FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Special considerations for precast water retention chambers and shrinkage and temperature crack control of mass concrete elements

David Lai, P. Eng., M. Eng., MICE (UK)

Technical Director

WSP Canada

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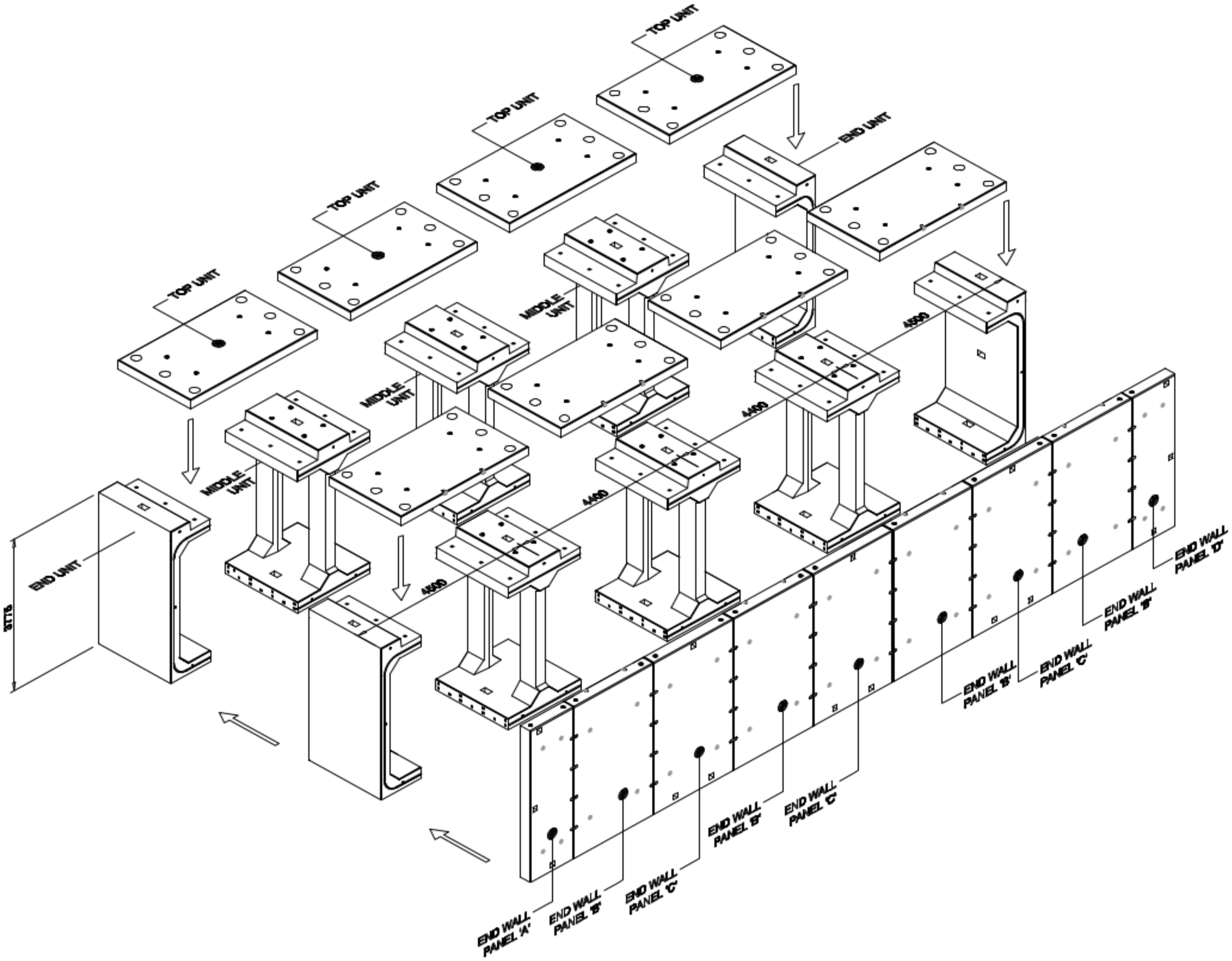
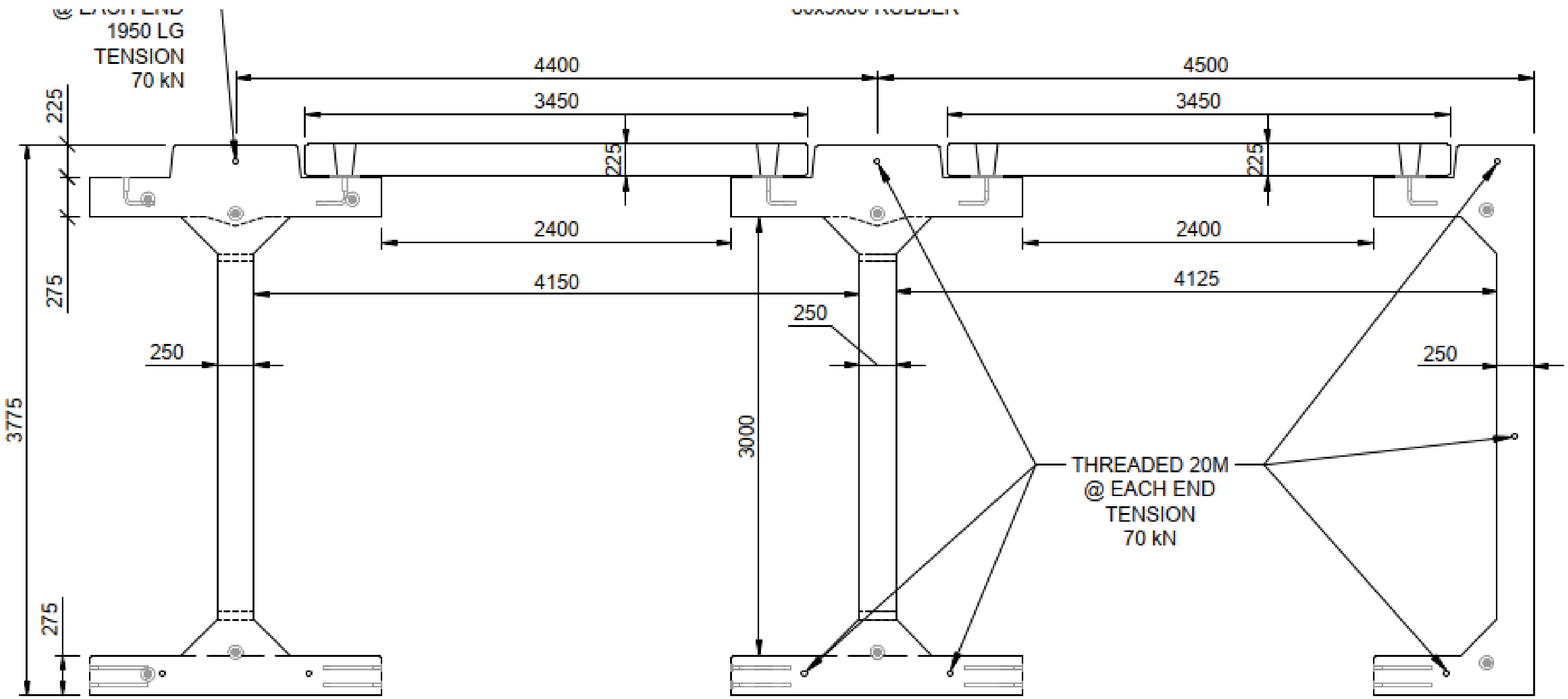
PULTRALL V-ROD FIBERGLASS Innovations ALTAIR MST BAR MAXIMUM STRENGTH GFRP SFTec ACMA American Composites Manufacturers Association FRP Rebar Manufacturers Council

Université de Sherbrooke NSERC CRSNG University of Miami Center for Integration of Composites into Infrastructure FDOT

Precast water retention chamber in Ontario

- Part of storm water management strategy for some municipalities in Ontario
- Original design using steel reinforcement was done in Japan
- Since storm water could contain de-icing chemicals and other contaminants that could cause corrosion of black steel, GFRP was proposed as an alternative where enhanced durability is required
- WSP was retained by the GFRP manufacturer/precaster to develop an alternative design


TOP UNIT
TOP UNIT
TOP UNIT
TOP UNIT
END UNIT
MIDDLE UNIT
MIDDLE UNIT
MIDDLE UNIT
END UNIT
3775
4500
4400
4400
4500
END WALL PANEL 'A'
END WALL PANEL 'B'
END WALL PANEL 'C'
END WALL PANEL 'B'
END WALL PANEL 'C'
END WALL PANEL 'B'
END WALL PANEL 'C'
END WALL PANEL 'B'
END WALL PANEL 'D'



