GFRP Applications in Bridge Decks

Gene Latour

VP Sales

V-ROD USA

Learning Objectives

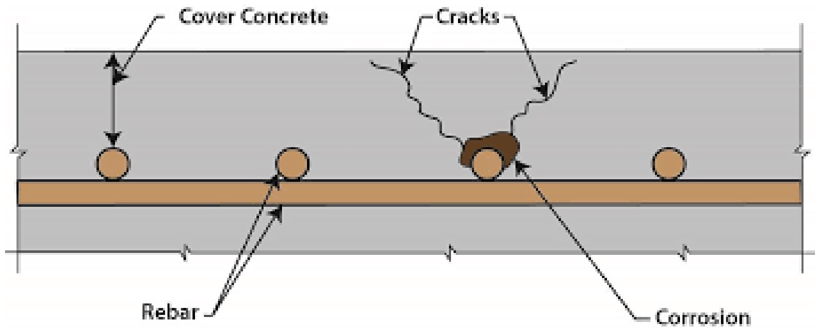
- Demonstrate GFRP performance and use in hundreds of real life bridge projects
- Understanding how GFRP removes corrosion from the equation – Life Cycle Costing
- Seeing exponential growth as various design codes, specifications and corrosion policies evolve
- Understanding how applications expand as engineers utilize its performance and Codes

Presentation Outline

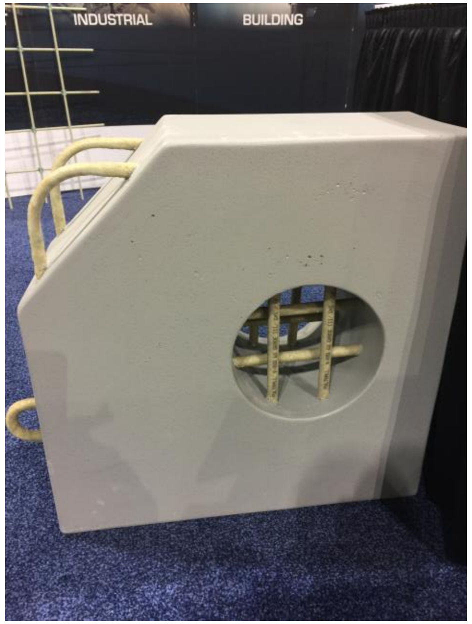
Why GFRP Composite Reinforcement

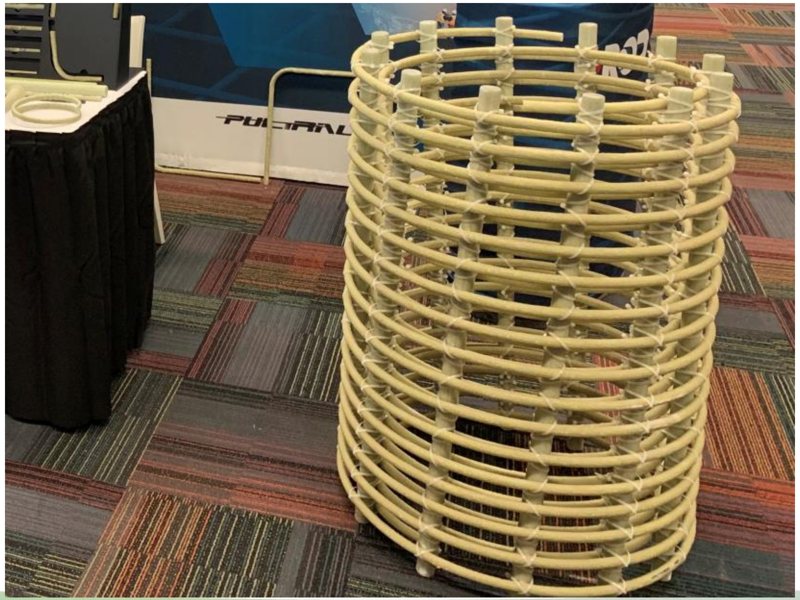
As engineers strive to deliver owners with more sustainable, safe and durable concrete structures, glass fiber reinforced polymer (GFRP) reinforcing is being used in innovative ways in a large range and scope of bridge decks and other structural components.

As opposed to more concrete cover, inhibitors or other corrosion protection measures, take care of the root problem in utilizing high performance, non-corrosive V-ROD GFRP!

