this specification are given in Annex A5.

1.5 Requirements for the relative deformation area of three-sided deformed bars are contained in Annex A4.

1.6 Bars are of three minimum yield strength levels, namely, 60 000 psi [420 MPa], 75 000 psi [520 MPa], and 80 000 psi [550 MPa], designated as Grade 60 [420], Grade 75 [520], or Grade 80 [550], respectively.

1.7 Plain bars in sizes up to and including 2 in. [50.8 mm] in diameter in coils or cut lengths are furnished in accordance with this specification in Grade 60 [420], Grade 75 [520], and Grade 80 [550], respectively. Mechanical testing, when required, shall be to the nearest nominal deformed bar size. Requirements providing for deformations and marking shall not be applicable to plain bars.

1.8 When stainless steel is to be welded, use a procedure suitable for the chemical composition and intended use or service.

NOTE 1—Welding of stainless steel reinforcement would occur after shipment from the manufacturer. Structural welding should be performed in accordance with the latest edition of AWS D1.6/D1.6M, any other internationally accepted stainless steel welding code, or a procedure suggested by the material manufacturer. AWS D1.6/D1.6M describes the proper selection of the filler metals, temperature control, as well as, performance, procedure qualification and inspection requirements.

1.9 This specification is applicable for orders in either inch-pound units (as Specification A955) or in SI units (as Specification A955M).

1.10 The text of this specification references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the specification.

1.11 The values stated in either inch-pound or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.12 *This specification does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this specification to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.13 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.05 on Steel Reinforcement.
Current edition approved May 15, 2019. Published May 2019. Originally approved in 1996. Last previous edition approved in 2018 as A955/A955M – 18b. DOI: 10.1520/A0955_A0955M-19.

***A Summary of Changes section appears at the end of this standard**

BRITISH STANDARD | BS 6744:2001

Stainless steel bars for the reinforcement of and use in concrete — Requirements and test methods

ICS 77.140.15, 91.080.40

"CONTROLLED"

2.7 Normes

Alliages :

ASTM	BS	Nom commun
S30400	1.4301	304
S32101	1.4162	Lean Duplex 2101
S31603	1.4436	316L
S31653	1.4429	316LN
S32304	1.4362	Lean Duplex 2304
S31803/S32205	1.4462	Duplex 2205
N08904	1.4529	Alloy 926
S32760	1.4501	Super Duplex 2507

PREN : Pitting resistance equivalent number

Grades :

ASTM : 420, 520 Mpa

BS : 200, 500, 650 MPa

2.8 Alliages

Corrosion galvanique :

Ne serait pas un enjeu selon la littérature sauf dans les zones d'éclaboussure.

Zone de rotule plastique :

Utilisation interdite.

Conception :

Comme pour acier au carbone.

ENGINEERING
ETN-M-2-18

Technical Note

CRSI Concrete Reinforcing Steel Institute

Frequently Asked Questions (FAQ) About Stainless Steel Reinforcing Bars

Introduction

CRSI routinely receives inquiries concerning various aspects of reinforcing bars, and reinforced concrete design and construction. This *Technical Note* presents a collection of typical questions that are asked regarding stainless steel reinforcing bars. Most of these questions come from licensed design professionals (LDPs), namely engineers and architects, field personnel (inspectors, code enforcement personnel, and contractors), and state Departments of Transportation (DOTs).

Stainless steel reinforcing bars are experiencing increased use in reinforced concrete projects because of the material's inherent properties, which depending upon the chemistry specified, may include corrosion resistance, low magnetic permeability, ductility, or a combination thereof. Figure 1 shows one example of the increased use of stainless steel reinforcing bars on a bridge deck in Minnesota. But what classifies steel as a stainless steel, as opposed to carbon steel? Stainless steel is defined by ASTM A941 (ASTM 2018b) as steel conforming to a specification that requires, by mass percent, a minimum chromium (Cr) content of 10.5 percent, and a maximum carbon (C) content of 1.20 percent. The carbon content of stainless steel reinforcing bars is less than 0.15 percent as indicated in Tables 1A and 1B. As presented herein, there are several stainless steel alloys used for reinforcing bars. The specific alloy used depends on the project requirements and design properties required by the LDP.