TYPICAL UNIT CONNECTION

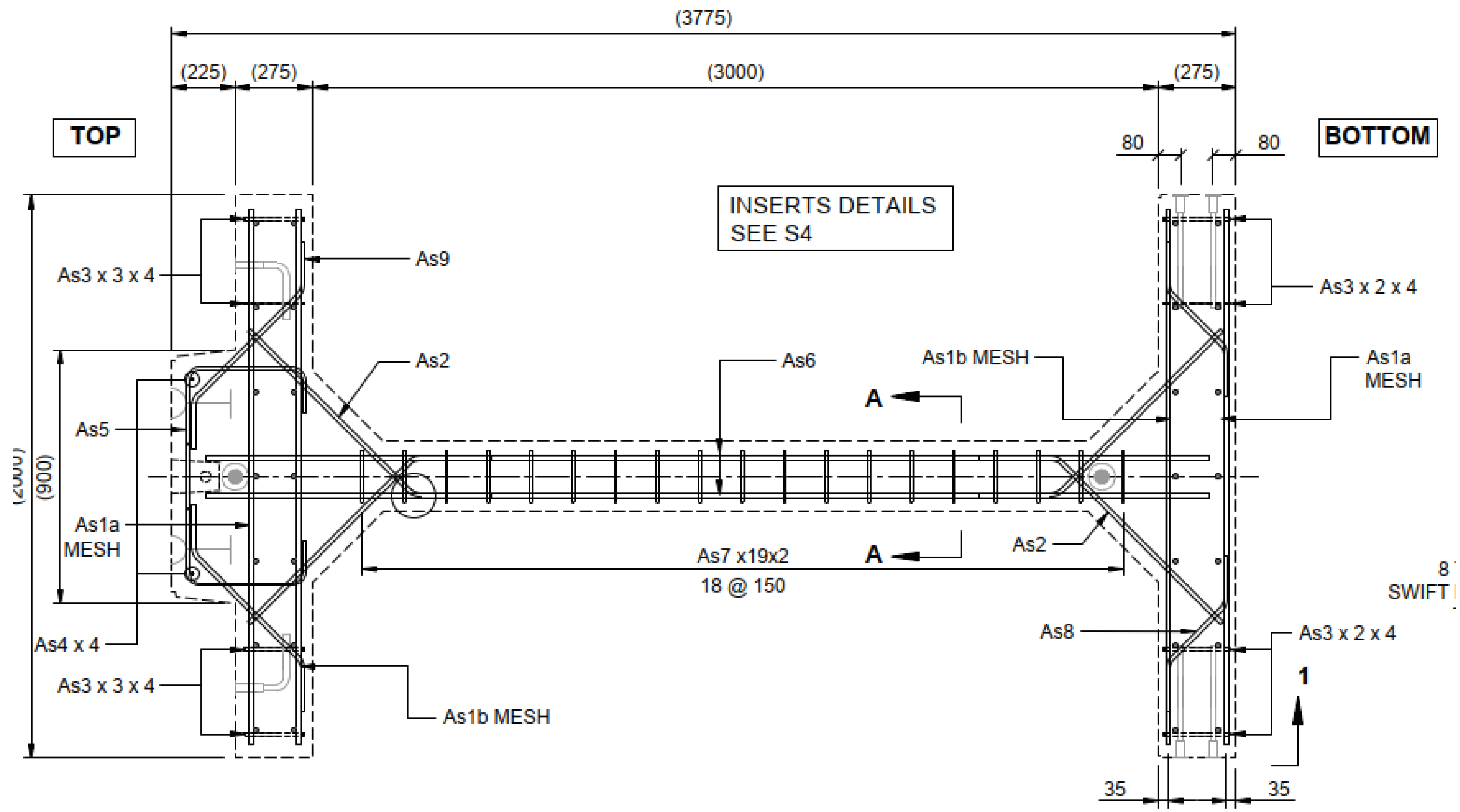
SCALE 1:50

Design challenges

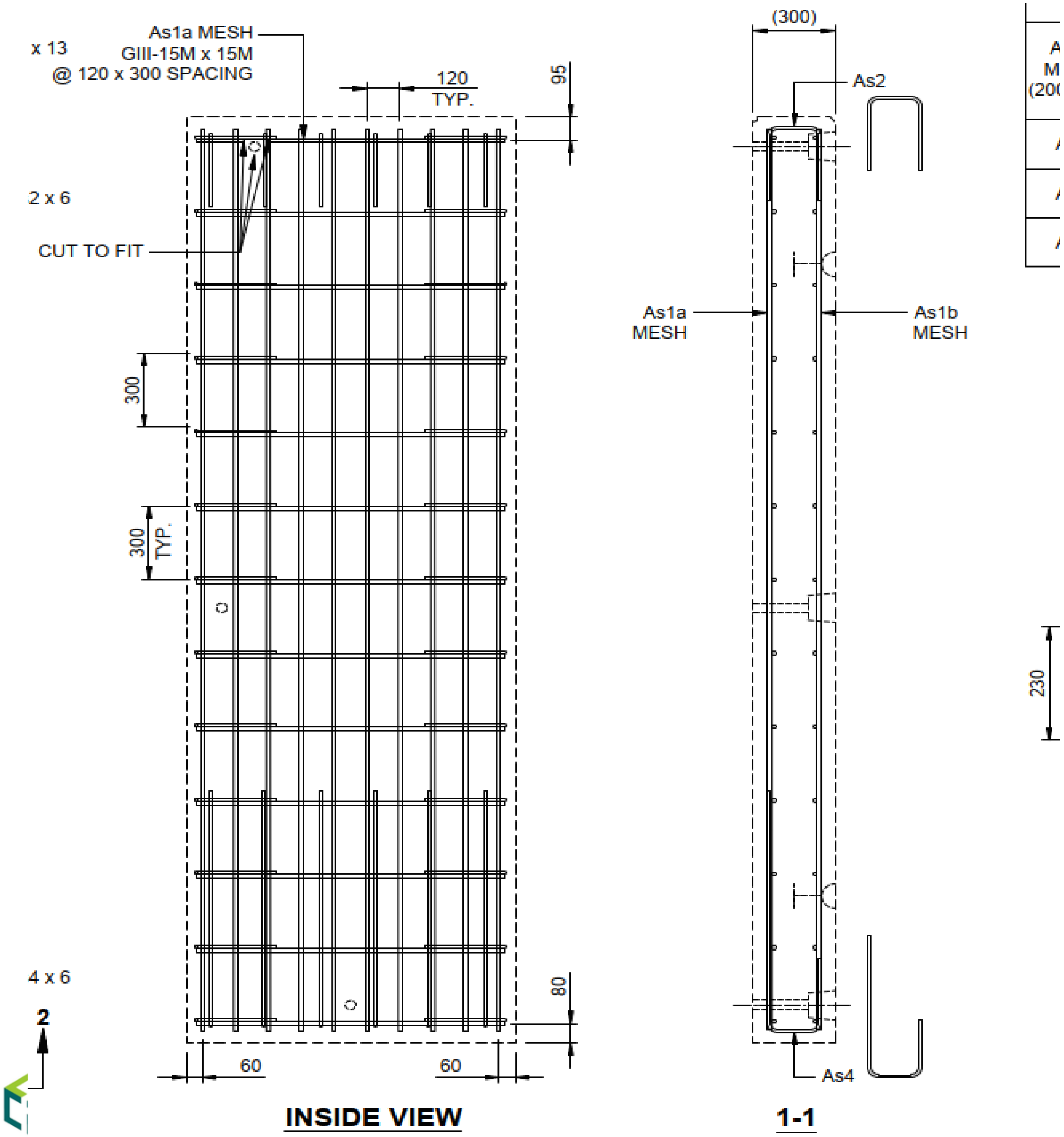
- Design for worst case with 3.5m of fill on top
- Current provisions for shear according to CSA S806 impose a significant reduction in Vc compared with steel
- Due to high sustained load, need to limit SLS stress to 25% Fu
- Top slab only 225mm thick sustains very high shear
- Supporting corbel designed by strut and tie model, but bent bars would suffer significant strength reduction at the bend
- Wall panels also sustain very high shear due to at rest pressure and hydrostatic pressure

Design solutions

- Reduce cover to 35mm to manage crack width and make full use of effective depth
- Specify high bond strength of 20 MPa tested according to ASTM D7913, max slip 0.5mm and Kb of 0.8 in order to develop adequate longitudinal tensile strength at high shear zone
- Use only Grade III 60 GPa
- Add inclined rebar at critical shear section of top and bottom corbel
- Add supplementary short longitudinal GFRP rebars at bottom of wall panels to improve Vc.


(3775)
(225)
(275)
(3000)
(275)
TOP
BOTTOM
80
80
INSERTS DETAILS
SEE S4
As3 x 3 x 4
As9
As3 x 2 x 4
As2
As6
As1b MESH
As1a
MESH
A
As5
(900)
As1a
MESH
As7 x19x2
18 @ 150
A
As2
SWIFT
As8
As4 x 4
As3 x 2 x 4
1
As3 x 3 x 4
As1b MESH
35
35

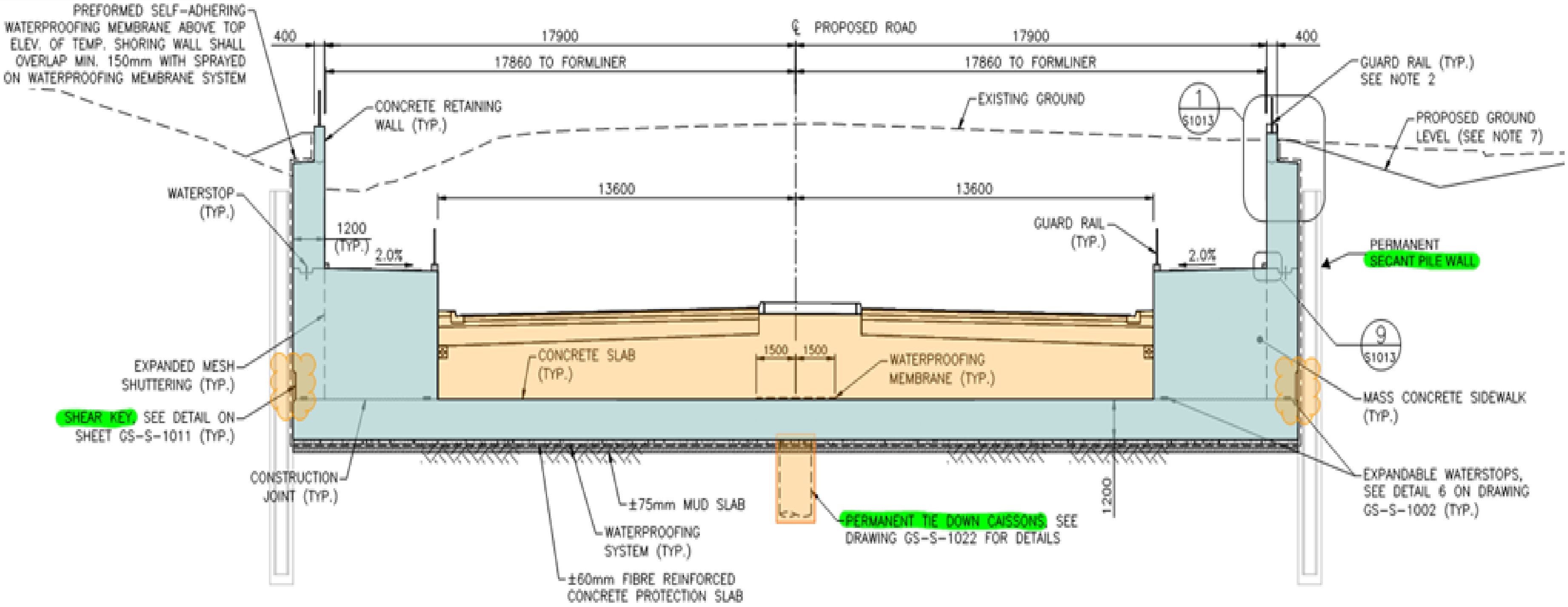
PLAN VIEW


x 13
As1a MESH
GIII-15M x 15M
@ 120 x 300 SPACING
120
TYP.
95
2 x 6
CUT TO FIT
300
300
TYP.
4 x 6
80
2
60
60
INSIDE VIEW
(300)
As2
As1a
MESH
As1b
MESH
230
As4
1-1

Mass concrete MUP for Rutherford Road Grade Separation with GFRP Reinforcement for Shrinkage and Temperature Cracking Control

- The Rutherford Road Grade Separation structure is a 300 m long by 40m wide reinforced concrete Tub System that is subjected to very high hydrostatic uplift due to two underground aquifer.
- The MUP mass concrete is part of the counterweight to resist buoyancy
- Contractor decided to pour MUP concrete together with the main retaining wall, so normal structural concrete mix was used and it was taken advantage of to reduce the bending moment, shear and deflection of the tall retaining wall

Completed construction and opened to traffic in 2022


PREFORMED SELF-ADHERING WATERPROOFING MEMBRANE ABOVE TOP ELEV. OF TEMP. SHORING WALL SHALL OVERLAP MIN. 150mm WITH SPRAYED ON WATERPROOFING MEMBRANE SYSTEM
400
17900
℄ PROPOSED ROAD
17900
400
17860 TO FORMLINER
17860 TO FORMLINER
GUARD RAIL (TYP.) SEE NOTE 2
CONCRETE RETAINING WALL (TYP.)
EXISTING GROUND
1 S1013
PROPOSED GROUND LEVEL (SEE NOTE 7)
WATERSTOP (TYP.)
13600
13600
1200 (TYP.)
2.0%
GUARD RAIL (TYP.)
2.0%
PERMANENT SECANT PILE WALL
9 S1013
EXPANDED MESH SHUTTERING (TYP.)
CONCRETE SLAB (TYP.)
1500
1500
WATERPROOFING MEMBRANE (TYP.)
MASS CONCRETE SIDEWALK (TYP.)
SHEAR KEY, SEE DETAIL ON SHEET GS-S-1011 (TYP.)
EXPANDABLE WATERSTOPS, SEE DETAIL 6 ON DRAWING GS-S-1002 (TYP.)
CONSTRUCTION JOINT (TYP.)
±75mm MUD SLAB
1200
WATERPROOFING SYSTEM (TYP.)
PERMANENT TIE DOWN CAISSONS, SEE DRAWING GS-S-1022 FOR DETAILS
±60mm FIBRE REINFORCED CONCRETE PROTECTION SLAB

Design challenges

- Temperature control of mass concrete during curing according to OPSS 904: max allowed core temperature = 70 degree C

  max allowed differential = 20 degree C

  Metrolinx Standard allows max SCM 25%

  Finite element analysis for thermal effect showed section could crack.
- Premium reinforcement is required due to salt splashing
- What should be the min GFRP reinforcement ?
  - CSA S806?
  - ACI 440?
  - ACI 350?

CSA S806

8.4.2.3

In slabs, a minimum area of reinforcement of $(400/E_F)\ A_g$ shall be used in each of the two orthogonal directions. This reinforcement shall not be less than $0.0025\ A_g$ and shall be spaced no farther apart than three times the slab thickness or 300 mm, whichever is less.

Afrp = (400 / 60000) Ag
= 0.0067 Ag

Too large and may be unreasonable

ACI 440.1R-2015

Min Afrp = 0.0018 x (414/1000) x (200/60)
= 0.0025 Ag

It does not have a maximum for massive elements

ment (deformed or smooth). ACI 318 also requires that the spacing of shrinkage and temperature reinforcement not exceed five times the member thickness or 18 in. (500 mm).

9.1—Minimum FRP reinforcement ratio

No experimental data are available for the minimum FRP reinforcement ratio for shrinkage and temperature. ACI 318, Section 7.12.2, states that for slabs with steel reinforcement having a yield stress exceeding 60 ksi (414 MPa) measured at a yield strain of 0.0035, the ratio of reinforcement to gross area of concrete should be at least 0.0018 × 60/f_y, where f_y is in ksi, but not less than 0.0014. The stiffness and the strength of shrinkage and temperature FRP reinforcement can be incorporated in this formula. Therefore, when deformed FRP shrinkage and temperature reinforcement is used, the amount of reinforcement should be determined by using Eq. (9.1)

$$\rho_{f,ts} = 0.0018 \times \frac{60{,}000}{f_{fu}} \frac{E_s}{E_f} \quad (9.1)$$

For SI units

$$\rho_{f,ts} = 0.0018 \times \frac{414}{f_{fu}} \frac{E_s}{E_f}$$

Due to limited experience, it is recommended that the ratio of temperature and shrinkage reinforcement given by Eq. (9.1) be taken not less than 0.0014, the minimum value specified by ACI 318 for steel shrinkage and temperature reinforcement. The licensed design professional may consider an upper limit for the ratio of temperature and shrinkage reinforcement equal to 0.0036, or compute the ratio based on calculated strain levels corresponding to the nominal flexural capacity rather than the strains calculated using Eq. (9.1). Spacing of shrinkage and temperature FRP reinforcement should not exceed three times the slab thickness or 12 in. (300 mm), whichever is less. The use of FRP for temperature and shrinkage reinforcement for slabs-on-ground is presented in Appendix A.

CHAPTER 10—DEVELOPMENT AND SPLICES OF REINFORCEMENT

ACI 440 -2022

24.4.3 *GFRP reinforcement*

24.4.3.1 Reinforcement to resist shrinkage and temperature stresses shall conform to 20.2.1.4 and shall be in accordance with 24.4.3.2 through 24.4.3.5.

24.4.3.2 The ratio of shrinkage and temperature reinforcement area to gross concrete area shall not be less than $\mathbf{140}/E_f$.

140 / 60000 = 0.0023 Ag

Basically the same as the 2015 version, and no maximum for massive elements.