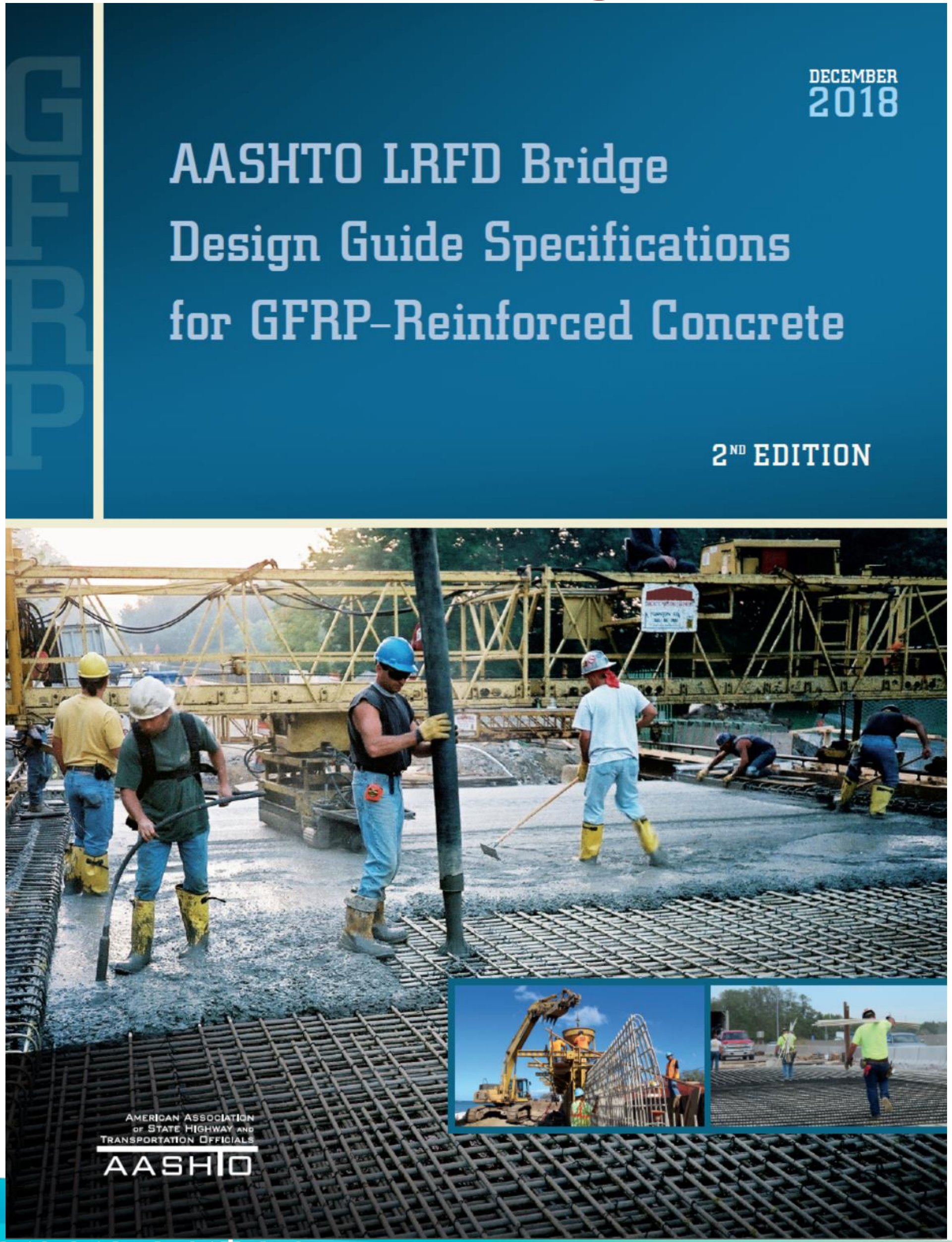


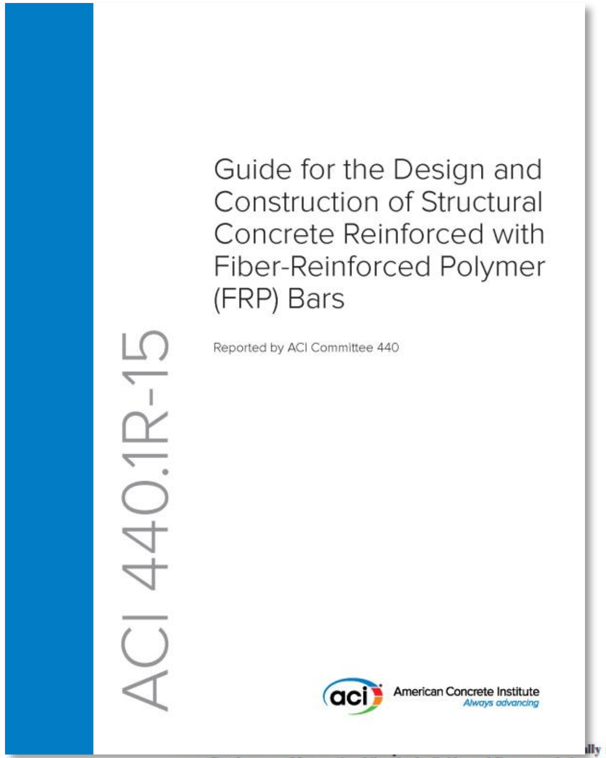

V-ROD G#5
V-ROD #4
PULTRALL.COM V-ROD HM
WWW.VROD.CA HM GRADE III / G#3

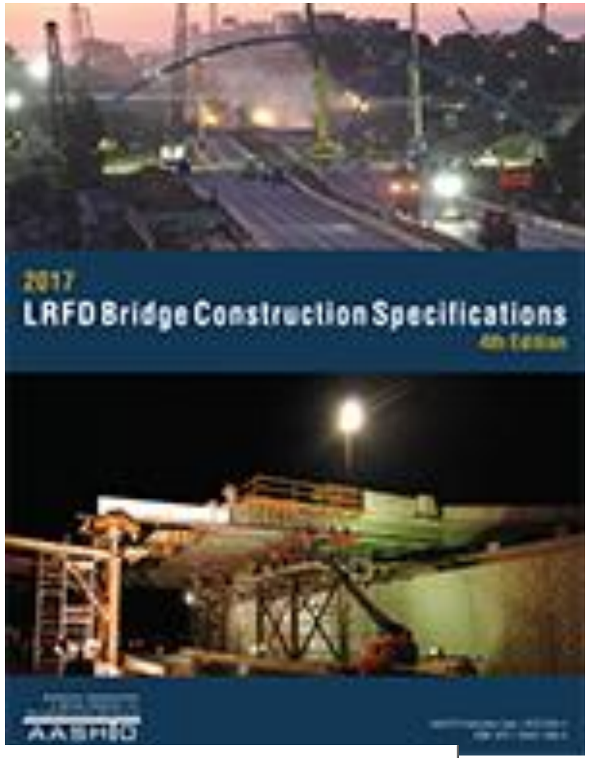

INDUSTRIAL
BUILDING

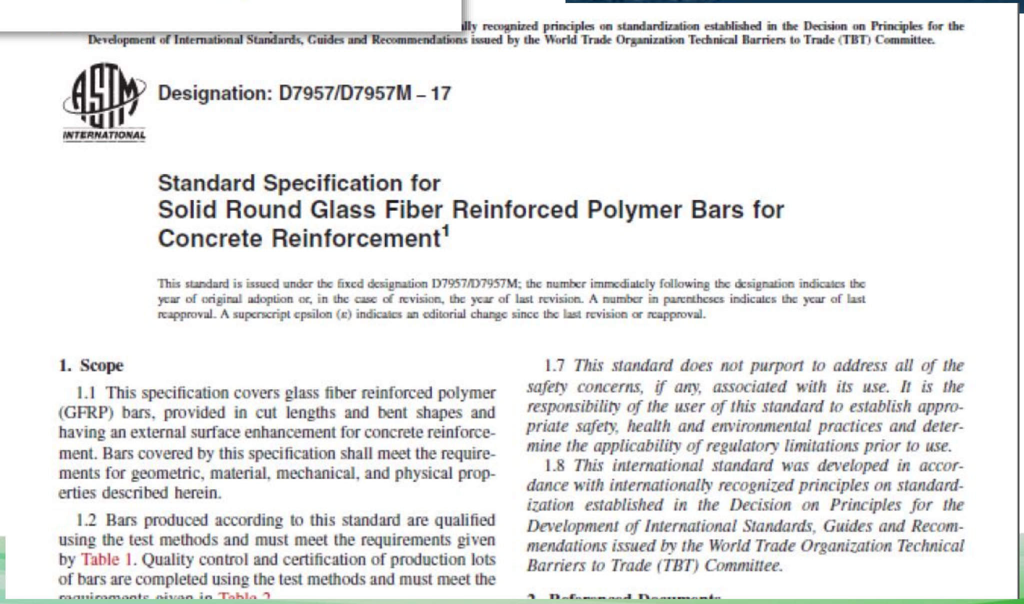


Design Codes & Certifications - USA









...lly 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.

ASTM INTERNATIONAL

Designation: D7957/D7957M – 17

Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement[1]

This standard is issued under the fixed designation D7957/D7957M; 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

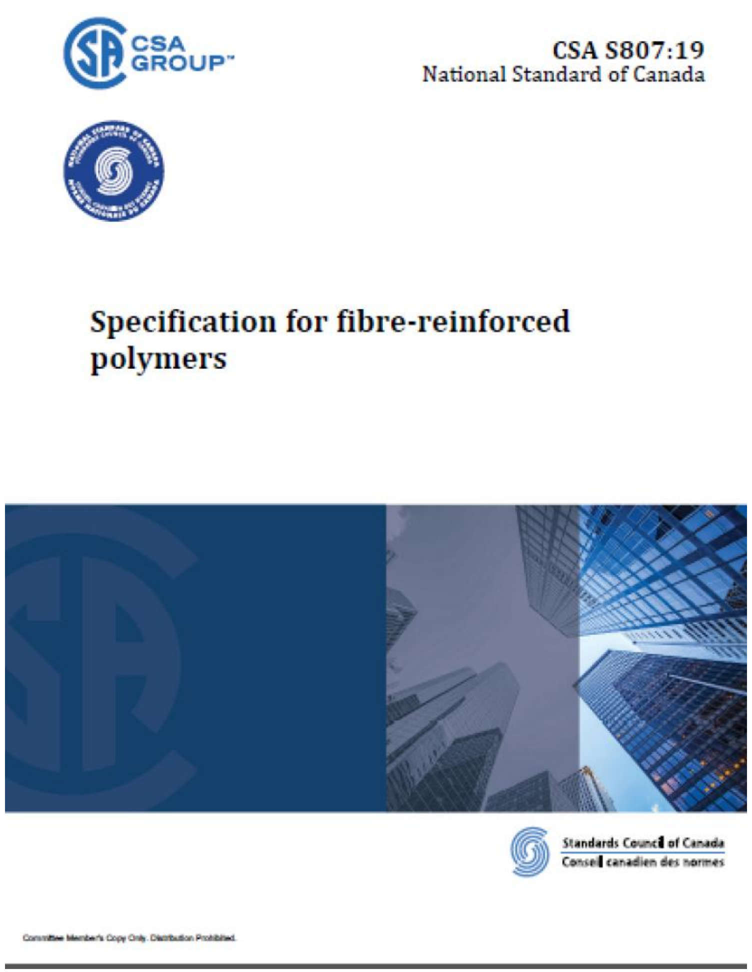
1.1 This specification covers glass fiber reinforced polymer (GFRP) bars, provided in cut lengths and bent shapes and having an external surface enhancement for concrete reinforcement. Bars covered by this specification shall meet the requirements for geometric, material, mechanical, and physical properties described herein.

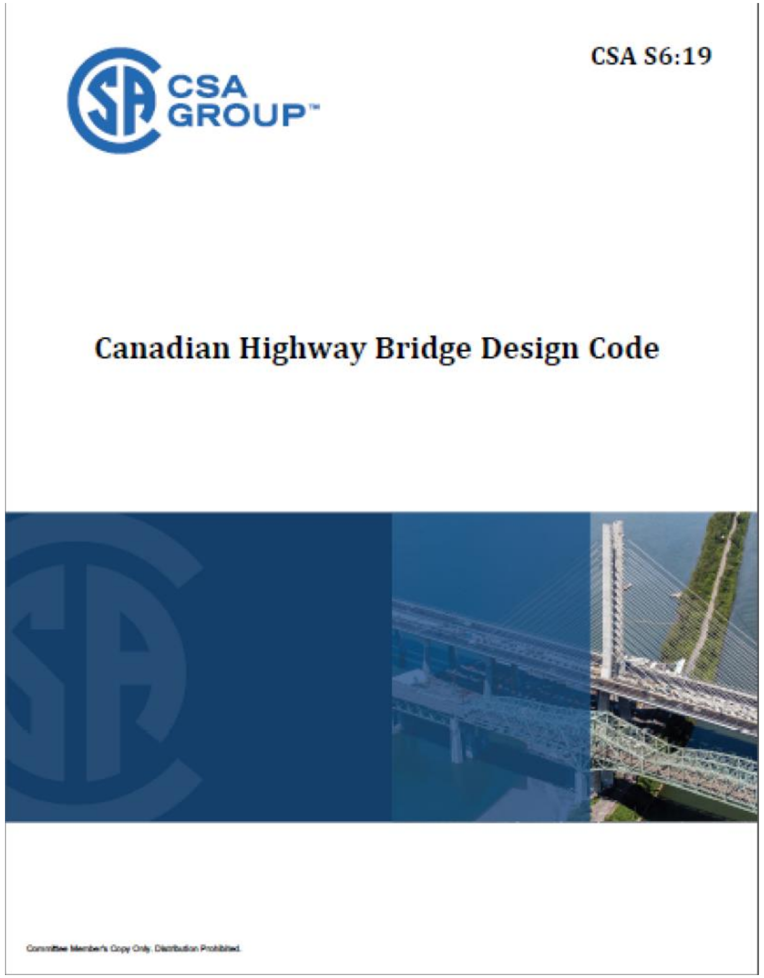
1.2 Bars produced according to this standard are qualified using the test methods and must meet the requirements given by Table 1. Quality control and certification of production lots of bars are completed using the test methods and must meet the

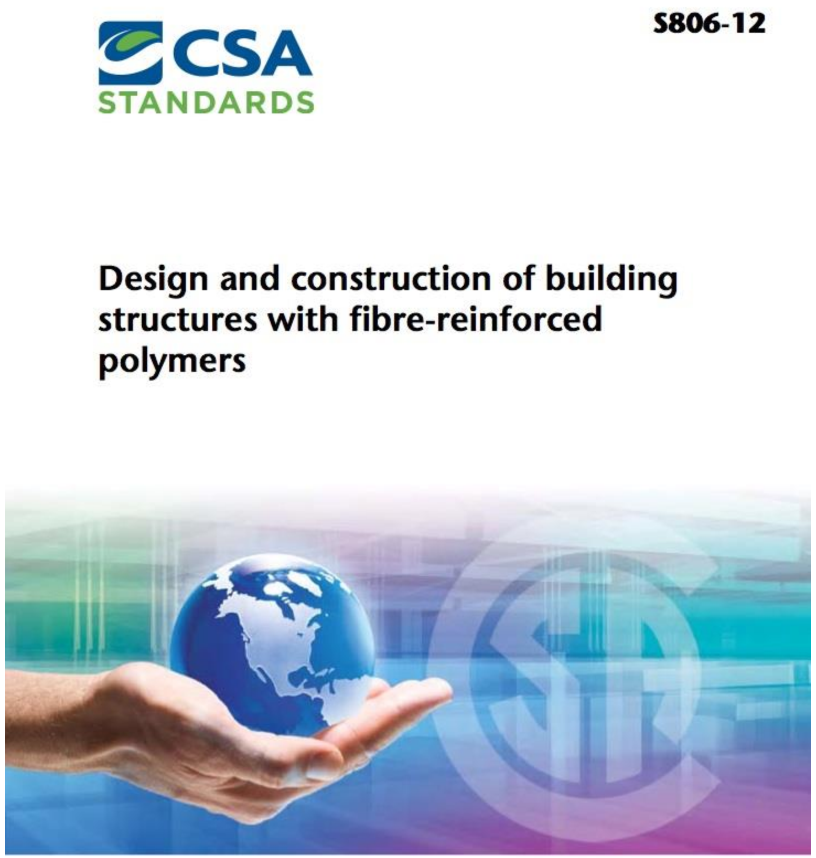
1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *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.*

Design Codes & Certifications - Canada







Overview of FRP Composite Reinforcement

With GFRP reinforcing used in hundreds of successful infrastructure projects to date, projects are becoming larger and more complex. Applications include new or rehab bridge construction of decks/barriers/approach slabs, sidewalks as well as precast bridge decks, box girders, RSS walls and curbs. Other applications include transit (LRT/BRT's), WTP's, parking garages, hydro/substations, airports, marine structures, mining, MRI's, tunneling etc

- superior tensile properties
- built-in corrosion resistance (non-corrosive)
- impervious to salt ions, chlorides and chemicals
- electrically/magnetically neutral (non-conductive)
- thermal benefits
- one-quarter the weight of steel
- FRP bridge/building codes and design manuals including ACI 440.1R and AASHTO LRFD in USA
- complies with ASTM D7957-17 Specification
- can be easily cut ie tunneling soft-eyes

As opposed to traditional design methods and materials, FRP's are 30% less cost than other alternatives as Life Cycle Costing evaluates the **total costs of ownership**.