Specific frequently asked questions (FAQ) and responses are provided below.

Basic Material Characteristics

What Standards govern stainless steel reinforcing bars? Stainless steel reinforcing bars should be specified according to ASTM A955/A955M, (ASTM 2018c). ASTM A276/A276M (ASTM 2017), is another standard for stainless steel which is the reference for the chemistry requirements of A955/A955M.

Figure 1 – Stainless steel reinforcing bar used in the deck of a bridge structure located in Minnesota.

What alloys of stainless steel do the ASTM standards permit as reinforcing bars? ASTM A955/A955M states that the "chemical composition of the stainless steel alloy shall be selected for suitability to the application involved by agreement between the manufacturer and the purchaser. This is an important consideration in achieving the desired corrosion resistance or controlled magnetic permeability or both, because these properties are not provided by all stainless steels".

The chemical composition of the alloy must conform to the requirements of Table 1 in ASTM A276/A276M. Each alloy is identified by the six-character Unified Numbering System (UNS) designation starting with the letter "S" followed by five numeric digits. Specifications should always include the UNS number because it indicates the specific chemistry requirement(s). In addition, when recognized by ASTM A276/A276M, the common generic name or AISI type designation for the stainless steel alloy is noted in the second column. ASTM A955/A955M provides guidance regarding alloys commonly used for concrete reinforcement, but this is not a complete list of the products that could meet the requirements of the standard.

Stainless steels are classified by their microstructure into families: austenitic, ferritic, martensitic, or duplex. Only austenitic or duplex stainless steels are produced to requirements of ASTM A955/A955M

2.9 Enjeux

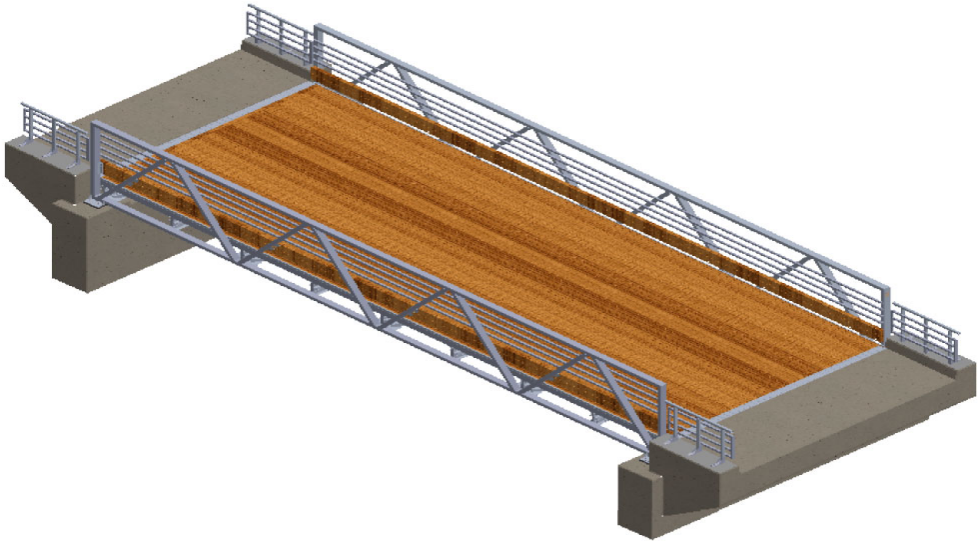
Coût armature 2304 seulement :
Galvanisé : 1,25 $/kg
Inoxydable : 5,00 $/kg (+400 %)

Coût armature 2304, pliage, livraison, installation :
Galvanisé : 2,25 $/kg
Inoxydable : 6,00 $/kg (+266 %)

Coût projet – Scénario dalle, culées, murs armature 2304 :
Galvanisé : XXX $
Inoxydable : XXX $ (+7,5 %)

Coût projet – Scénario dalle armature 2304 :
Galvanisé : XXX $
Inoxydable : XXX $ (+2,5 %)