ACI 350

7.12.2.1 — For members subjected to environmental exposure conditions or required to be liquid-tight, the area of shrinkage and temperature reinforcement shall provide at least the ratios of reinforcement area to gross concrete area shown in Table 7.12.2.1:

Concrete sections that are at least 24 in. may have the minimum shrinkage and temperature reinforcement based on a 12 in. concrete layer at each face. The reinforcement in the bottom of base slabs in contact with soil may be reduced to 50 percent of that required in Table 7.12.2.1.

TABLE 7.12.2.1—MINIMUM SHRINKAGE AND TEMPERATURE REINFORCEMENT

Length between movement joints, ft	Minimum shrinkage and temperature reinforcement ratio	
	Grade 40	Grade 60
Less than 20	0.0030	0.0030
20 to less than 30	0.0040	0.0030
30 to less than 40	0.0050	0.0040
40 and greater	0.0060*	0.0050*

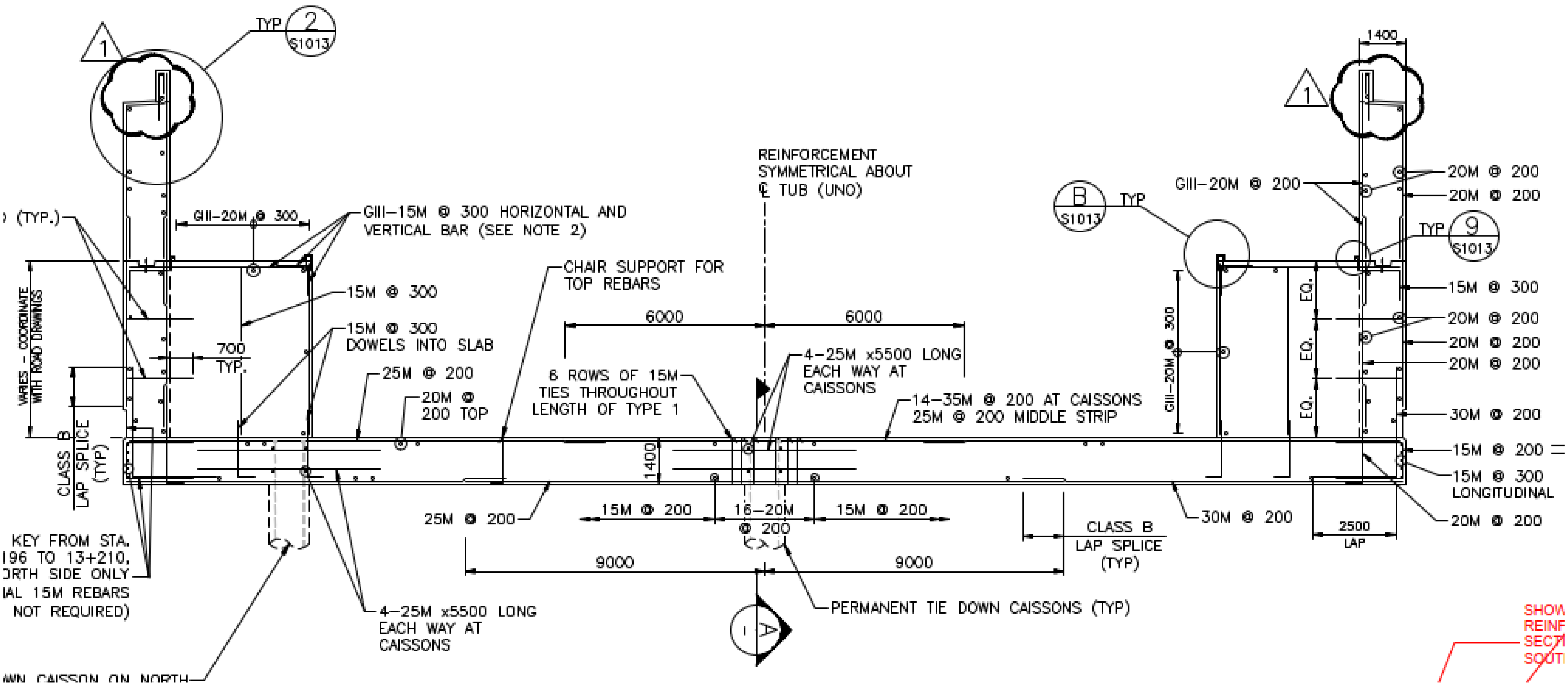
*Maximum shrinkage and temperature reinforcement where movement joints are not provided.

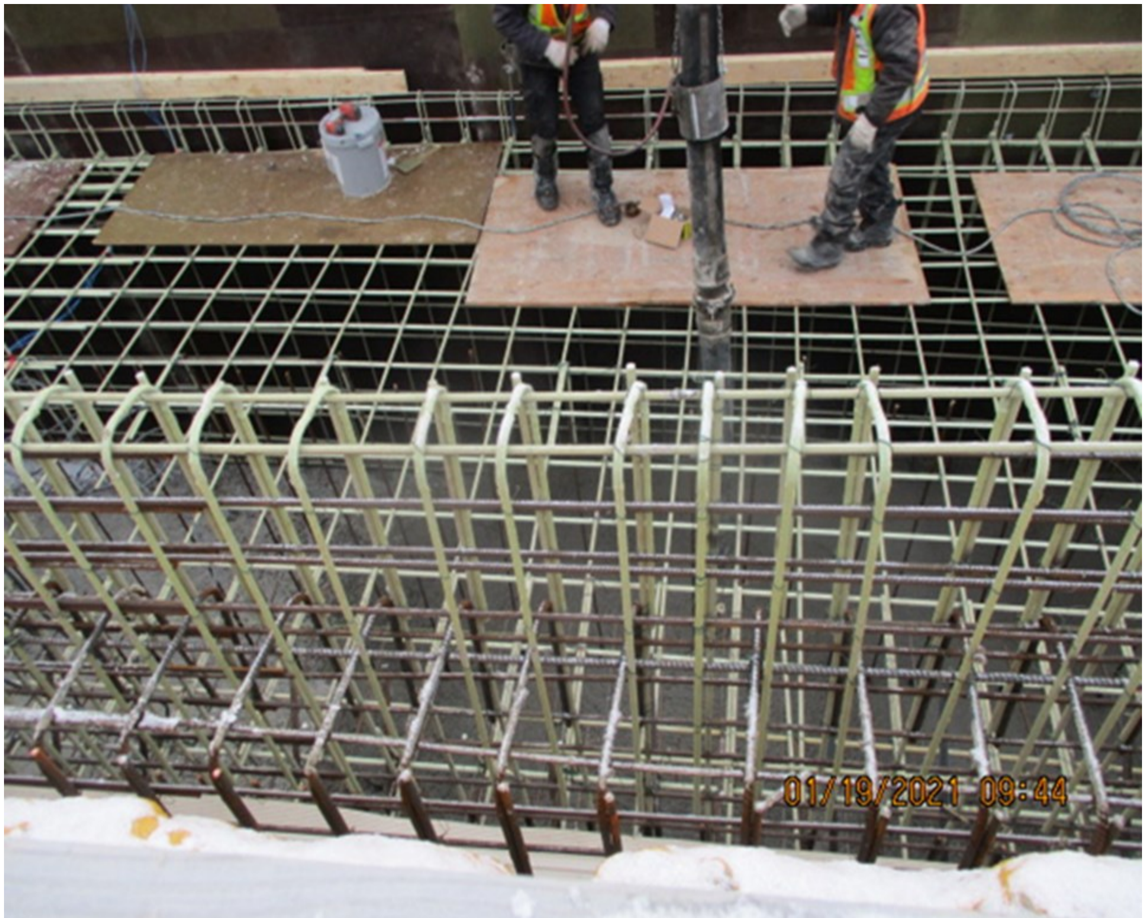
Note: This table applies to spacing between expansion joints and full contraction joints. When used with partial contraction joints, the minimum reinforcement ratio shall be determined by multiplying the actual length between partial contraction joints by 1.5.

Allow to consider maximum thickness of 300mm per face.

300mm x 1000mm x 0.005

= 1500 mm^2/ m 20M @ 200


TYP 2 S1013
REINFORCEMENT SYMMETRICAL ABOUT ℄ TUB (UNO)
GIII–15M @ 300 HORIZONTAL AND VERTICAL BAR (SEE NOTE 2)
GIII–20M @ 300
15M @ 300
15M @ 300 DOWELS INTO SLAB
700 TYP.
25M @ 200
20M @ 200 TOP
CHAIR SUPPORT FOR TOP REBARS
6000
6000
6 ROWS OF 15M TIES THROUGHOUT LENGTH OF TYPE 1
4–25M x5500 LONG EACH WAY AT CAISSONS
14–35M @ 200 AT CAISSONS 25M @ 200 MIDDLE STRIP
B S1013 TYP
GIII–20M @ 200
TYP 9 S1013
1400
20M @ 200
20M @ 200
15M @ 300
20M @ 200
20M @ 200
20M @ 200
30M @ 200
15M @ 200
15M @ 300 LONGITUDINAL
20M @ 200
2500 LAP
GIII–20M @ 300
EQ.
EQ.
EQ.
30M @ 200
CLASS B LAP SPLICE (TYP)
15M @ 200
16–20M @ 200
15M @ 200
25M @ 200
9000
9000
1400
PERMANENT TIE DOWN CAISSONS (TYP)
4–25M x5500 LONG EACH WAY AT CAISSONS
A
CLASS B LAP SPLICE (TYP)
VARIES – COORDINATE WITH ROAD DRAWINGS
(TYP.)
KEY FROM STA. 196 TO 13+210, RTH SIDE ONLY
AL 15M REBARS NOT REQUIRED)
WN CAISSON ON NORTH
SHOW REINF SECT SOUT

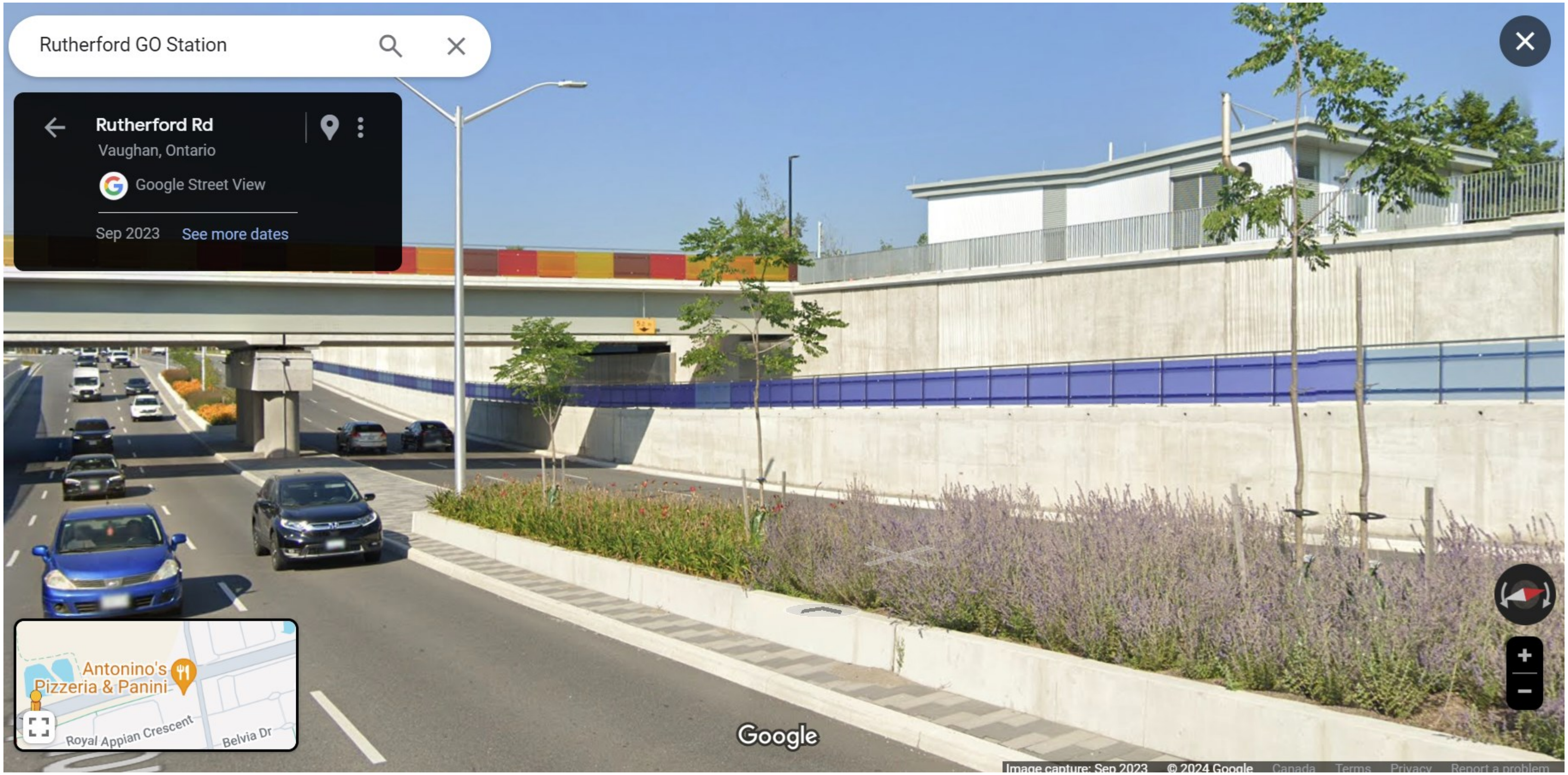


Mass concrete MUP with GFRP reinforcement

-Increase dead weight to counteract buoyancy

-Reduce bending and shear of retaining walls

Final product and observation



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Special considerations for wind turbine foundations in KSA and large slab on grade for container facility in Australia