Product Data Sheet – V•ROD 46

		#2 (6M)	#3 (10M)	#4 (12M)	#5 (15M)	#6 (20M)	#7 (22M)	#8 (25M)	#9 (30M)	#10 (32M)
Guaranteed tensile strength* (ASTM D7205)	MPa	1000	1000	1000	1000	1000	950	850	800	800
	ksi	145.0	145.0	145.0	145.0	145.0	137.8	123.3	116	116
Minimum tensile modulus (ASTM D7205)	GPa	46								
	ksi	6800								
Guaranteed transverse shear capacity (ASTM D7617)	MPa	160								
	ksi	23.2								
Resin		vinylester								
Weight	g/m	73.4	150.8	264.5	403.7	567.4	760.5	1012.6	1281.6	1582.2
	lb/ft	0.049	0.101	0.178	0.271	0.381	0.511	0.680	0.861	1.063
Effective cross-sectional area (including sand coating)** (CSA S806 Annex A)	mm²	36.5	71.12	123.9	195.8	277.1	377.2	477.8	604.7	746.6
	in²	0.057	0.110	0.192	0.303	0.430	0.585	0.741	0.937	1.157
Effective diameter	mm²	6.65	9.49	12.56	15.61	18.52	21.71	24.66	27.7	30.8
	in²	0.262	0.374	0.494	0.615	0.729	0.855	0.971	1.091	1.213
Nominal cross-sectional area (CSA S807 Table 1)	mm²	32	71	129	199	284	387	510	645	819
	in²	0.050	0.110	0.199	0.308	0.440	0.599	0.790	1	1.269

COMPLIES WITH THE FOLLOWING STANDARDS:

- **GRADE I CSA** S807-10
- **GRADE I MTO**
- **ASTM D7957** D7957-17

* The nominal guaranteed tensile strength must not be used to calculate the strength of the bent portion of a bent bar. Instead use the minimum guaranteed tensile strength found in the technical data sheet of bent **V•ROD bars**.

** Please contact **Pultrall** for dowelling applications.

Development and splice length are available upon request but should be determined by the design engineer.

The guaranteed value presented in this document is the mean value minus 3 times the standard deviation.

It is the responsibility of the design engineers to contact the bar manufacturer to get the latest updates of this technical data sheet (also available at **www.vrod.ca**). For any additional technical results or litterature, please contact **Pultrall**.

Product Data Sheet – V•ROD 50

		#2 (6M)	#3 (10M)	#4 (12M)	#5 (15M)	#6 (20M)	#7 (22M)	#8 (25M)	#9 (30M)	#10 (32M)
Guaranteed tensile strength* (ASTM D7205)	MPa	1000	1000	1000	1000	1000	1000	900	800	800
	ksi	145	145	145	145	145	145	130.5	116	116
Minimum tensile modulus (ASTM D7205)	GPa	50								
	ksi	7252								
Guaranteed transverse shear capacity (ASTM D7617)	MPa	179								
	ksi	24.7								
Resin		vinylester								
Weight	g/m	77	157	278	431	619	867	1122	1420	1862
	lb/ft	0.052	0.105	0.187	0.290	0.416	0.583	0.754	0.954	1.251
Effective cross-sectional area (including sand coating)** (CSA S806 Annex A)	mm²	41	81	139	214	309	397	529	670	825
	in²	0.063	0.126	0.215	0.332	0.479	0.615	0.820	1.039	1.279
Effective diameter	mm²	7.2	10.2	13.3	16.5	19.8	22.5	26.0	29.2	32.3
	in²	0.284	0.400	0.523	0.650	0.781	0.885	1.022	1.15	1.271
Nominal cross-sectional area (CSA S807 Table 1)	mm²	32	71	129	199	284	387	510	645	819
	in²	0.050	0.110	0.199	0.308	0.440	0.599	0.790	1	1.269

COMPLIES WITH THE FOLLOWING STANDARDS:

- **GRADE II CSA** S807-10
- **GRADE II MTO**
- **ASTM D7957** D7957-17

* The nominal guaranteed tensile strength must not be used to calculate the strength of the bent portion of a bent bar. Instead use the minimum guaranteed tensile strength found in the technical data sheet of bent **V•ROD bars**.

** Please contact **Pultrall** for dowelling applications.

Development and splice length are available upon request but should be determined by the design engineer.

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Product Data Sheet – V•ROD 60

		#2 (6M)	#3 (10M)	#4 (12M)	#5 (15M)	#6 (20M)	#7 (22M)	#8 (25M)	#9 (30M)	#10 (32M)
Guaranteed tensile strength* (ASTM D7205)	MPa	1100	1100	1100	1100	1100	1100	1100	1000	1000
	ksi	159.5	159.5	159.5	159.5	159.5	159.5	159.5	145	145
Minimum tensile modulus (ASTM D7205)	GPa	60								
	ksi	8702.3								
Guaranteed transverse shear capacity (ASTM D7617)	MPa	180								
	ksi	26.1								
Resin		vinylester								
Weight	g/m	78	175	310	442	633	863	1127	1426	1761
	lb/ft	0.052	0.118	0.208	0.297	0.425	0.58	0.757	0.958	1.183
Effective cross-sectional area** (including sand coating) (CSA S806 Annex A)	mm²	37.2	83.8	145	232.9	326.8	438.2	572.3	724.3	894.2
	in²	0.058	0.130	0.225	0.361	0.507	0.679	0.887	1.123	1.386
Effective diameter	mm²	6.9	10.33	13.59	17.22	20.39	23.6	26.99	30.4	33.7
	in²	0.272	0.407	0.535	0.678	0.803	0.929	1.063	1.197	1.327
Nominal cross-sectional area (CSA S807 Table 1)	mm²	32	71	129	199	284	387	510	645	819
	in²	0.05	0.110	0.199	0.308	0.440	0.6	0.790	1	1.269

Available Anchor Heads

		#4 GFRP	#5 GFRP	#6 GFRP
Minimum pull-out strength	kN	80	100	100
	kips	18	22	22

COMPLIES WITH THE FOLLOWING STANDARDS:

- **GRADE III CSA** S807-10
- **GRADE III MTO**
- **ASTM D7957** D7957-17

* The nominal guaranteed tensile strength must not be used to calculate the strength of the bent portion of a bent bar. Instead use the minimum guaranteed tensile strength found in the technical data sheet of bent **V•ROD bars**.

** Please contact **Pultrall** for dowelling applications.

Development and splice length are available upon request but should be determined by the design engineer.

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It is the responsibility of the design engineers to contact the bar manufacturer to get the latest updates of this technical data sheet (also available at **www.vrod.ca**). For any additional technical results or litterature, please contact **Pultrall**.

Product Data Sheet - V•ROD BENT BARS 50

REVISION : Feb 2018

		#3 GFPR	#4 GFPR	#5 GFPR	#6 GFPR	#7 GFPR	#8 GFPR
		bent bar	bent bar	bent bar	bent bar	bent bar	bent bar
Minimum tensile strength (straight portion) *(ASTM D7205)*	MPa	1022	1019	1001	1028	1005	992
	ksi	148	148	145	149	146	144
Nominal tensile modulus (straight portion) *(ASTM D7205)*	GPa	50					
	ksi	7246					
Minimum tensile strength (bent portion) *(ACI 440.3R B5)*	MPa	460	459	450	463	452	446
	ksi	67	66	65	67	66	65
Glass content *(ASTM D3171)*	% weight	77,8	78	77,5	78,9	78,4	76,1
Weight	g/m	167	292	443	651	887	1136
	lb/ft	0.112	0.196	0.298	0.437	0.596	0.763
Nominal cross-sectional area	mm²	71.26	126.68	197.93	285.02	387.95	506.71
	in²	0.1105	0.1963	0.3068	0.4418	0.6013	0.7854
Effective cross-sectional area *(CSA S806 Annex A)*	mm²	81.60	145.70	240.29	332.96	439.40	582.72
	in²	0.1265	0.2258	0.3725	0.5161	0.6811	0.9032

COMPLIES WITH THE FOLLOWING STANDARDS:

- **CSA S807 Grade II**
- **MTO Grade III**
- **ASTM D7957**

It is the responsibility of the design engineers to contact the bar manufacturer to get the latest updates of this technical data sheet (also available at www.vrod.ca).

Life Cycle Costing – Carbon Footprint

Life Cycle Costing/LCA

Thomas Cadenazzi,[1] Giovanni Dotelli,[2] Marco Rossini,[3] Steven Nolan,[4] and Antonio Nanni[3]

Life-Cycle Cost and Life-Cycle Assessment Analysis at the Design Stage of a Fiber-Reinforced Polymer-Reinforced Concrete Bridge in Florida

Reference

T. Cadenazzi, G. Dotelli, M. Rossini, S. Nolan, and A. Nanni, "Life-Cycle Cost and Life-Cycle Assessment Analysis at the Design Stage of a Fiber-Reinforced Polymer-Reinforced Concrete Bridge in Florida," *Advances in Civil Engineering Materials* 8, no. 2 (2019): 128–151. https://doi.org/10.1520/ACEM20180113

ABSTRACT

To support and promote the deployment of innovative technologies in infrastructure, it is fundamental to quantify their implications in terms of both economic and environmental impacts. Glass Fiber-Reinforced Polymer (GFRP) bars and Carbon Fiber-Reinforced Polymer (CFRP) strands are validated corrosion-resistant solutions for Reinforced Concrete (RC) and Prestressed Concrete

Comparing conventional and innovative bridge deck options: A life cycle engineering and costing approach

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Professor, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

P.N. Christensen
Professional Affiliate, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