2.10 Coûts

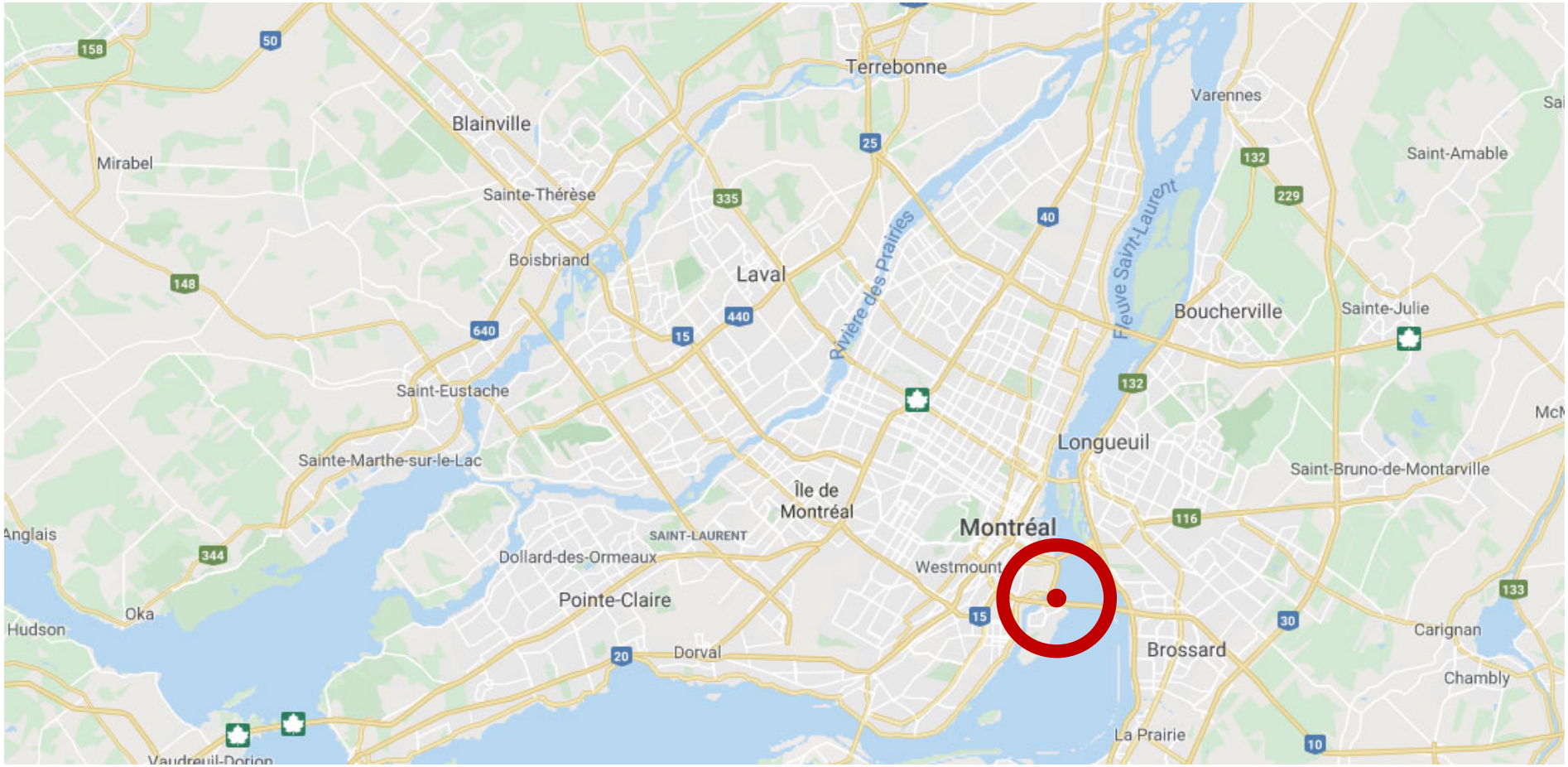


Projet pilote : Construction de la passerelle Pointe-Nord

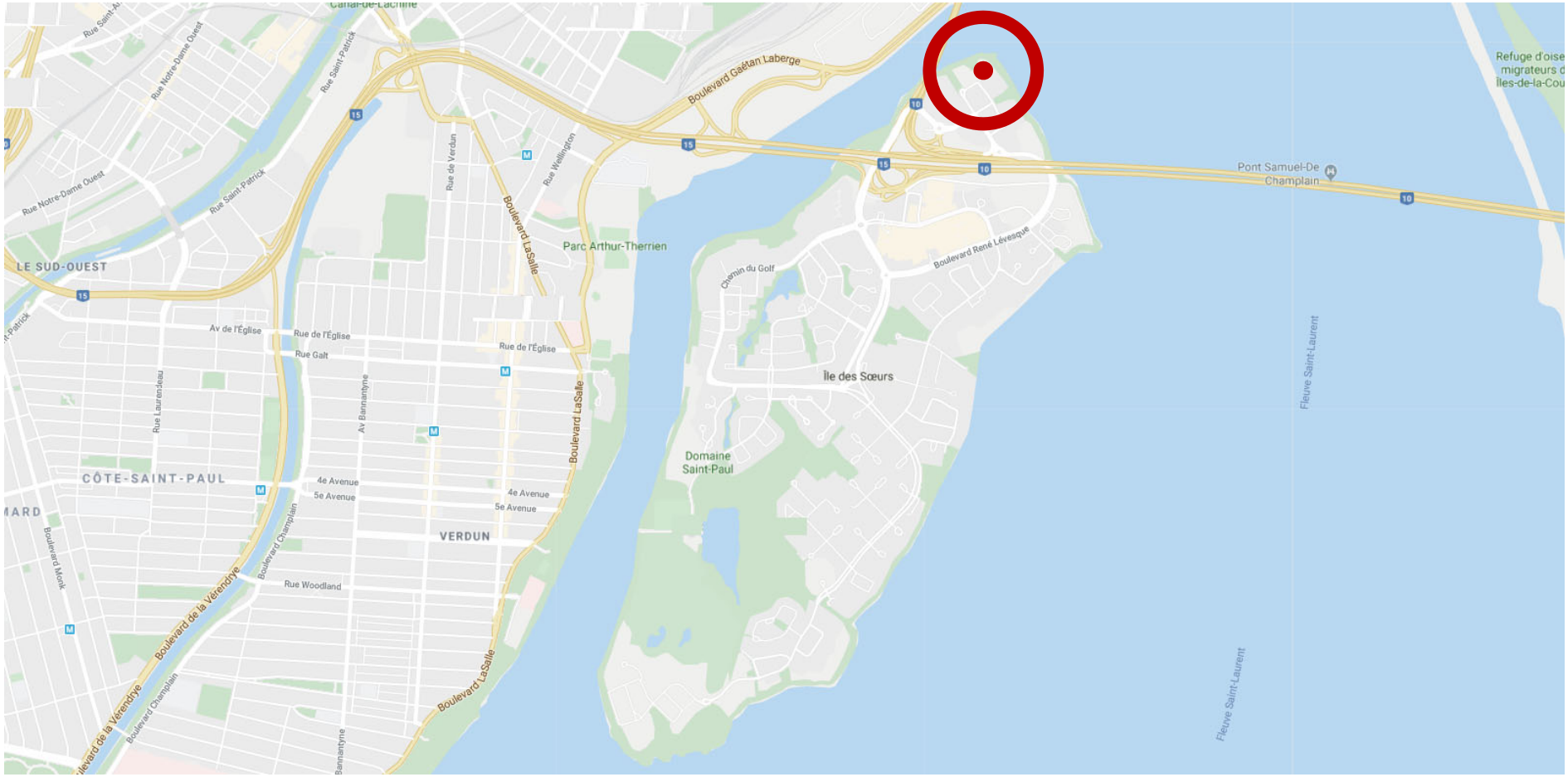
Année : 2019

Conception : SNC-Lavalin / Poralu Marine

3.1 Passerelle en aluminium

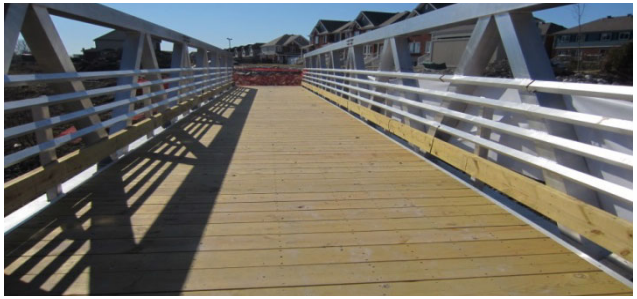


3.2 Localisation



3.2 Localisation

3.2 Localisation



3.3 Exemples

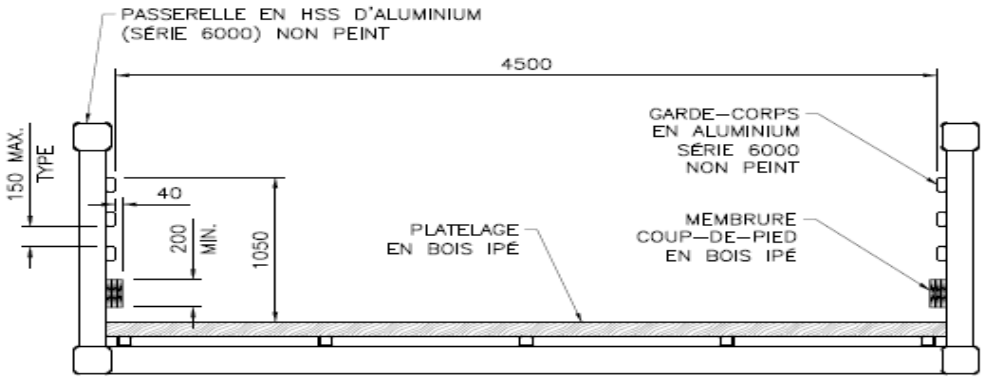
Charpente :
Alliage 6005A-T61

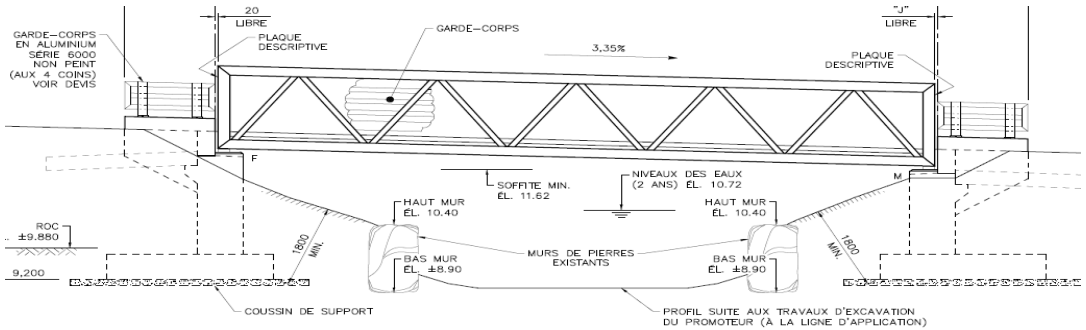