David Lai, P. Eng., M. Eng., MICE (UK)

Technical Director

WSP Canada

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MST BAR
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SFTec
ACMA
American Composites Manufacturers Association
FRP Rebar Manufacturers Council
UNIVERSITÉ DE SHERBROOKE
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UNIVERSITY OF MIAMI
Center for Integration of Composites into Infrastructure
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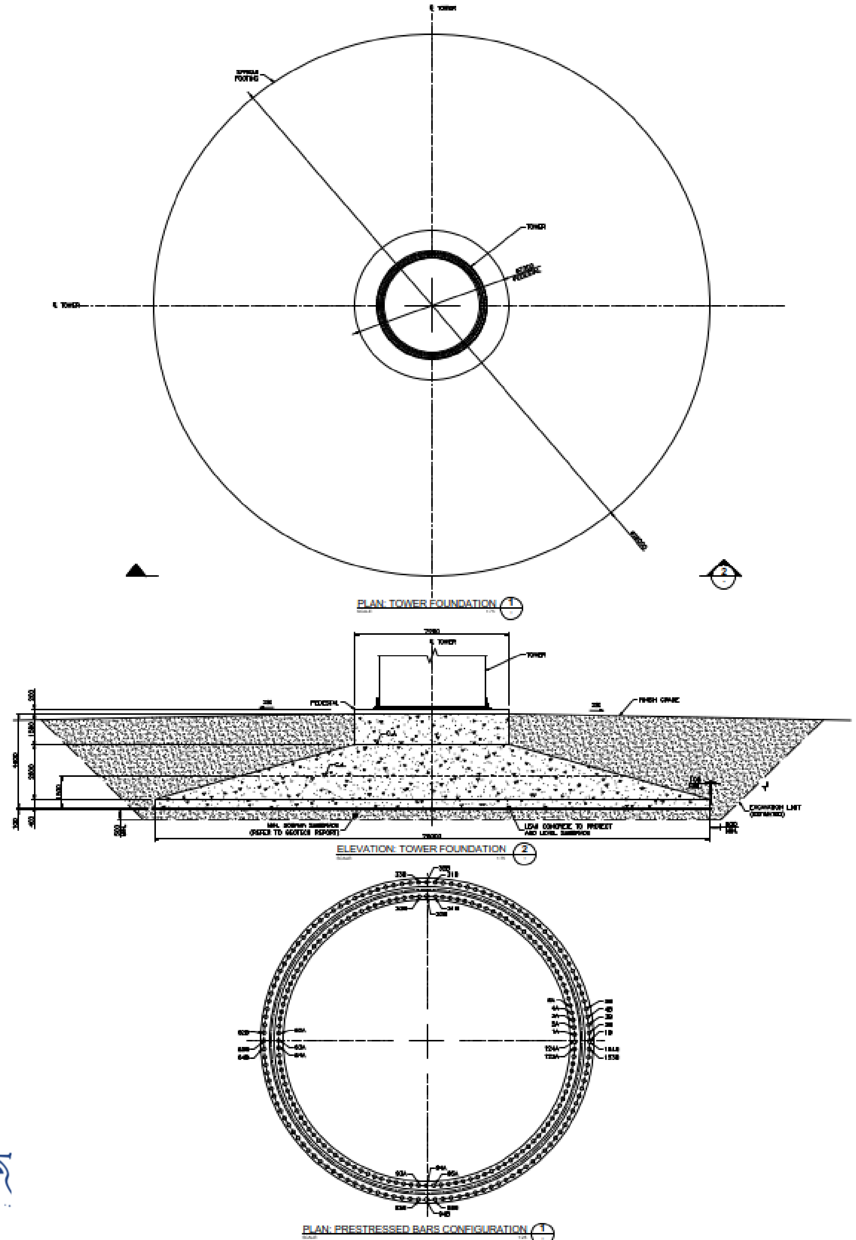
Wind turbine foundation for NEOM

- WSP Canada was retained by NEOM to carry out a feasibility study on the use of GFRP reinforcement for wind turbine foundations, and if found feasible, develop a pilot design.
- Project objectives:
  - Use of green technologies
  - Maximize use of local resources
  - Availability and development of local industry
  - Set the path for other applications

Major design considerations and conclusions

- Circular foundation was chosen instead of octagonal to avoid bent bars at the ridges and sudden changes in direction
- Setting limitation on radius and bar sizes for field bending of top circumferential bars
- A hybrid design, using steel rebars for shear reinforcement and to avoid concrete residual on GFRP due to staged construction
- Used only 60 GPA high modulus GFRP that meets the CSA S807 requirements
- Significant reduction in GHG emissions compared with all steel design based on current percentage of recycled steel in the middle east



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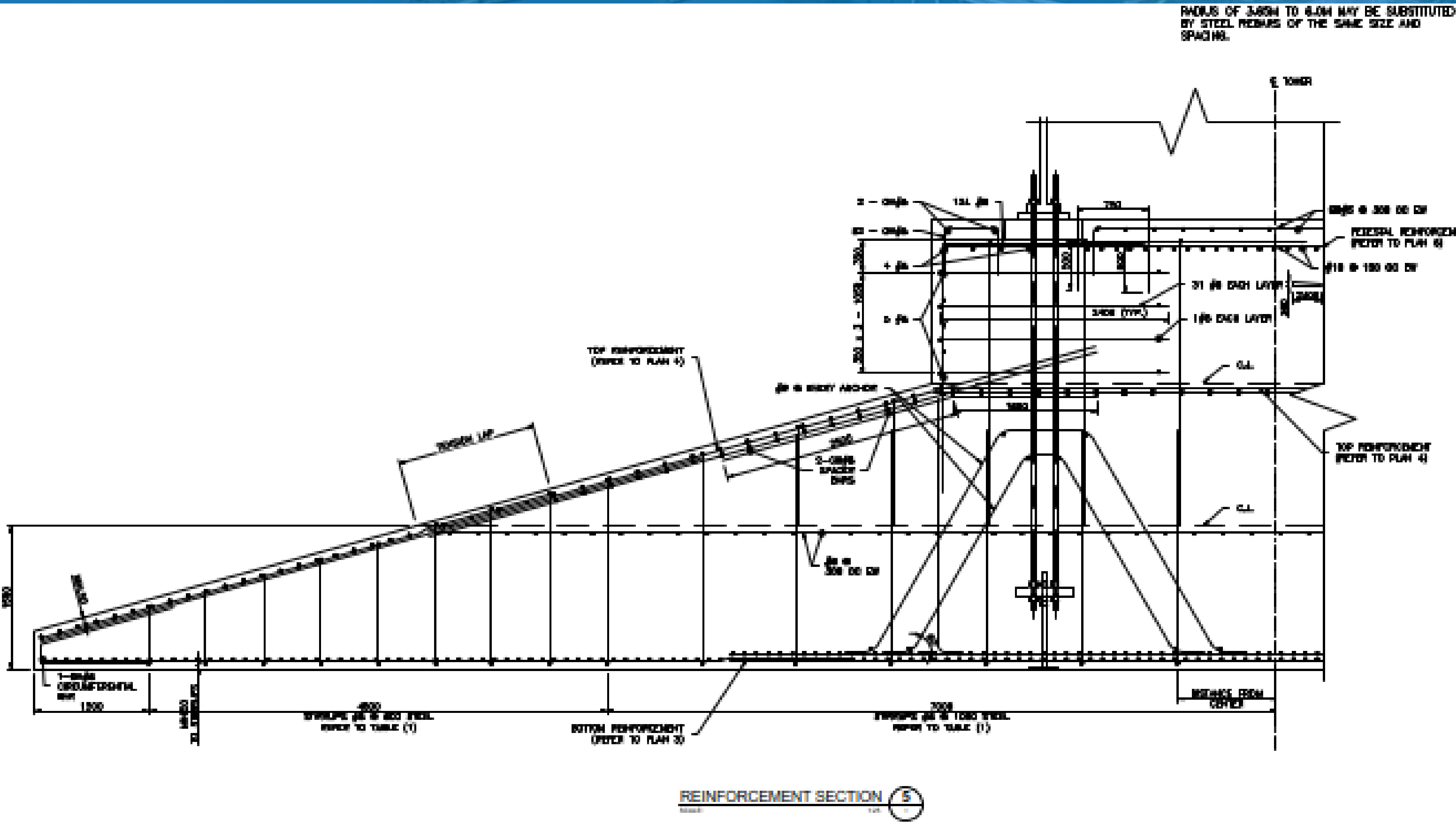
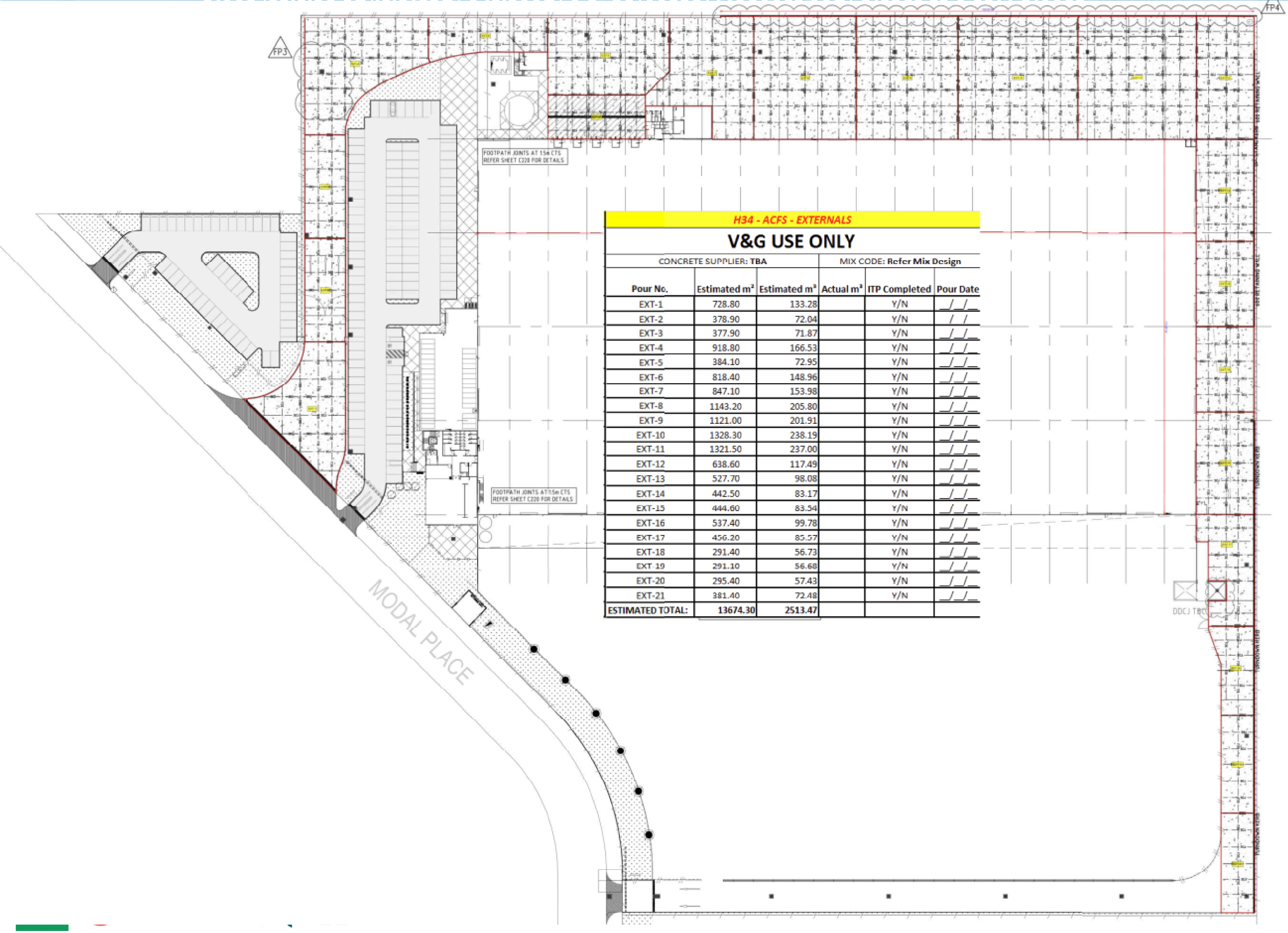

RADIUS OF 3.65M TO 6.0M MAY BE SUBSTITUTED BY STEEL REBARS OF THE SAME SIZE AND SPACING.
TOP REINFORCEMENT (REFER TO PLAN 4)
BOTTOM REINFORCEMENT (REFER TO PLAN 3)
C.L.
C.L.
REINFORCEMENT SECTION 5


15

Questions?