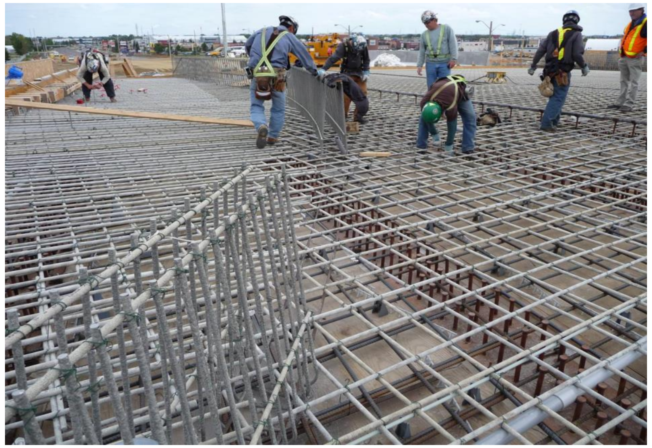
G. Tadros
President, SPECO Engineering, Calgary, Alberta, Canadaa

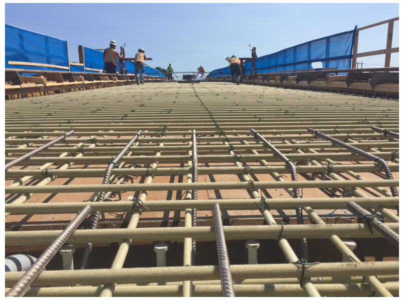
ABSTRACT: Engineering design is a complex process facilitated by experience and past practice. Design methods, concrete and surface options, reinforcement materials, and geometry, combine to permit hundreds – if not thousands – of possible bridge deck alternatives. Given such a staggering list of possible options, a traditional, stepwise, deterministic life cycle costing (LCC) approach inevitably bogs down in its search for optimality. Moreover, the results reached fail to inform decision-makers of the risks surrounding each deck alternative and may, therefore, limit confidence in any recommendations emerging through the LCC analysis. The authors of this paper, propose an iterative life cycle engineering and costing (LCE&C) approach to gradually hone a list of potential deck design alternatives. Embracing uncertainty in an explicit way, the results derived and reported herein provide decision-makers with comparable, stochastic life cycle cost estimates.

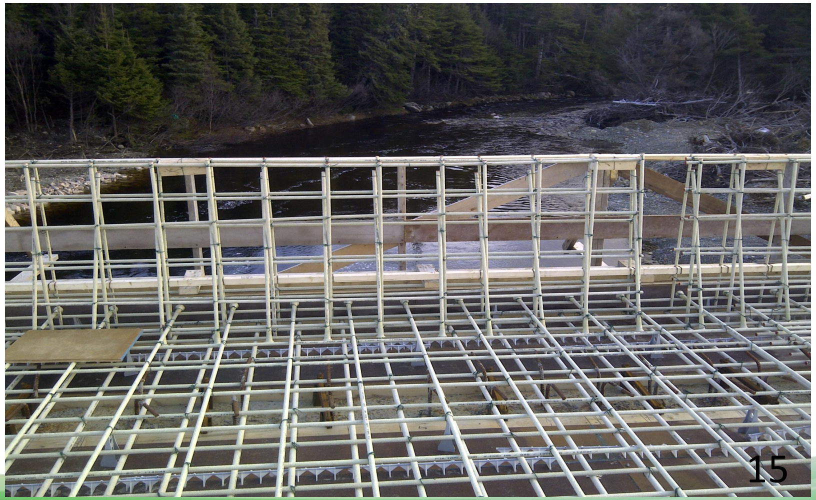
Crash test of TL-5 Barriers

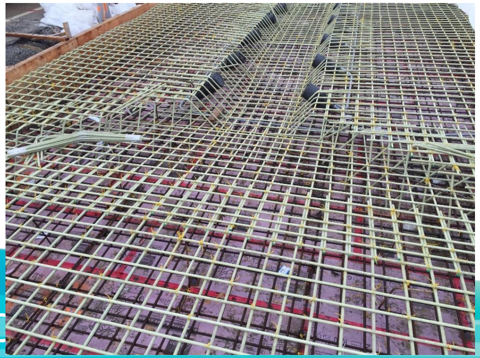
Crash Test at Texas TTI with 60Gpa headed bar now approved for TL-5 barriers

Project examples of Cast in place bridge decks









Wotten Bridge 2001 – QC

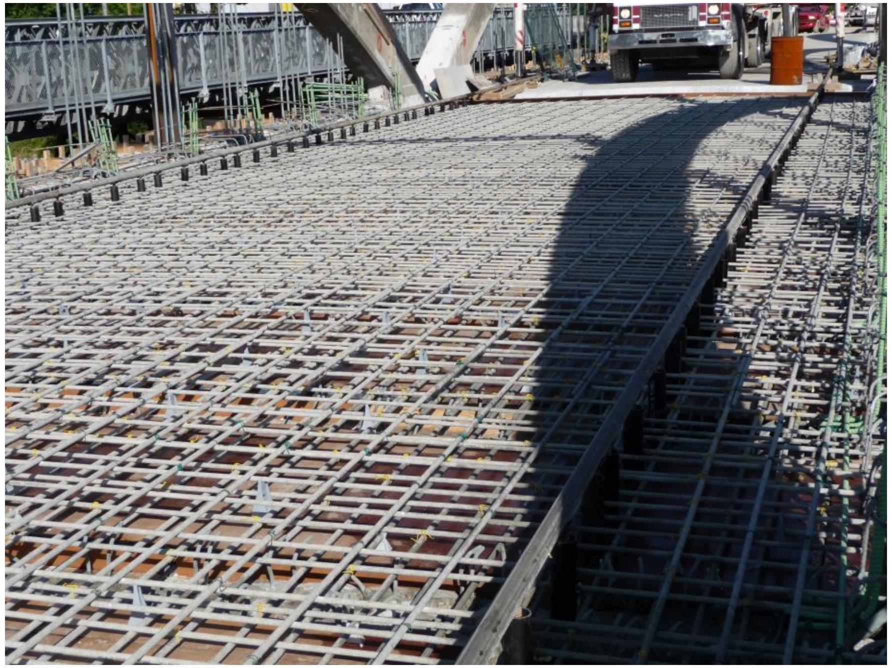
MTQ - Hwy 410 overpass in Sherbrooke, QC