Platelage :
Bois ipé

Dimensions :
Longueur : 12,0 m
Largeur : 4,5 m

Charges :
Véhicule d'entretien 80 kN
4 kPa

Coût :
700 000 $





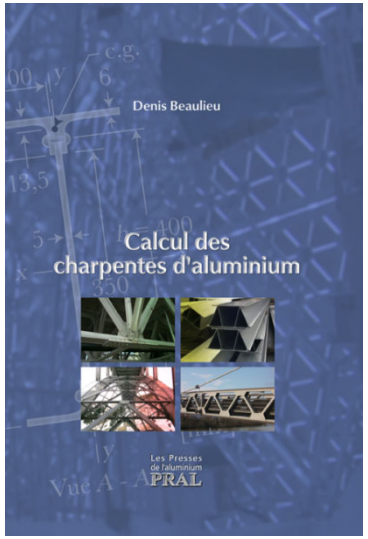
3.4 Conception

3.5 Construction

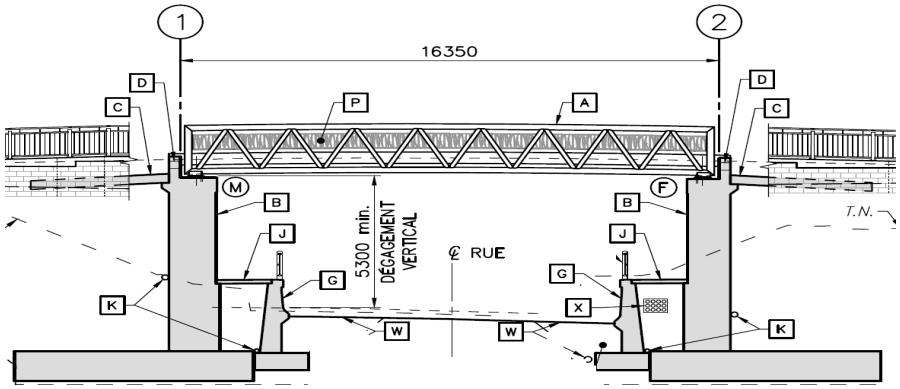
3.5 Construction

Ressources :
Centre d’expertise sur l’aluminium
Mario Fafard, ing., Ph.D.

Calcul des charpente d’aluminium
Denis Beaulieu, ing., Ph.D.



3.6 Ressources