Large slab on grade for container facility in Australia

- WSP was retained by the GFRP manufacturer to carry out an alternative design to replace all steel with GFRP
- Slab thickness is 175mm and 200mm
- Design loading: Max truck axle load as per new Highway loading or 30 KPa



H34 - ACFS - EXTERNALS

V&G USE ONLY

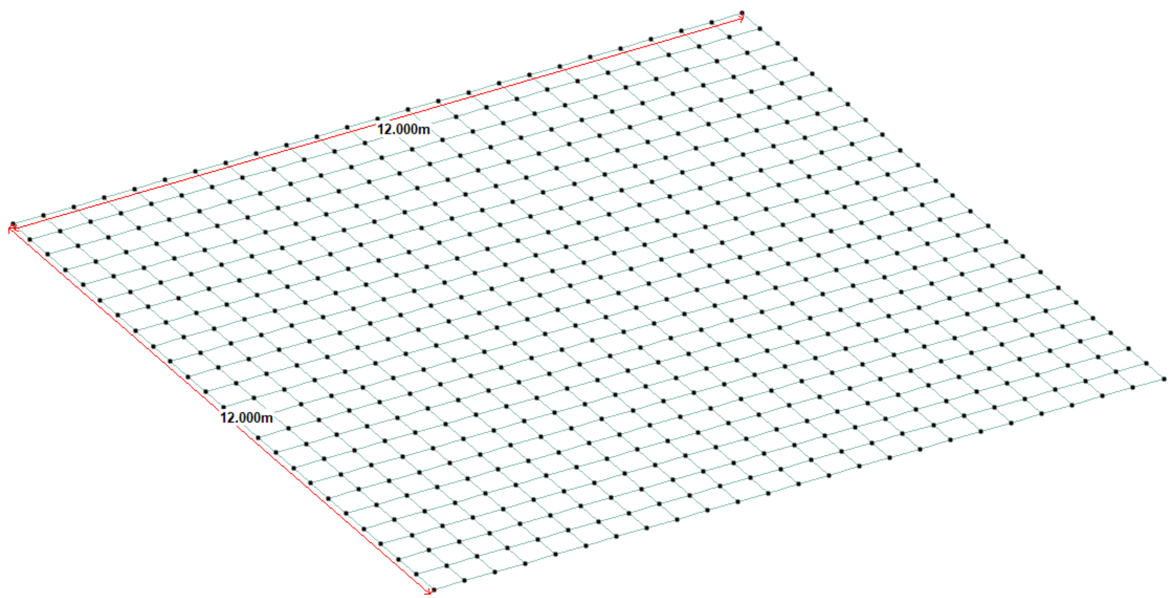
CONCRETE SUPPLIER: **TBA**			MIX CODE: **Refer Mix Design**		
Pour No.	Estimated m^2	Estimated m^3	Actual m^3	ITP Completed	Pour Date
EXT-1	728.80	133.28		Y/N	__/__/__
EXT-2	378.90	72.04		Y/N	/ /
EXT-3	377.90	71.87		Y/N	__/__/__
EXT-4	918.80	166.53		Y/N	__/__/__
EXT-5	384.10	72.95		Y/N	__/__/__
EXT-6	818.40	148.96		Y/N	__/__/__
EXT-7	847.10	153.98		Y/N	__/__/__
EXT-8	1143.20	205.80		Y/N	__/__/__
EXT-9	1121.00	201.91		Y/N	__/__/__
EXT-10	1328.30	238.19		Y/N	__/__/__
EXT-11	1321.50	237.00		Y/N	__/__/__
EXT-12	638.60	117.49		Y/N	__/__/__
EXT-13	527.70	98.08		Y/N	__/__/__
EXT-14	442.50	83.17		Y/N	__/__/__
EXT-15	444.60	83.54		Y/N	__/__/__
EXT-16	537.40	99.78		Y/N	__/__/__
EXT-17	456.20	85.57		Y/N	__/__/__
EXT-18	291.40	56.73		Y/N	__/__/__
EXT 19	291.10	56.68		Y/N	__/__/__
EXT-20	295.40	57.43		Y/N	__/__/__
EXT-21	381.40	72.48		Y/N	__/__/__
ESTIMATED TOTAL:	**13674.30**	**2513.47**			

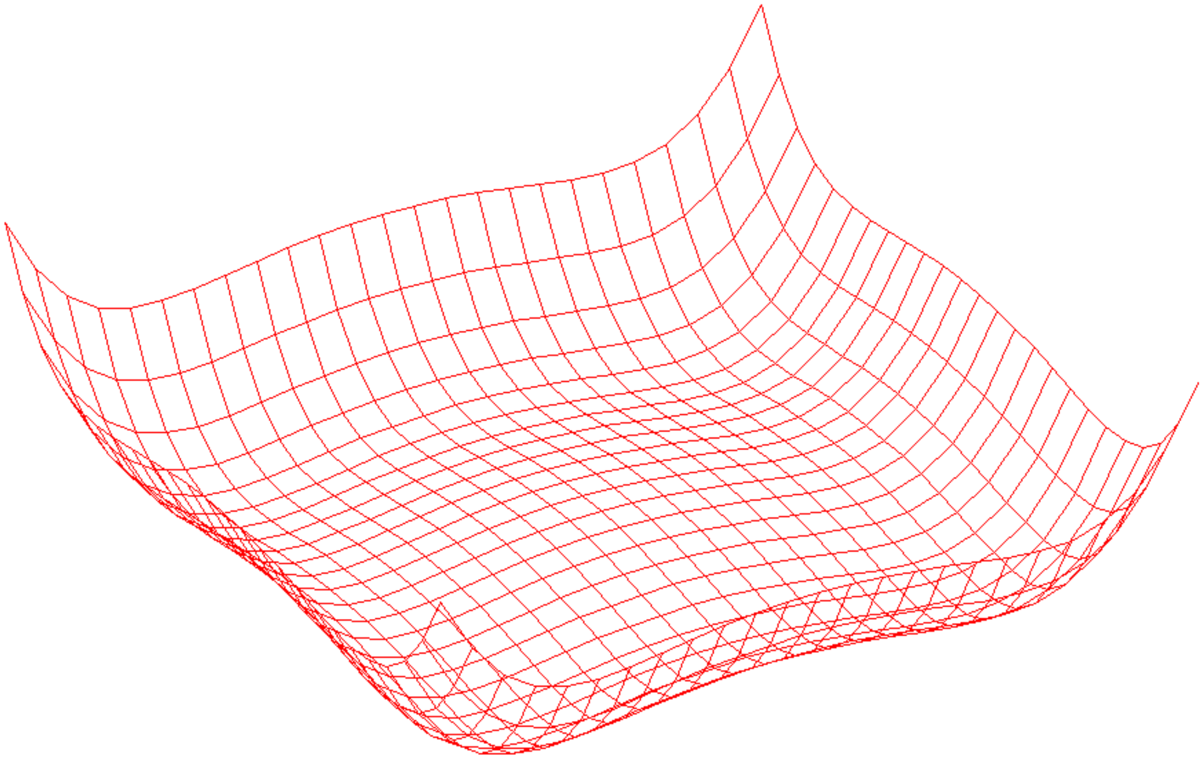
Major design considerations

- Thermal gradient can be either positive or negative, with corresponding bending moments
- Live load applied onto the deformed profile of the slab under thermal gradient would govern the design
- Crack control instead of structural safety
- Usual fatigue criteria for concrete pavement of highways would not be appropriate due to small number of cycles

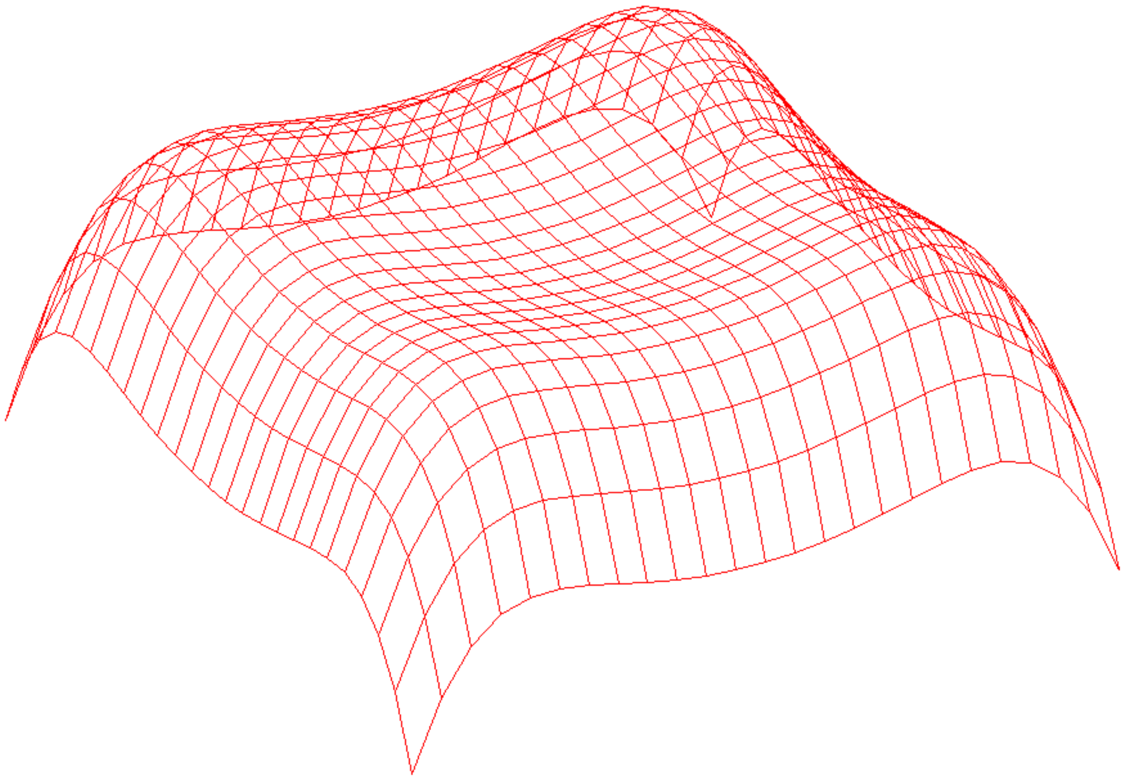
Finite Element Analysis

- 12m x 12m slab divided into 0.5m x 0.5m plates
- 2500 kN/m compression only spring at middle nodes
- 1250 kN/m compression only spring along sides
- 625 kN/m compression only spring at 4 corners





Temperature gradient -25 degree C



Temperature gradient +35 degree C

A single mat of GIII-10M @400 at mid-depth with additional two GIII-10M along top of expansion joints and free edges


HANSEN

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

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GFRP Reinforced Concrete Bridge Design Experience in Atlantic Canada

Calvin MacAulay, P.Eng.

HARBOURSIDE Engineering Consultants

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Outline

About Harbourside

Local Experience in Atlantic Canada

Examples

- Clyde River Bridge
  - Post-Tensioned Precast Deck Slabs
  - Precast Barriers
- Little Harbour Bridge
  - Integral abutments/wingwalls
- HWY 102/107 Interchange
  - Curved deck
- Rusticoville Bridge
  - Detailing placement drawings

Design and Detailing Challenges

Recommendations

Questions/Discussion

HARBOURSIDE ENGINEERING GROUP

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About Harbourside Engineering Group

- Harbourside Engineering Group is one of Atlantic Canada's largest independently owned heavy civil/transportation infrastructure engineering design firms.
- Offices in Dartmouth, NS, Charlottetown, PE, St. John's, NL, and Hamilton, ON.
- 110 engineers, technicians, drafters, and administration
- Comprised of four companies:
  - **Harbourside Engineering Consultants** (HEC) - Structural
  - **Harbourside Transportation Consultants** (HTC) – Transportation & Municipal Services
  - **Harbourside Geotechnical Consultants** (HGC) – Geotechnical & Materials Testing
  - **Harbourside Project Management (HPM)** – Project Management

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About Harbourside Engineering Consultants

- Established in 2008.
- Specializing in bridges, marine, and coastal structures.
- Harbourside excels in the design, project management, construction implementation, and asset management of heavy civil infrastructure.
  - Design and construction of new structures
  - Assessment, rehabilitation, and demolition of existing structures.
- Harbourside has experience with FRP on both the design side, designing new bridges, and on the supplier side, developing bar placement shop drawings.

HARBOURSIDE ENGINEERING GROUP

GFRP Design Experience in Atlantic Canada

- One of Harbourside's first GFRP bridge designs, in 2013.