MTQ - Hwy 410 overpass in Sherbrooke, QC

Cookshire
Bridge 2003 –
Cookshire, QC

Val Alain
Bridge 2004 –
Hwy 20E, QC

Manitoba Floodway bridges



Bridgeport Bridge deck replacement Region of Waterloo, ON

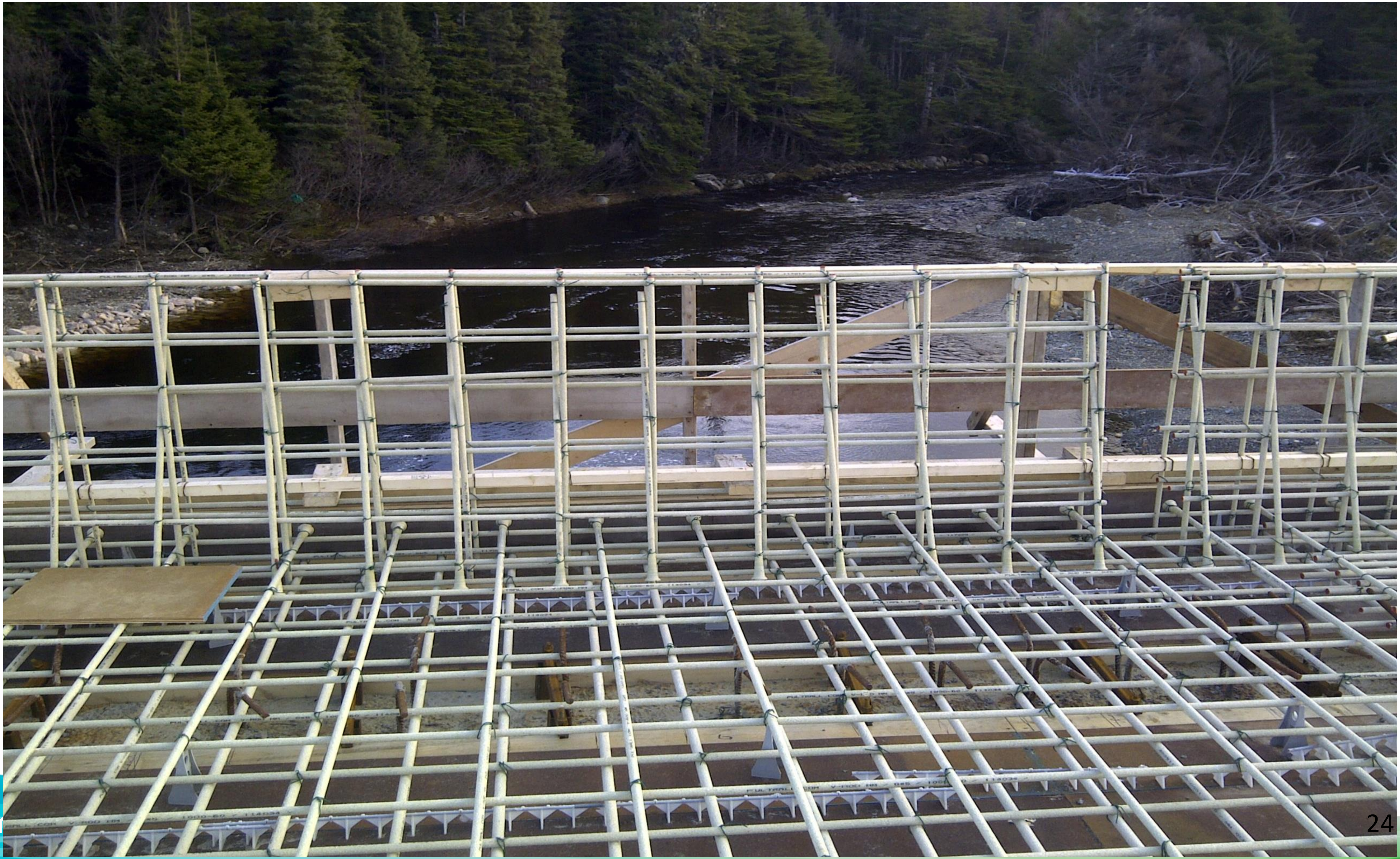
Dorchester Bridge, Kitchener, ON

Skagit River Bridge – BC MOT

MTO 2009-2020 (Hwy 401 in Toronto) multiple cast in place deck structures

MTO 2009-2020 (Hwy 401/Islington Ave completed deck

Rattle Brook Bridge - N’fld DOT - 2011

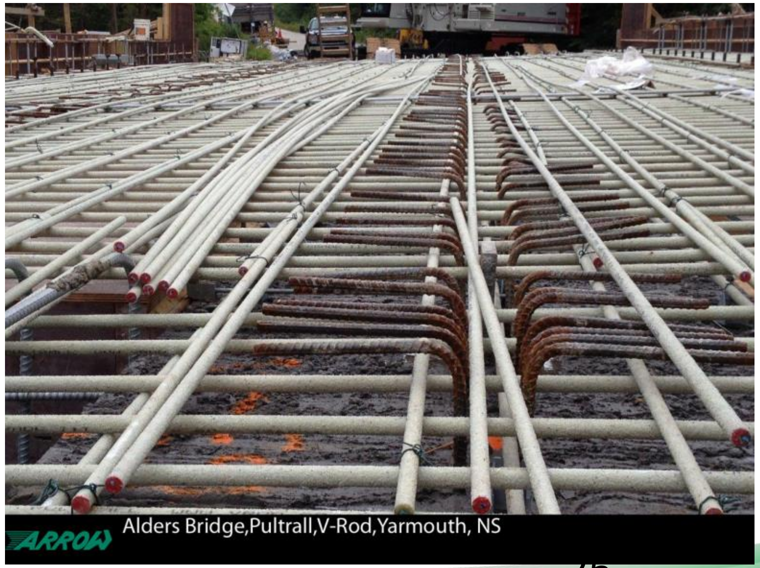


Rattle Brook Bridge N'fld - 2011

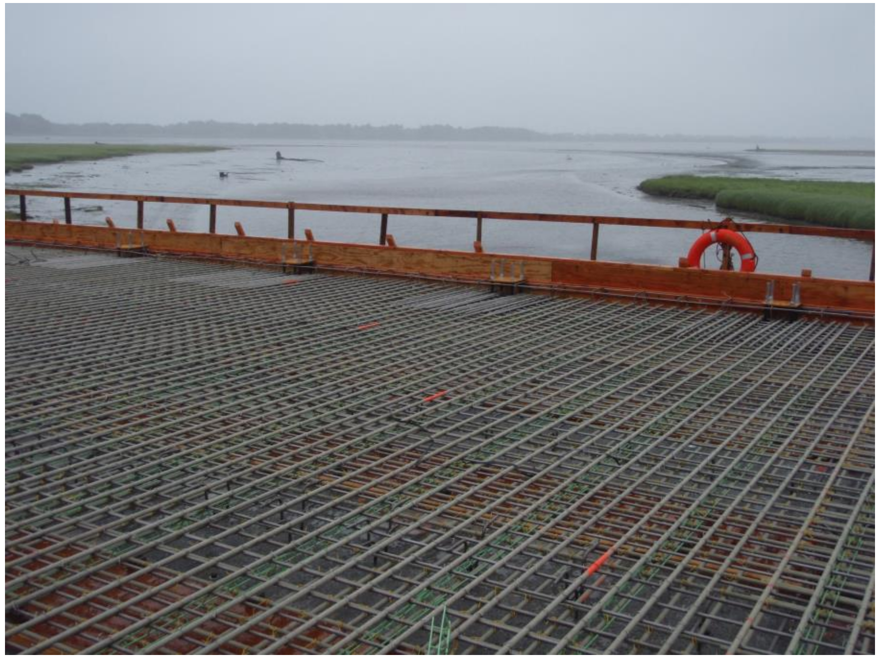
Montague Bridge, PEI, 2006

Victoria Bridge, PEI, 2009

Alders Bridge, NS, 2015

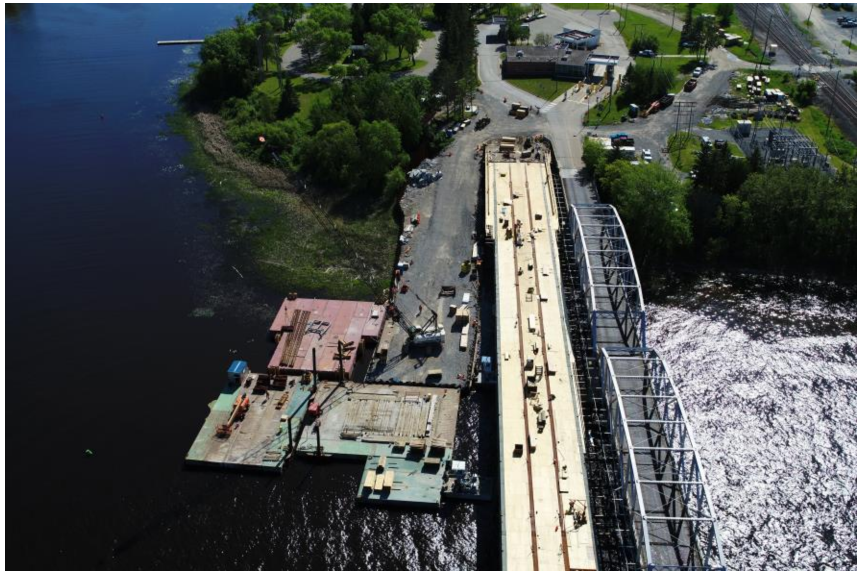


Millport Slough, Oregon

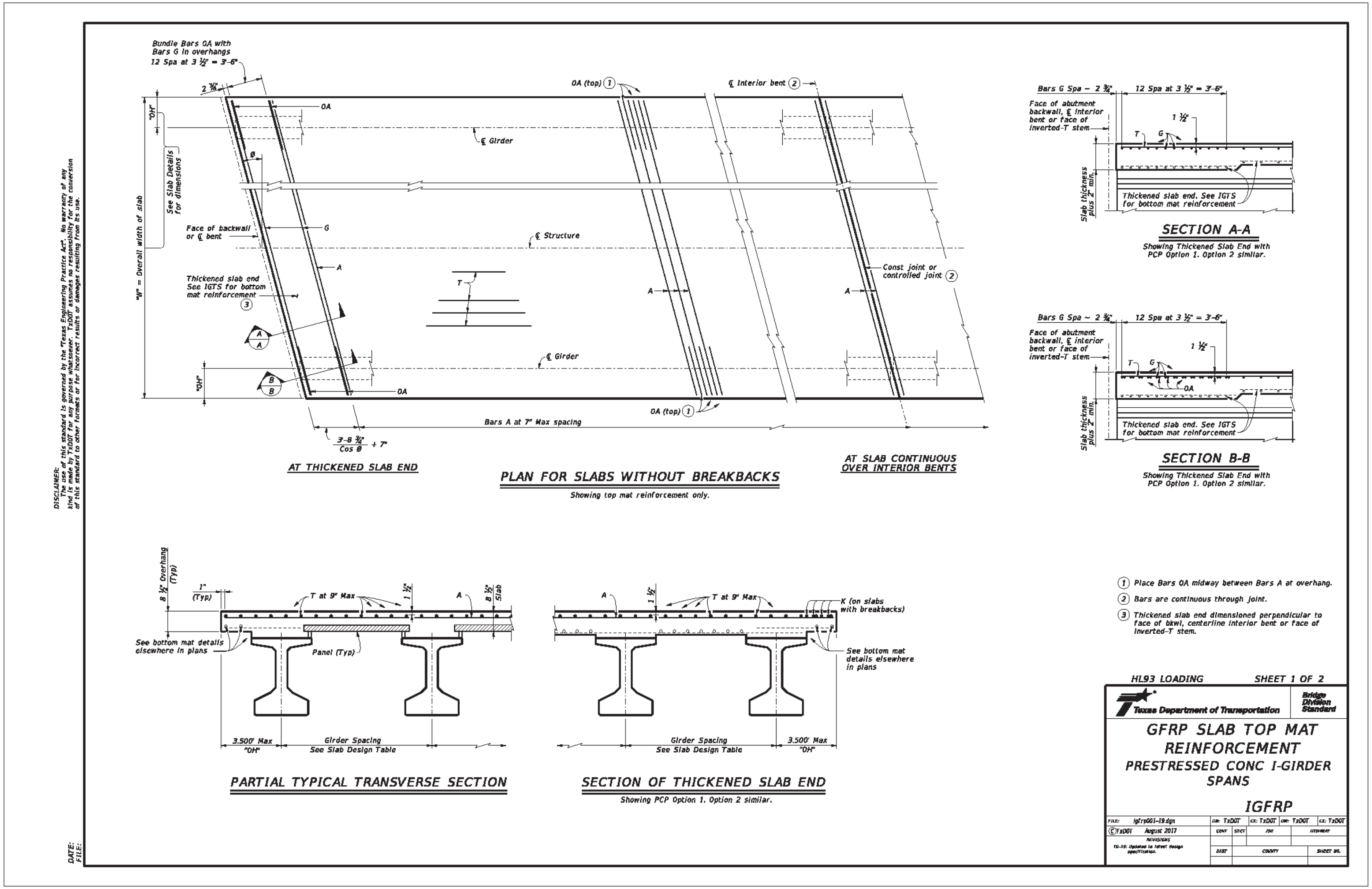



U-HAUL
STORIE

Morristown Bridge, Vermont



Baudette Bridge, MNDOT



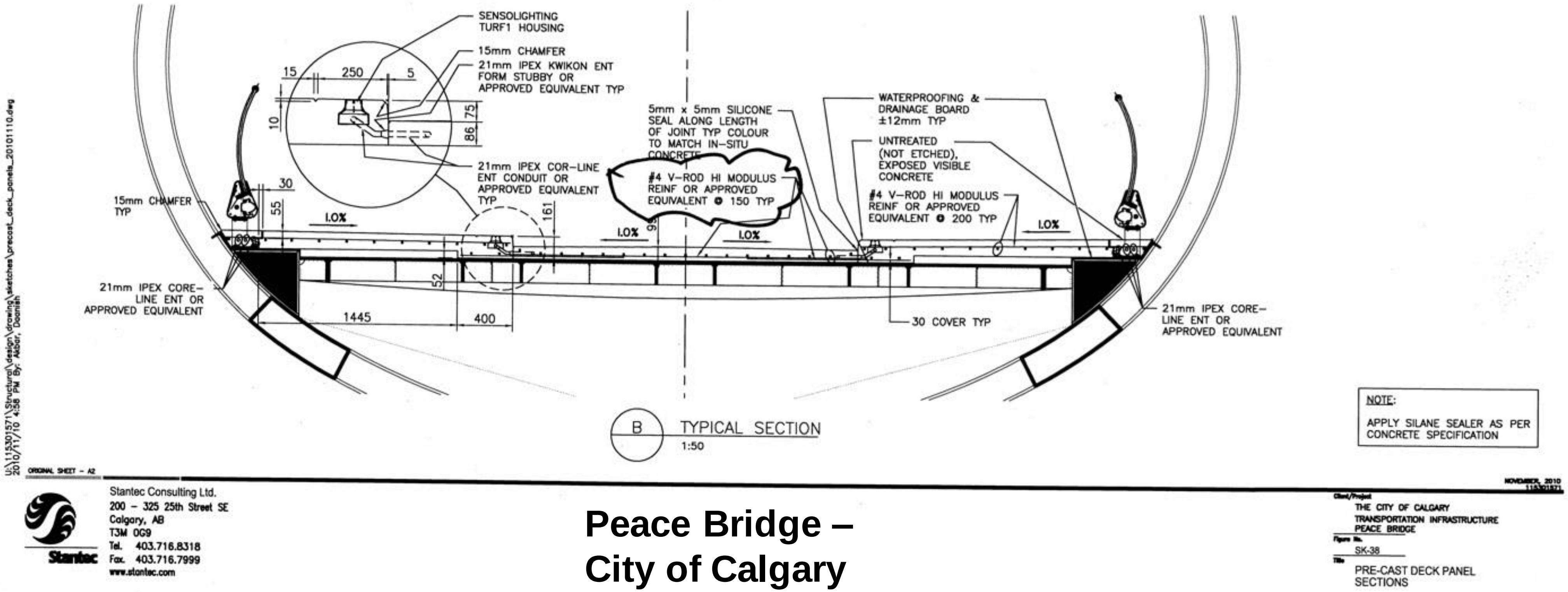
Bundle Bars OA with Bars G in overhangs
12 Spa at 3 ½" = 3'-6"
OA (top) ①
℄ Interior bent ②
℄ Girder
℄ Structure
Face of backwall or ℄ bent
See Slab Details for dimensions
"W" = Overall width of slab
"OH"
Thickened slab end See IGTS for bottom mat reinforcement ③
Const joint or controlled joint ②
Bars A at 7" Max spacing
AT THICKENED SLAB END
PLAN FOR SLABS WITHOUT BREAKBACKS
Showing top mat reinforcement only.
AT SLAB CONTINUOUS OVER INTERIOR BENTS
Bars G Spa ~ 2 ¾"