Projet pilote : Construction d’une passerelle avec dalle armée entièrement de barres PRF

Année : 2020

Conception : Exp

4.1 Barre d’armature en PRF

Projet pilote : Construction de la passerelle Isabey-Darnley en BFUP
Année : 2016
Conception : Ville de Montréal

5.1 Béton fibré à ultra-hautes performances

Programme de recherche portant sur le développement d'éléments préfabriqués et de réparations en BFUP

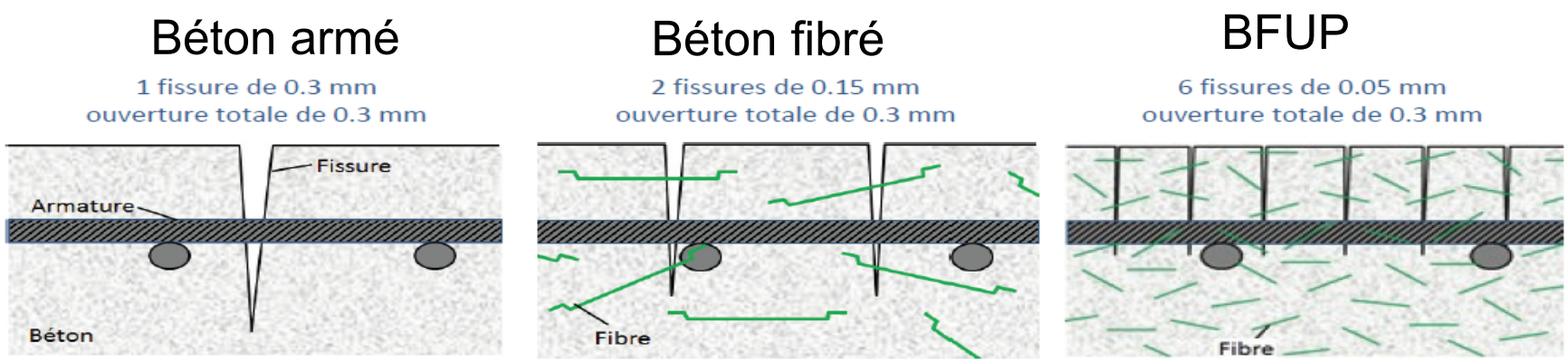
Partenaires : Ville de Montréal, PJCCI, Béton Brunet, Euclid et CRSNG

En collaboration avec :

Prof. Jean-Philippe Charron, ing., Ph.D.
Clélia Desmettre, ing., Ph.D.
Polytechnique Montréal

POLYTECHNIQUE MONTRÉAL
LE GÉNIE EN PREMIÈRE CLASSE

5.1 Béton fibré à ultra-hautes performances



-Résistance mécanique élevée
-Ductilité élevée

-Faible perméabilité
-Contrôle de la fissuration

5.1 Béton fibré à ultra-hautes performances









Conclusion