Souris Bridge, Souris, PE

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GFRP Design Experience in Atlantic Canada

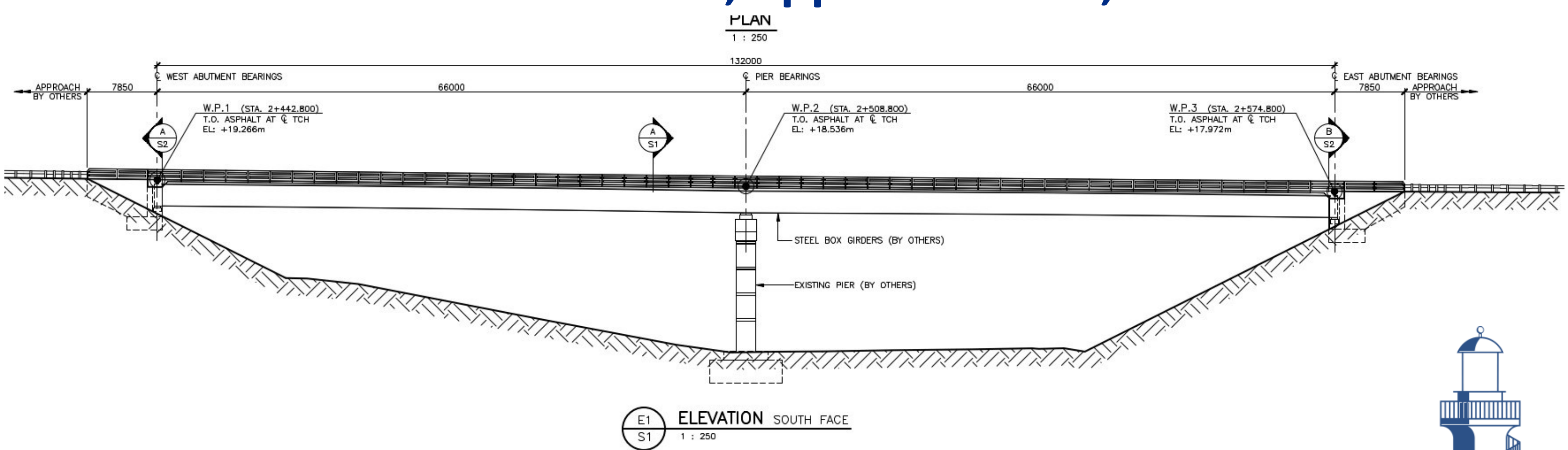
- **Most of Harbourside's FRP experience comes from bridges constructed in Nova Scotia and Prince Edward Island.**
  - Prince Edward Island uses GFRP in all bridge components except the girders.
  - Nova Scotia uses GFRP in the Deck and Barriers and Approach slabs only.
- **A note on seismic:**
  - Nova Scotia and Prince Edward Island are areas of very low seismic activity.

GFRP Design Experience in Atlantic Canada

- **No local manufacturers so everything is shipped in**
  - Critical to review shop drawings in detail, to ensure that nothing is missed, otherwise there can be delays and additional shipping costs.
  - Three manufacturers in recent projects we've been involved in are Pultrall V-ROD, TUFBar and, MST-BAR.

Example 1: Clyde River Bridge, PEI

- Two Span continuous, 132-meter-long structure
- Precast, post-tensioned, full depth concrete deck panels on Steel Box Girders
- Semi-integral abutments
- GFRP was used in abutments, approach slabs, deck and barriers.



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Example 1: Clyde River Bridge, PEI

- Harbourside was hired by the Contractor to design a precast, post-tensioned deck as an alternative to the C.I.P. deck.

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Example 1: Clyde River Bridge, PEI

- **GFRP was used in the Precast Deck Panels**

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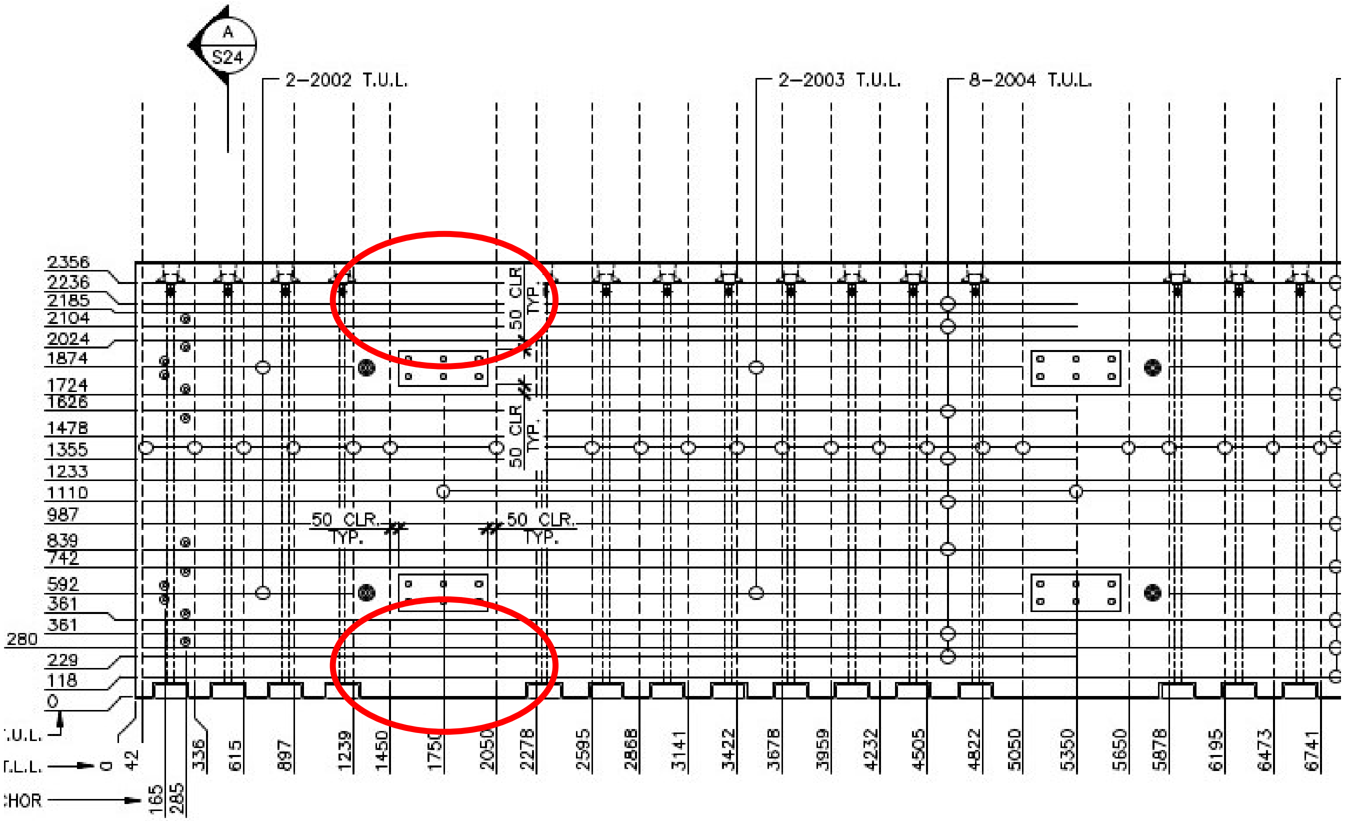
Example 1: Clyde River Bridge, PEI

- Congestion around pockets, particularly for the negative moment reinforcing (T.U.L.) over the exterior flanges.



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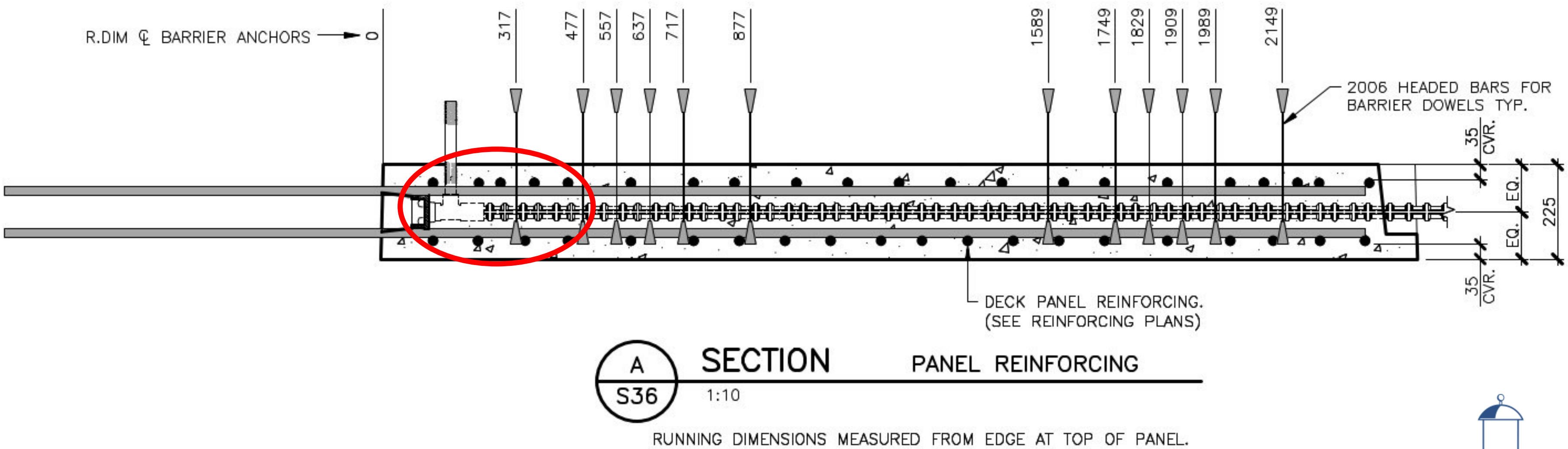
Example 1: Clyde River Bridge, PEI

- Congestion around pockets



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Example 1: Clyde River Bridge, PEI

- **Precast GFRP Reinforced Barriers, with GFRP Headed Anchors**

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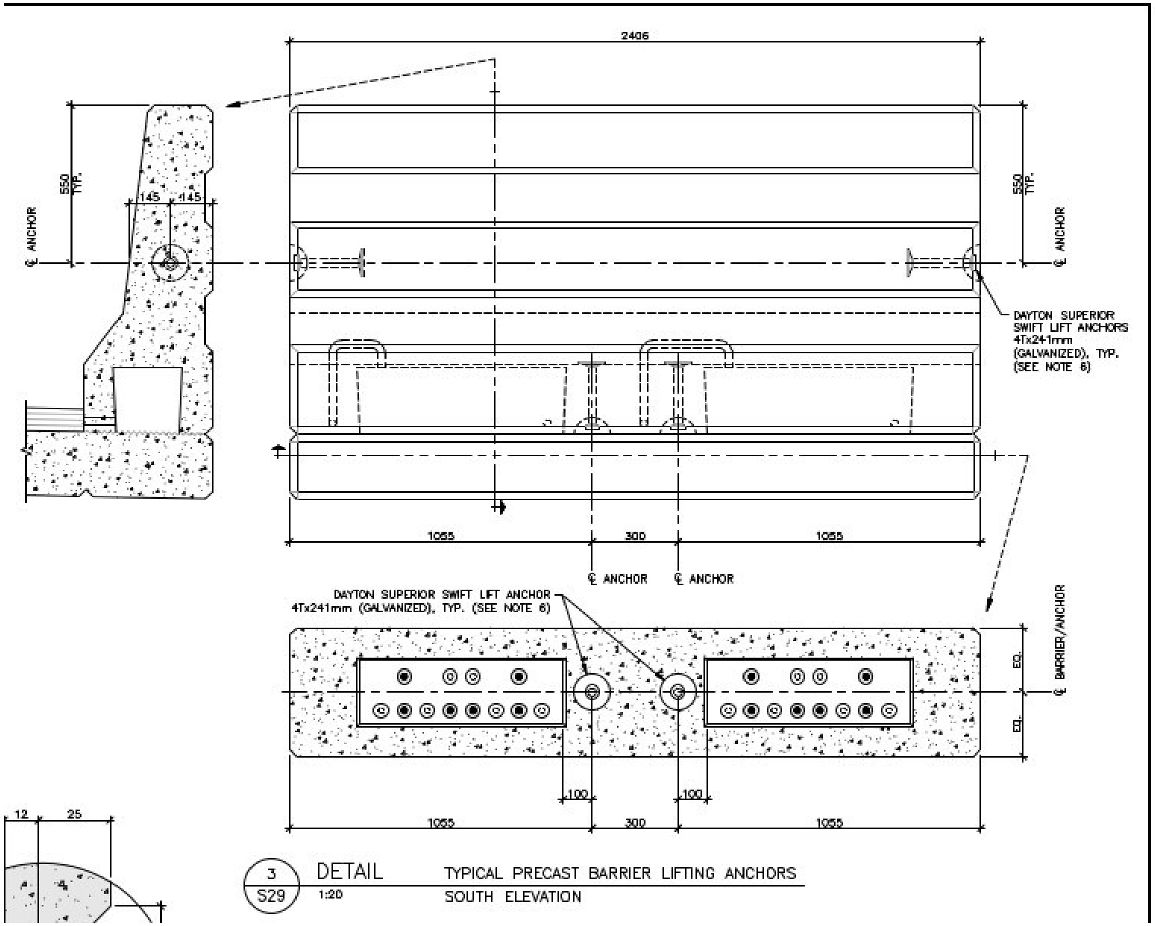
Example 1: Clyde River Bridge, PEI