Face of abutment backwall, ℄ interior bent or face of inverted-T stem
Slab thickness plus 2" min.
Thickened slab end. See IGTS for bottom mat reinforcement
SECTION A-A
Showing Thickened Slab End with PCP Option 1. Option 2 similar.
SECTION B-B
Showing Thickened Slab End with PCP Option 1. Option 2 similar.
8 ½" Overhang (Typ)
1" (Typ)
T at 9" Max
8 ½" Slab
See bottom mat details elsewhere in plans
Panel (Typ)
3.500' Max "OH"
Girder Spacing See Slab Design Table
PARTIAL TYPICAL TRANSVERSE SECTION
K (on slabs with breakbacks)
SECTION OF THICKENED SLAB END
Showing PCP Option 1. Option 2 similar.
① Place Bars OA midway between Bars A at overhang.
② Bars are continuous through joint.
③ Thickened slab end dimensioned perpendicular to face of bkwl, centerline interior bent or face of inverted-T stem.
HL93 LOADING
SHEET 1 OF 2
Texas Department of Transportation
Bridge Division Standard
GFRP SLAB TOP MAT REINFORCEMENT
PRESTRESSED CONC I-GIRDER SPANS
IGFRP
DISCLAIMER: The use of this standard is governed by the "Texas Engineering Practice Act". No warranty of any kind is made by TxDOT for any purpose whatsoever. TxDOT assumes no responsibility for the conversion of this standard to other formats or for incorrect results or damages resulting from its use.
DATE:
FILE:

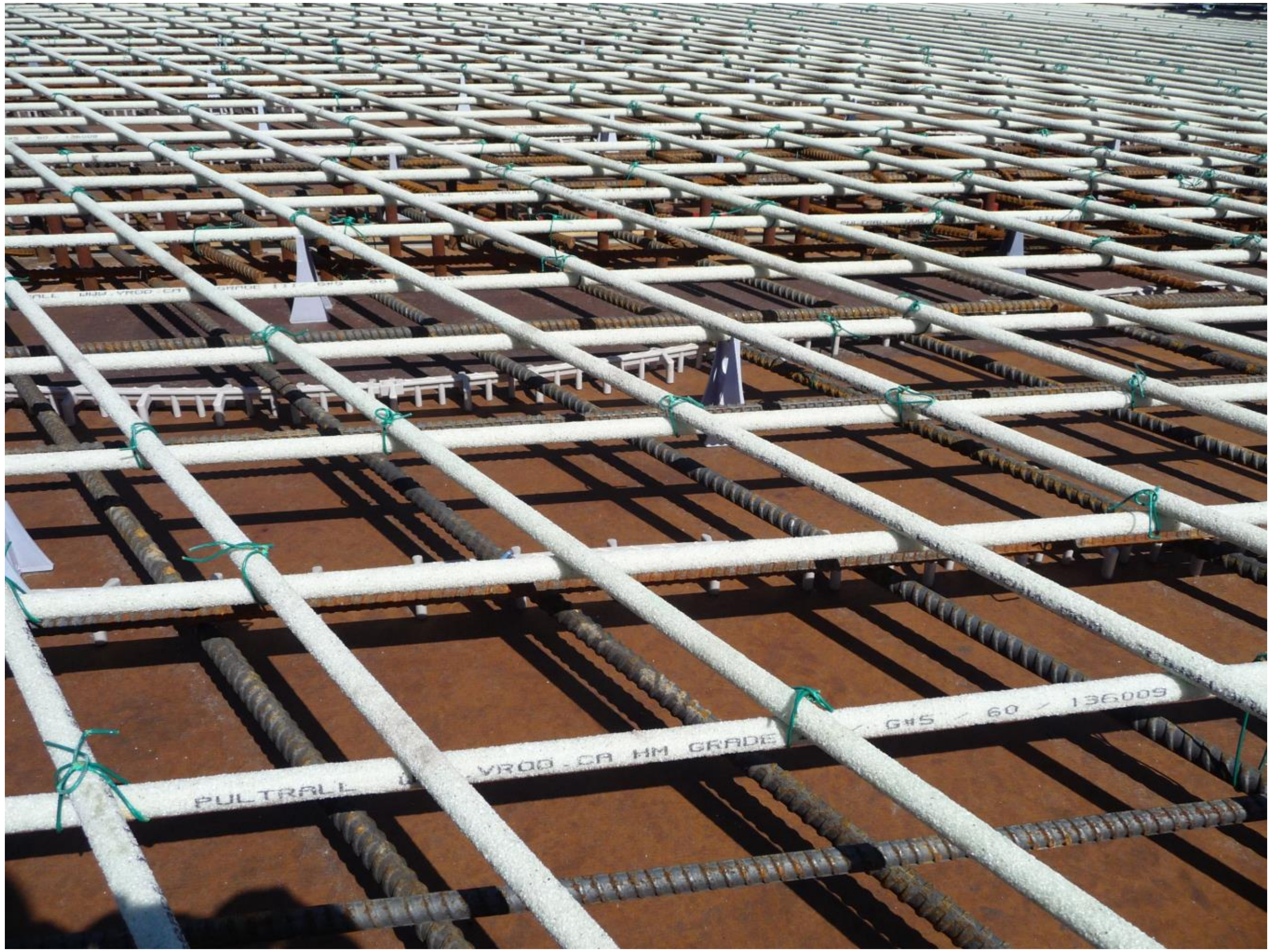
23rd Ave/Gateway Blvd –
Edmonton, AB
Deck bar ready for casting