- **Precast Barrier**

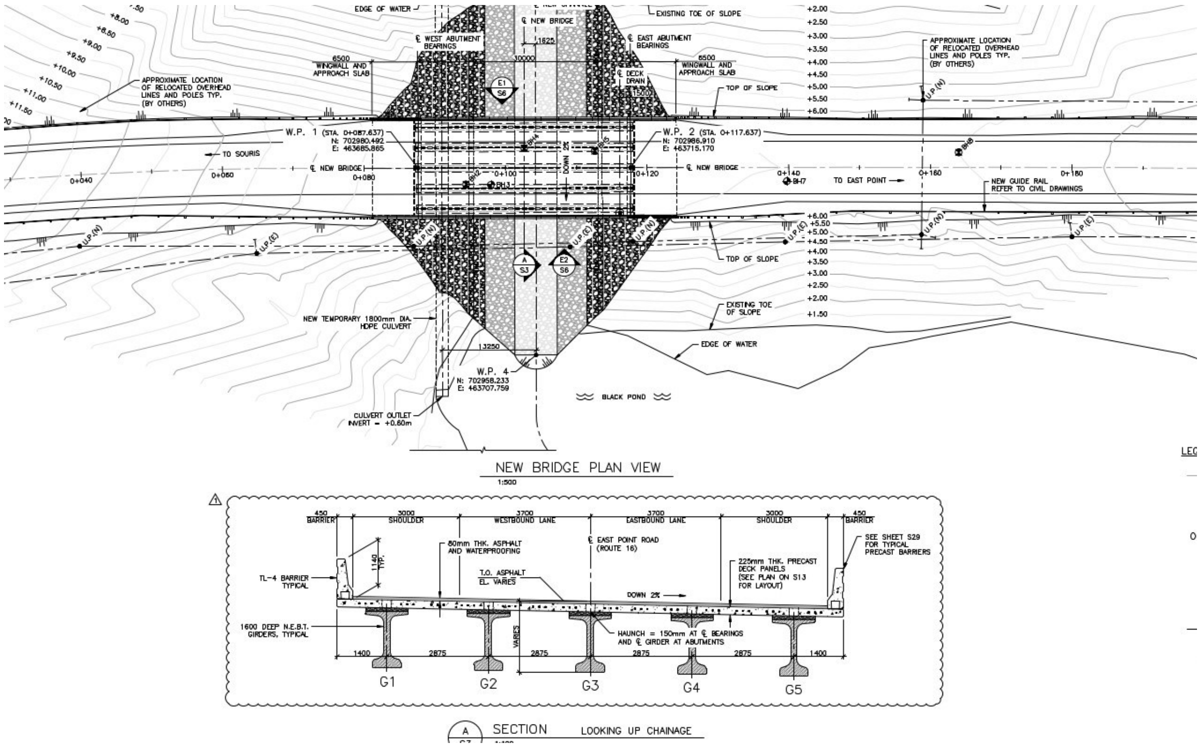


Example 1: Clyde River Bridge, PEI

- Precast Barrier

Example 2: Little Harbour Bridge, PEI

- Single Span, 30-meter-long structure
- Precast, post-tensioned, full depth, concrete deck slabs on 1600mm NEBT Concrete Girders
- Integral abutments



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Example 2: Little Harbour Bridge, PEI

- **Integral Abutment with GFRP**

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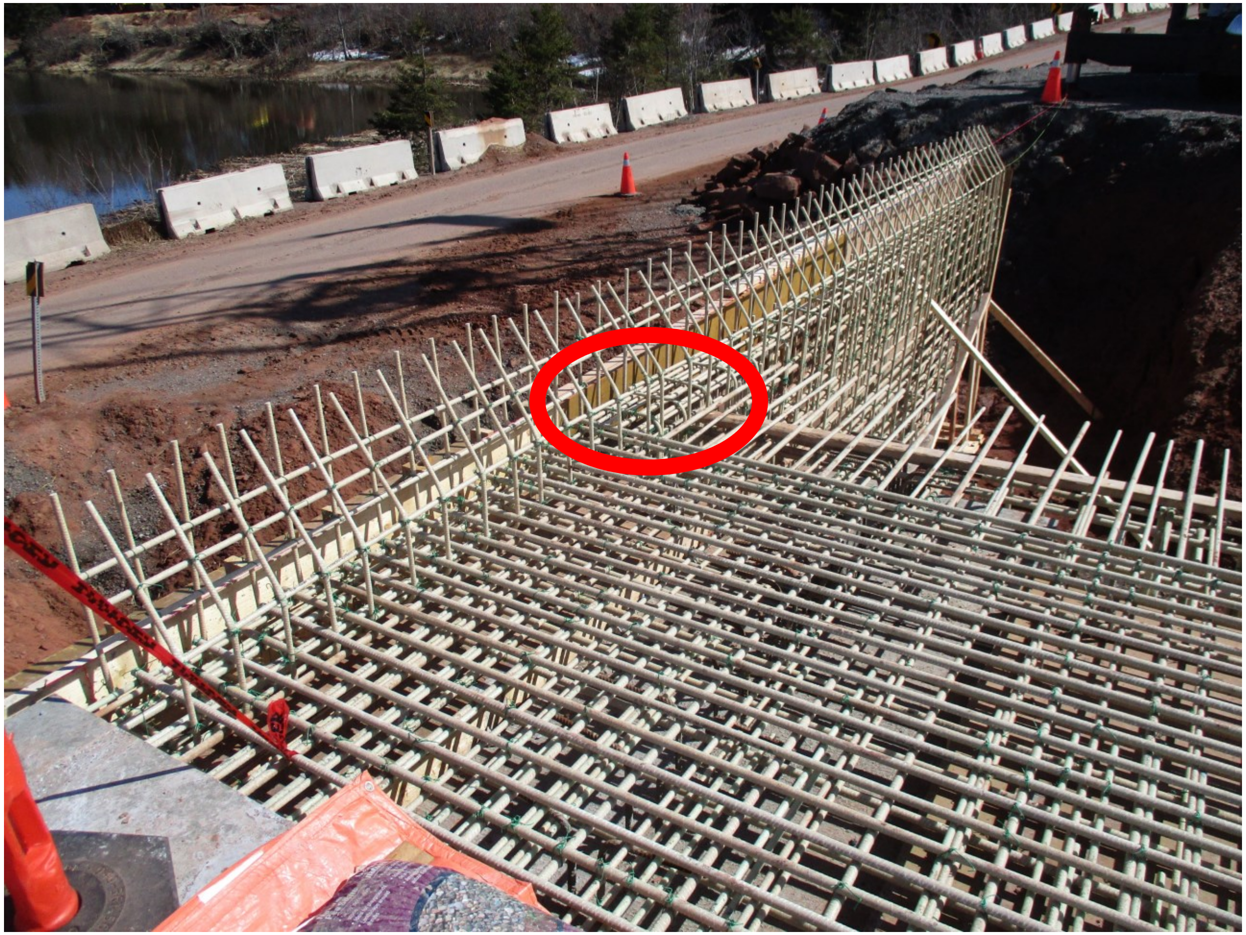
Example 2: Little Harbour Bridge, PEI

- Integral Abutment with GFRP



Example 2: Little Harbour Bridge, PEI

- **Congestion at the top of the wingwall**

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Example 3: HWY 102/107, NS

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Example 3: HWY 102/107, NS

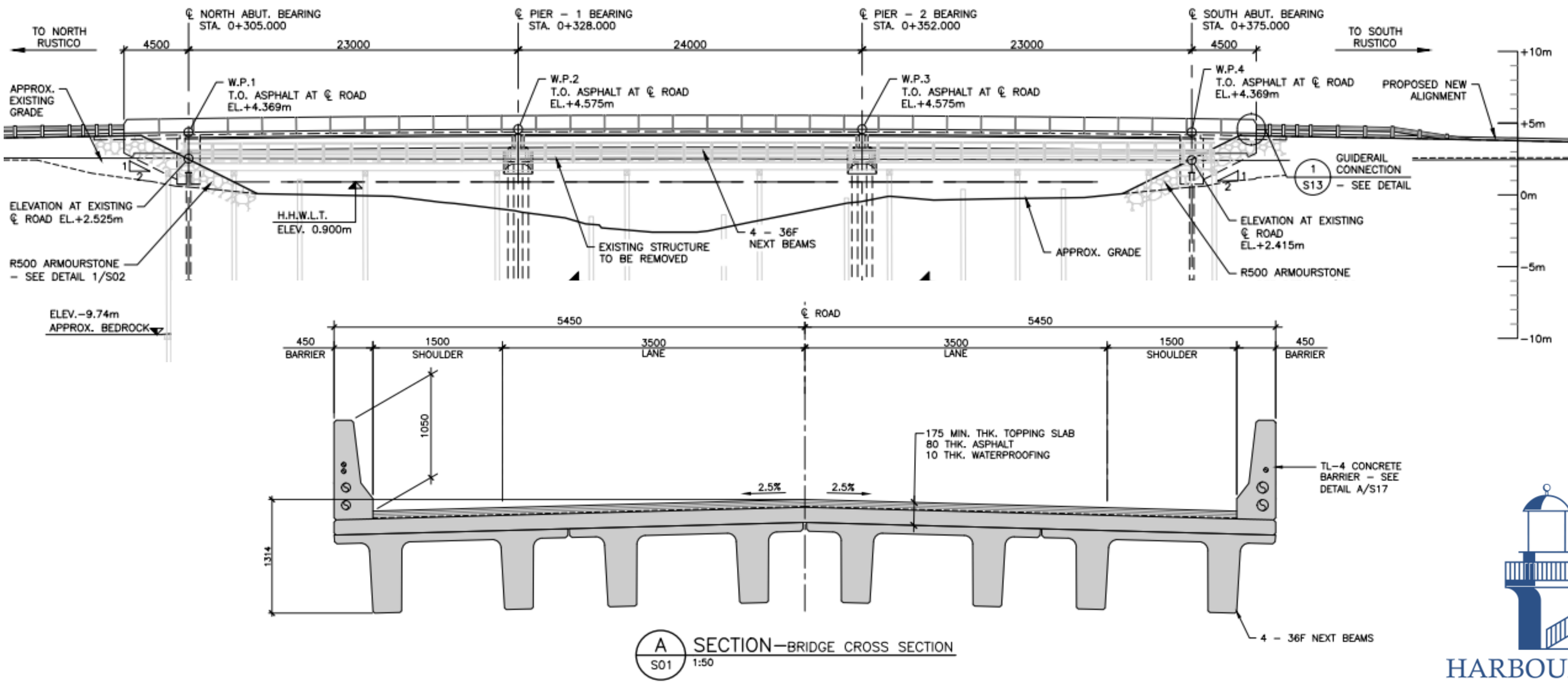
- 120.8m long, 3-span continuous, C.I.P. concrete deck on steel box girders.
- Curved structure with skewed abutments (25°)
- Semi-integral abutments with a slab thickening

Example 3: HWY 102/107, NS

- Deck bars were placed radially along the structure and then fanned at the abutments. This was done to make bar placement easier, but did cause some bar bunching on obtuse corners.

Example 4: Rusticoville Bridge, PEI

- 70m, 3-span continuous, C.I.P. concrete deck on 36" NEXT Beams
- Harbourside developed the GFRP placement drawings



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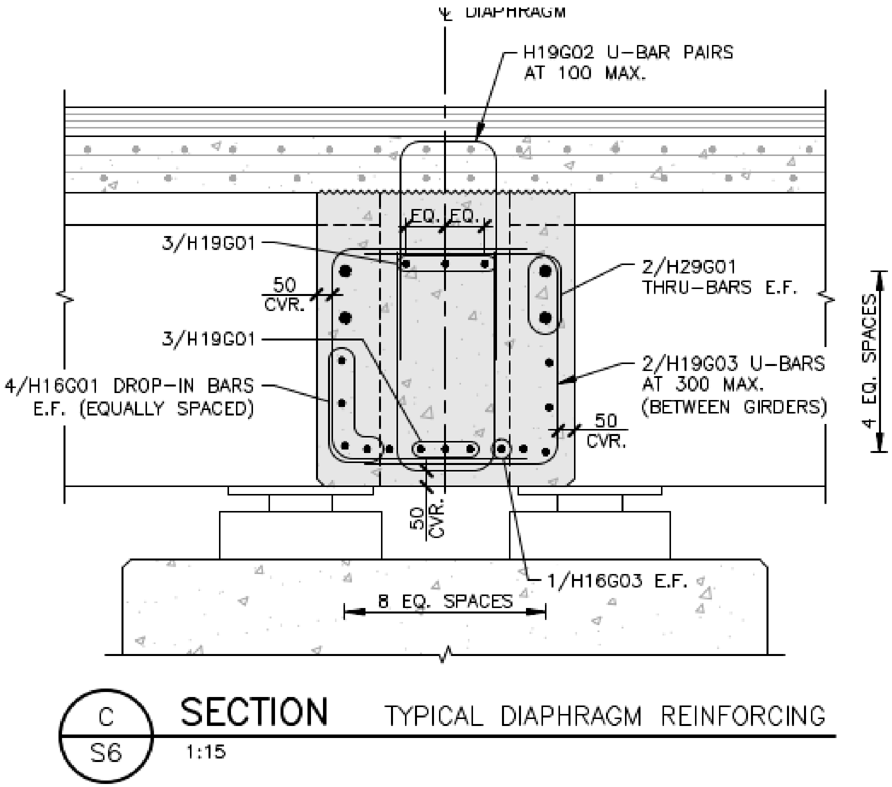
Example 4: Rusticoville Bridge, PEI