MTO 2010-4004
rapid replacement

East Hamilton pedestrian bridge

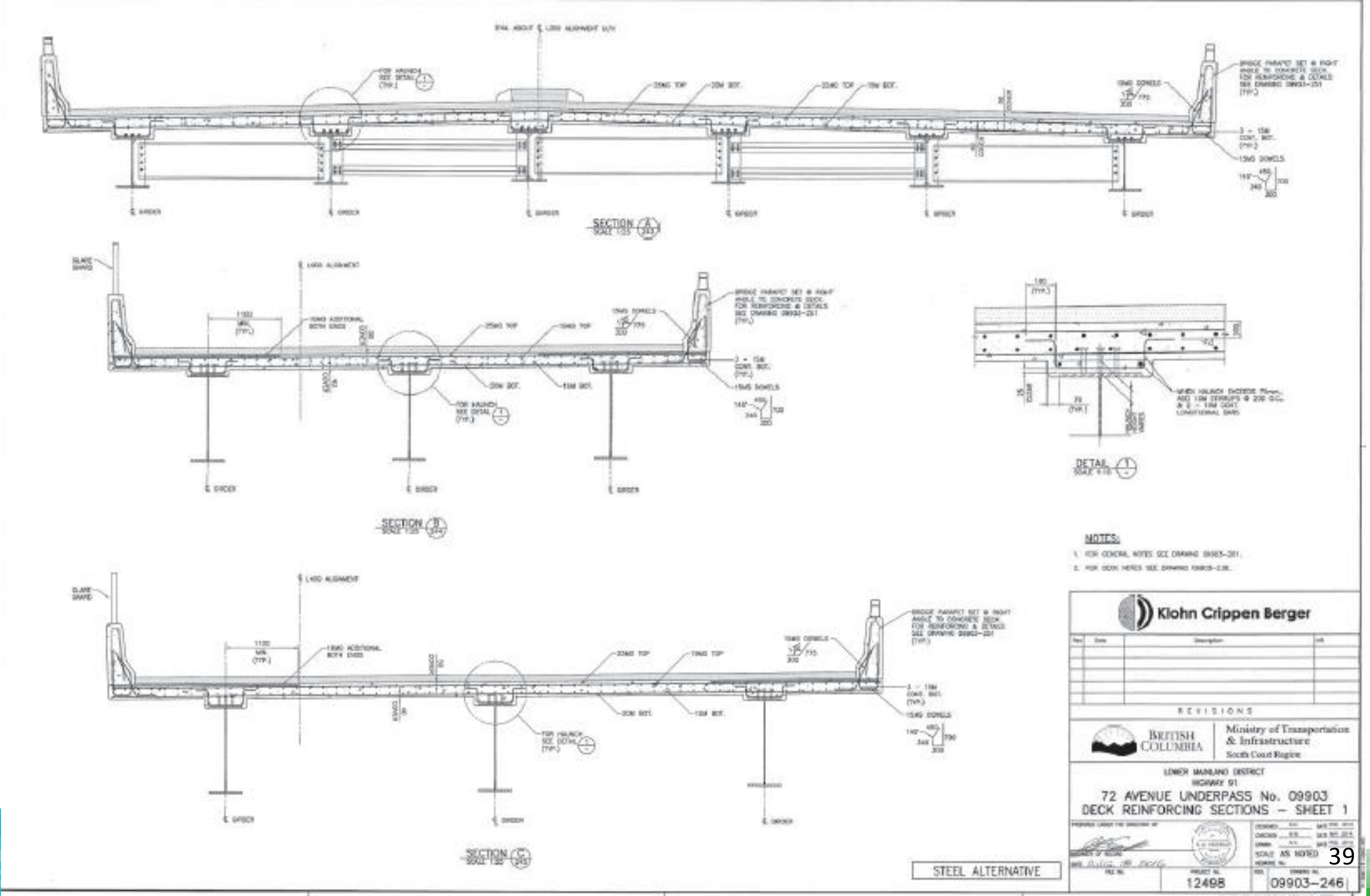
Peace Bridge – City of Calgary





MTO 2012-4001 (Carling Av/Kirkwood Av overpass Rapidlifts, Hwy 417 in Ottawa, ON

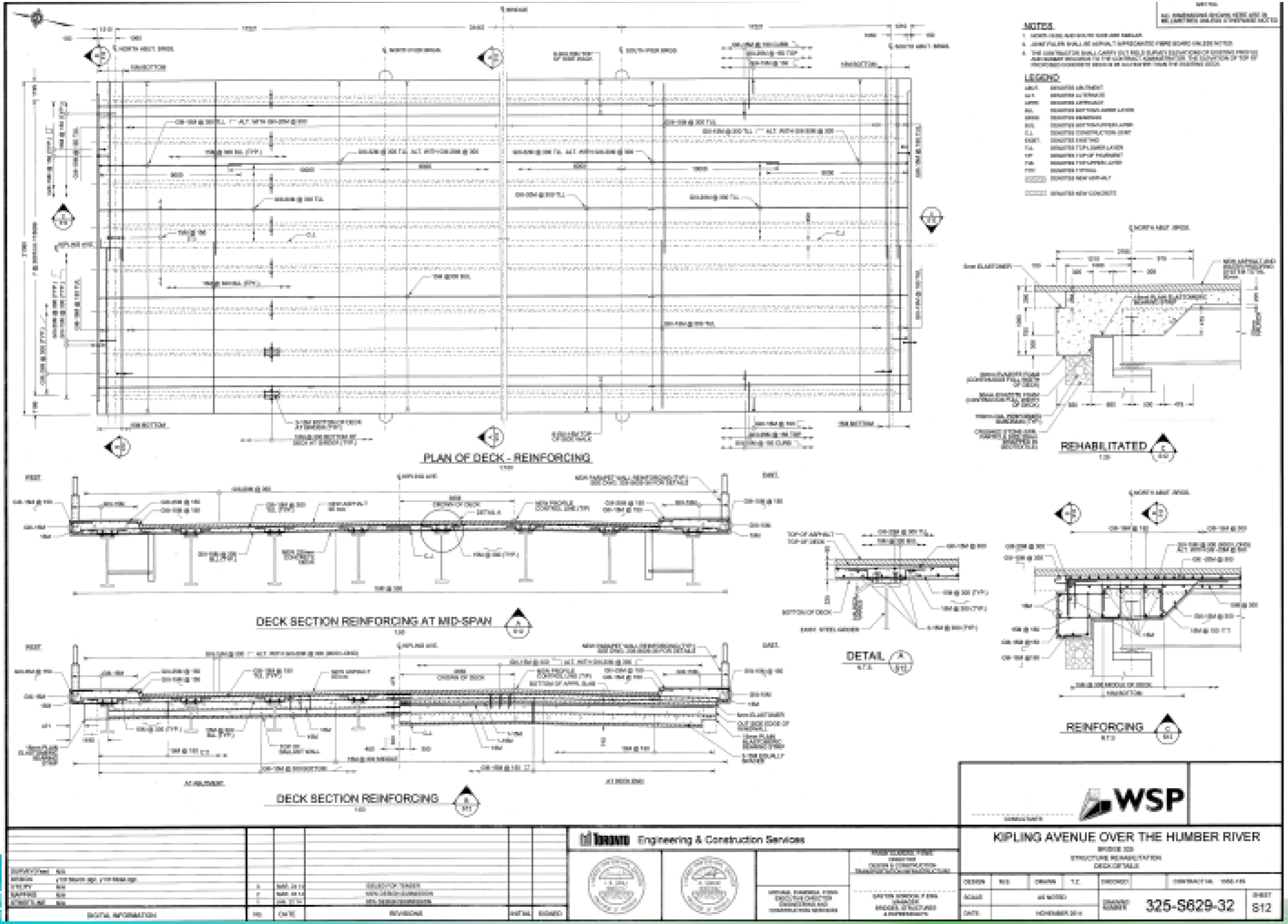
MTO 2009-4726
(Beaver Creek)


SECTION A
SECTION B
SECTION C
DETAIL 1
NOTES:
Klohn Crippen Berger
REVISIONS
BRITISH COLUMBIA
Ministry of Transportation & Infrastructure
South Coast Region
LOWER MAINLAND DISTRICT
HIGHWAY 91
72 AVENUE UNDERPASS No. 09903
DECK REINFORCING SECTIONS – SHEET 1
STEEL ALTERNATIVE
SCALE AS NOTED
12498
09903-246

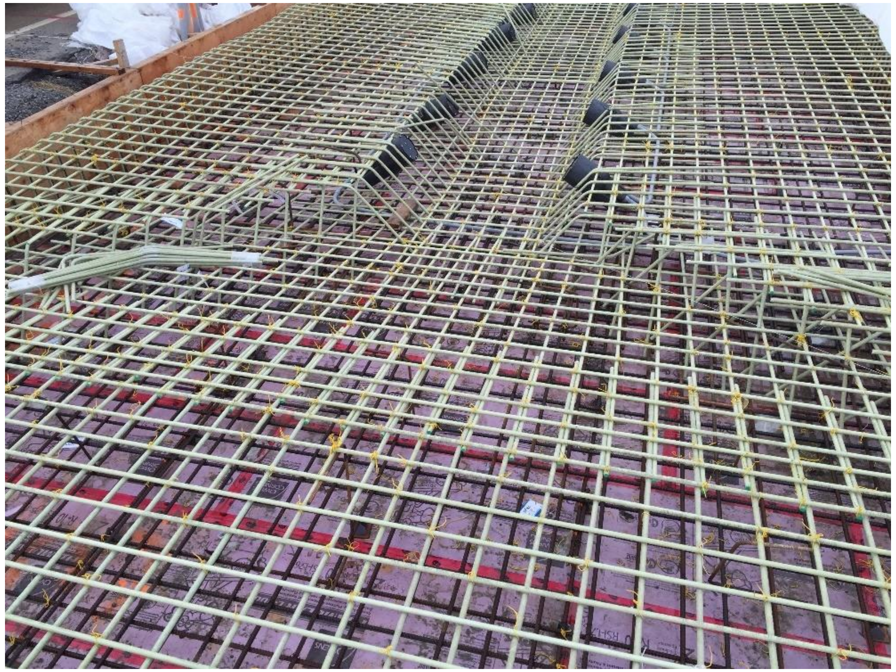
Compo

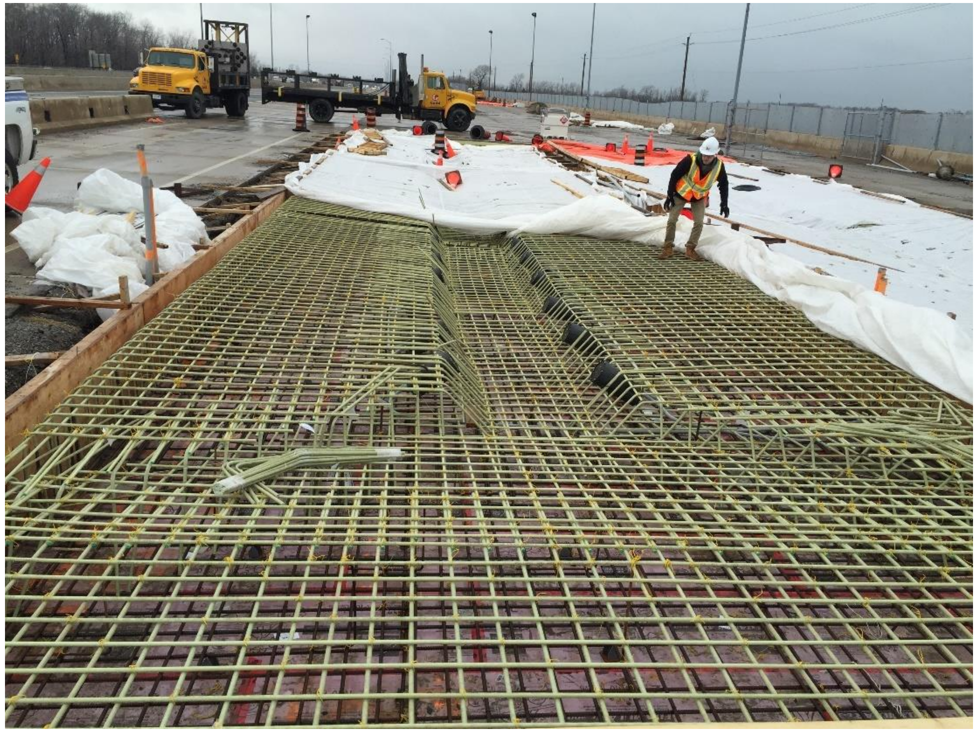
Kipling Ave Bridge
City of Toronto
Designer - WSP

Composites

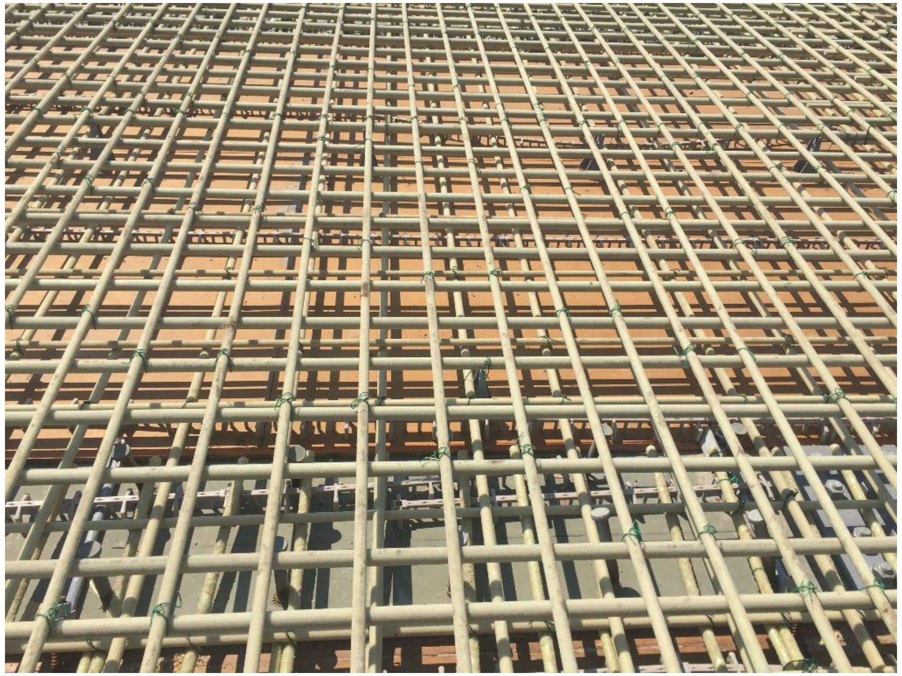

NOTES
LEGEND
PLAN OF DECK - REINFORCING
REHABILITATED
DECK SECTION REINFORCING AT MID-SPAN
DETAIL
REINFORCING
DECK SECTION REINFORCING
WSP
TORONTO Engineering & Construction Services
KIPLING AVENUE OVER THE HUMBER RIVER
325-S629-32
S12

Non-conductivity for cameras and sensors – tolling areas





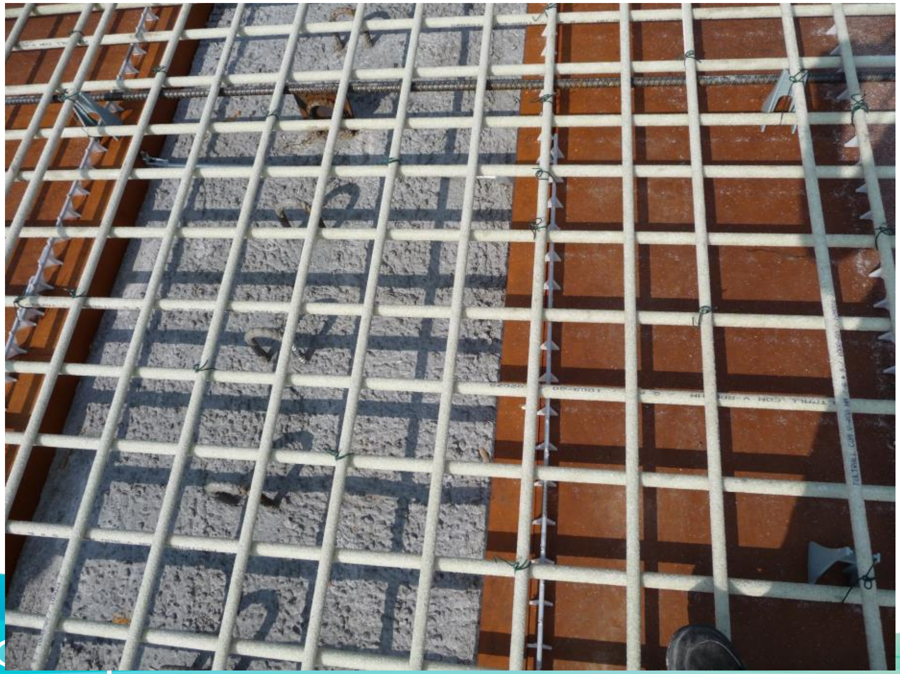
Rideau River Crossing
City of Ottawa
Designer – WSP
Contractor - Pomerleau



Composites

O’Reilly’s Bridge, Niagara Region, ON

MTO 2009-5156



Rehabilitation

Addington Av,
City of Toronto

Bridgeport Bridge,
Kitchener, ON

HILTI

Sika
CONSTRUCTION

Bakers Haulover bridge - Florida

Pineda Causeway - Florida

MTO 2010-2054 (Warden Ave over Hwy 401 in Toronto - bar on site and placed in deck

MTO 2010-2054 (Warden Ave) over Hwy 401 in Toronto - deck bar already poured

Project Applications – Precast Decks

Sunshine Creek- 2007,
MTO NW Region

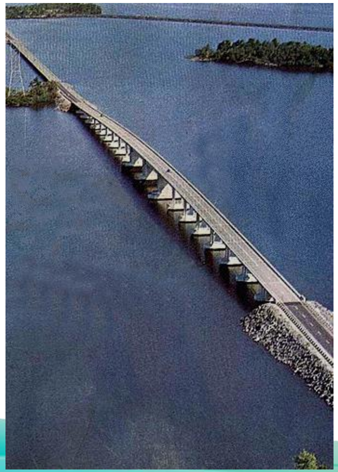
Pre-cast box girders

Rainy Lake - 2006,
MTO NW Region

Pre-cast panels decks

Noden Causeway, MTO NW Region

Pre-cast panels in place



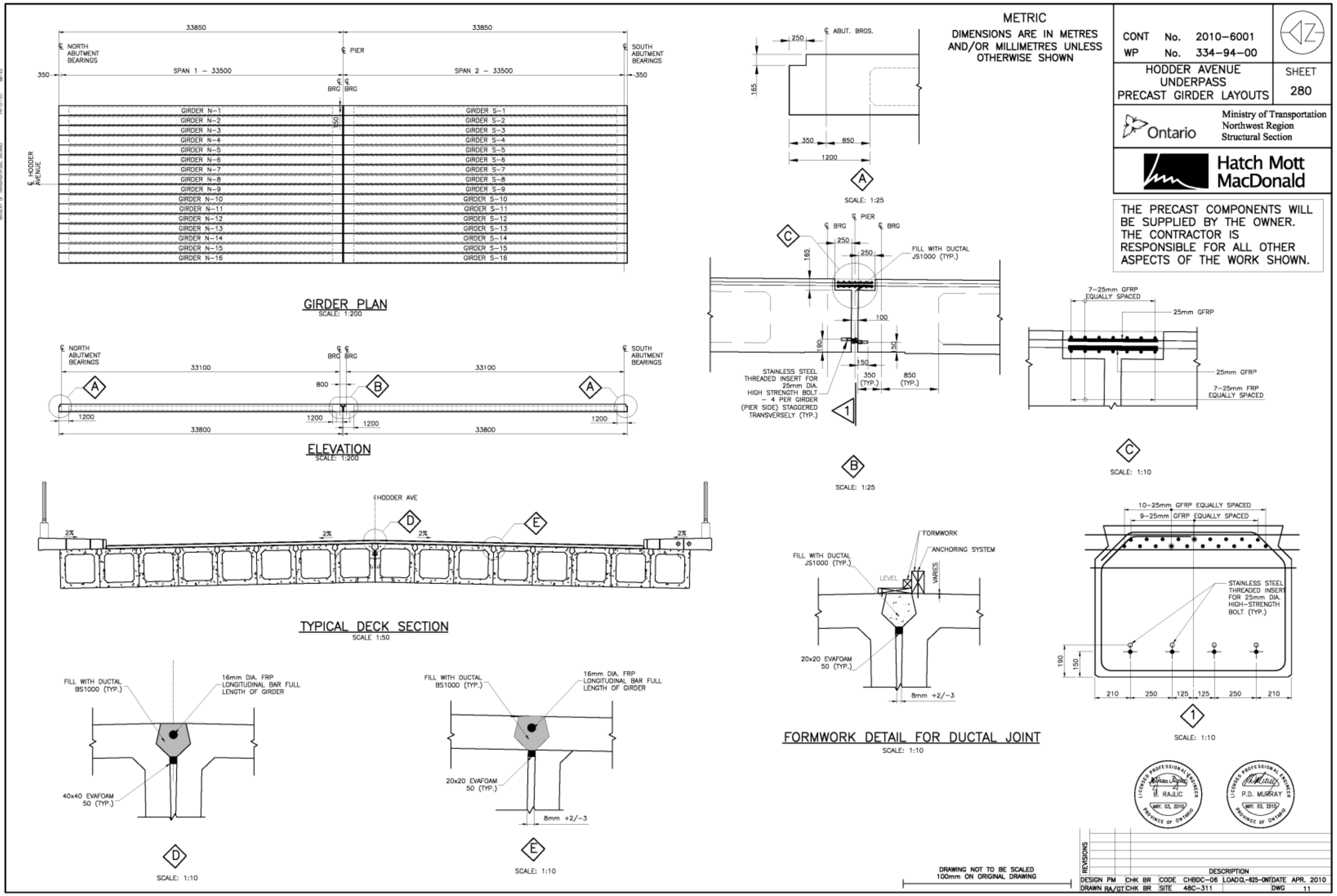

2008 8 13


2008 8 13


PC-1-1


17 07 2015

MTO 2010-6043
McKenzie River Bridge


METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN
CONT No. 2010-6001
WP No. 334-94-00
HODDER AVENUE UNDERPASS PRECAST GIRDER LAYOUTS
SHEET 280
Ministry of Transportation Northwest Region Structural Section
Ontario
Hatch Mott MacDonald
THE PRECAST COMPONENTS WILL BE SUPPLIED BY THE OWNER. THE CONTRACTOR IS RESPONSIBLE FOR ALL OTHER ASPECTS OF THE WORK SHOWN.
GIRDER PLAN
SCALE: 1:200
ELEVATION
SCALE: 1:200
TYPICAL DECK SECTION
SCALE 1:50
FORMWORK DETAIL FOR DUCTAL JOINT
SCALE: 1:10
FILL WITH DUCTAL JS1000 (TYP.)
STAINLESS STEEL THREADED INSERT FOR 25mm DIA. HIGH-STRENGTH BOLT (TYP.)
DRAWING NOT TO BE SCALED 100mm ON ORIGINAL DRAWING
DESIGN PM CHK BR CODE CHBDC-06 LOAD CL-625-ONT DATE APR. 2010
DRAWN RA/GT CHK BR SITE 48C-311 DWG 11

Precast decks placed on Hodder Ave Bridge (MTO 2010-6001)

<u>Nipigon Cable Stayed Bridge</u>

Owner – ON Ministry of Transportation

Designer – MMM/WSP/ Buckland & Taylor

Contractor – BOT/Ferrovial

GFRP in all precast deck panels

Example of typical precast box girders, approach slabs and pre-stressed curbs
MTO 2014-6032

Chukuni River– MTO NW

Steel River– MTO NW


G

Hall’s River project
Florida DOT

Flagler Beach

Owner – Florida DOT

Designer – Mott MacDonald

Contractor – Malcolm Drilling

Supplied 19 flatbeds loads of material for secant pile cages

Composites

Conclusions

- As the GFRP technology continues to advance and prove its performance and durability in the field, owners and asset managers should be more comfortable in utilizing this concrete reinforcing
- As codes and specifications also continue to evolve, the tools and design considerations for GFRP allow engineers to be more confident in designing GFRP reinforced structures and expand applications

Contacts

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VP Sales