- Placement of the reinforcing was particularly challenging in the diaphragms



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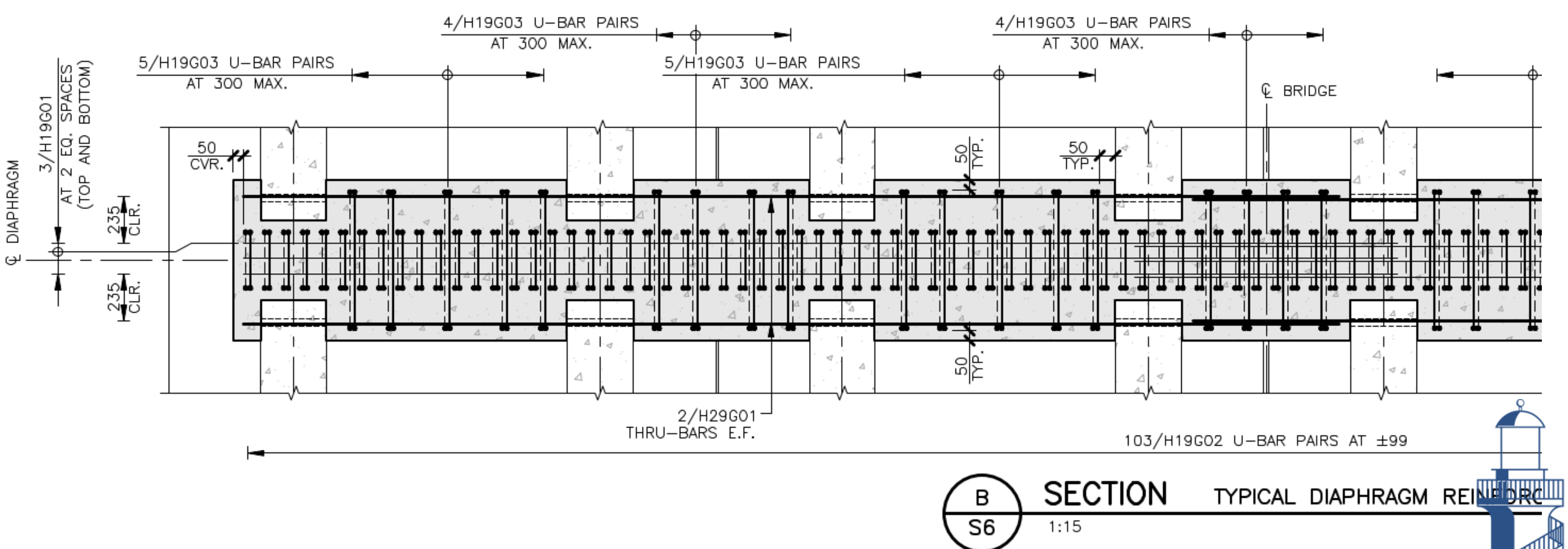
Example 4: Rusticoville Bridge, PEI

- **The manufacturer substituted lapped U-bars for stirrups and significant congestion occurred trying to place multiple lapped bars adjacent to each other.**



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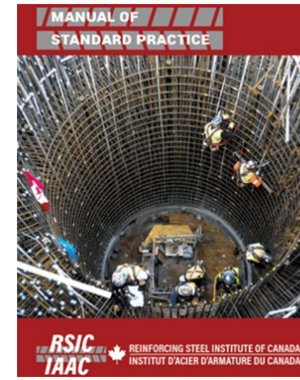
Design and Detailing Challenges



- **There is no GFRP equivalent to the RSIC Manual of Standard Practice for Steel Rebar.**
- **Designers cannot consistently account for bend restrictions because the restrictions change between Manufacturers:**
    - Bend Radii for circular bends
    - 3D shape restrictions
    - Number of bends in a single bar
    - Length of bar between bends, length of legs
- **Extra time spent on shop drawings (compared to steel) to account for the bars that fabricators can't make.**
    - Also complicates review process due to the many additional bar marks.
- **Difficult to detail small/thin elements like curbs and diaphragms.**

Construction Challenges

- ***Example:*** ***Closed stirrups being replaced by two overlapping U-bars***
  - Increases in total bar quantity (sometimes quite significantly),
  - Increases congestion;
  - Can slow down installation.
- **Precast elements and projecting bars**
  - Cannot bend on site, extra care during placement to ensure proper alignment.
  - Risk of breaking projections during shipping.
    - Could cause the rejection of the entire element.
  - Non-metallic GFRP couplers are not readily available.

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Recommendations

- **Development of a Standard Practice/Guideline for design of GFRP, to allow designers to account for manufacturer specific GFRP restrictions at the design phase, including:**
  - Standard bar bends/shapes
    - Including limitations on lengths, etc.
  - Lap Length Tables
  - Development Length Tables
  - Bend Radii
  - Headed bar capacities and geometries

Essentially, the appendices from the RSIC

- **Development of Non-metallic couplers for GFRP bar.**

Recommendations

By publishing product data in a standardized and accessible form, it will allow designers to:

- Create more efficient designs
  - Reduced bar quantities
- Reduce congestion issues
- Provide more accurate quantity estimates
- Lower the overall cost of the project

Ultimately making GFRP more desirable as an alternative to steel.

Questions/Discussion

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FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Use of GFRP in Geotechnics, Tunnels and Caverns

Dextra

Pierre Hofmann

Dextra Group

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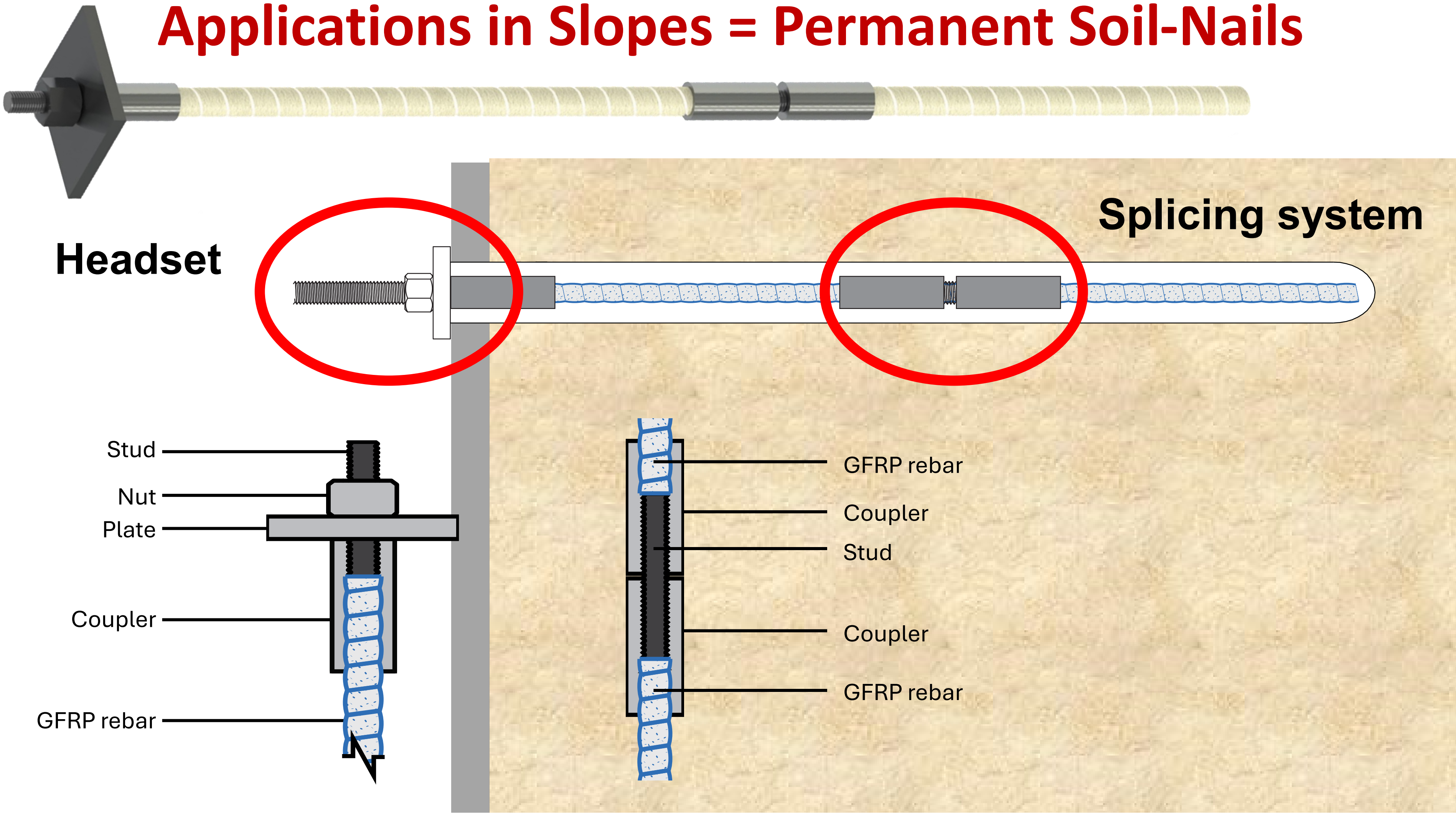
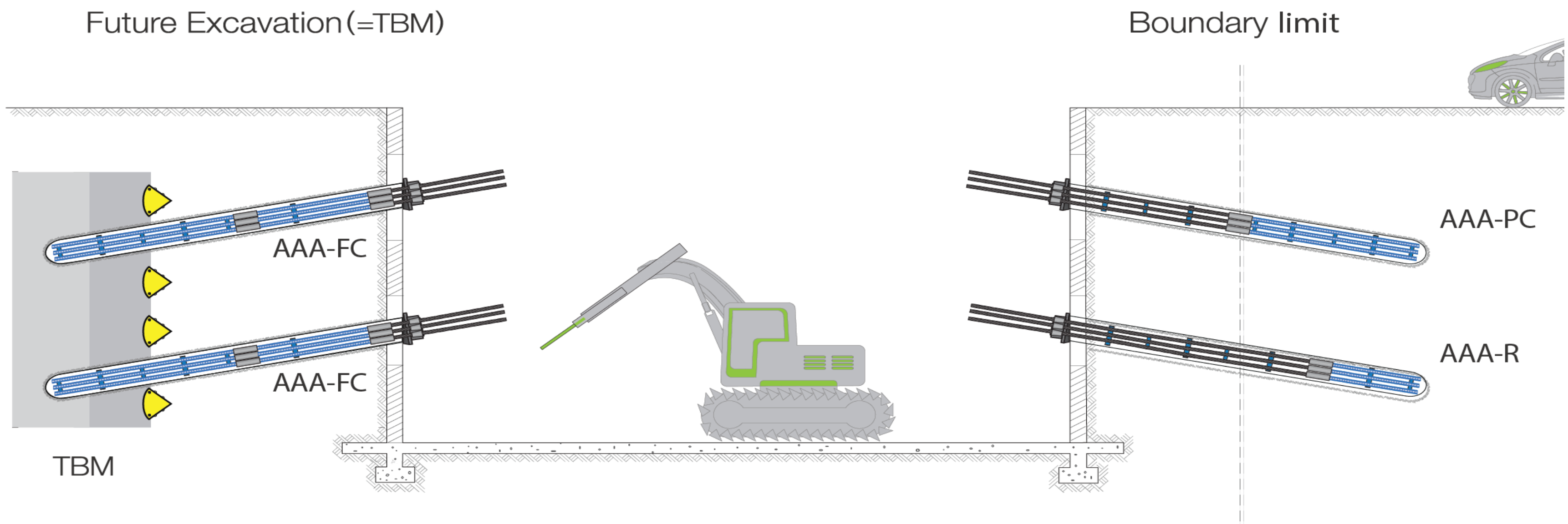
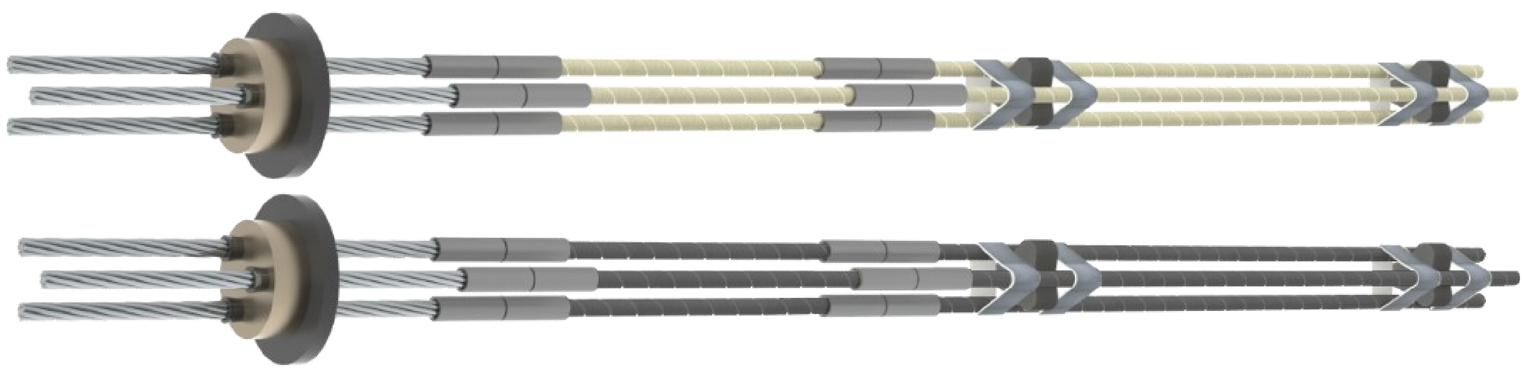
Applications in Slopes = Permanent Soil-Nails

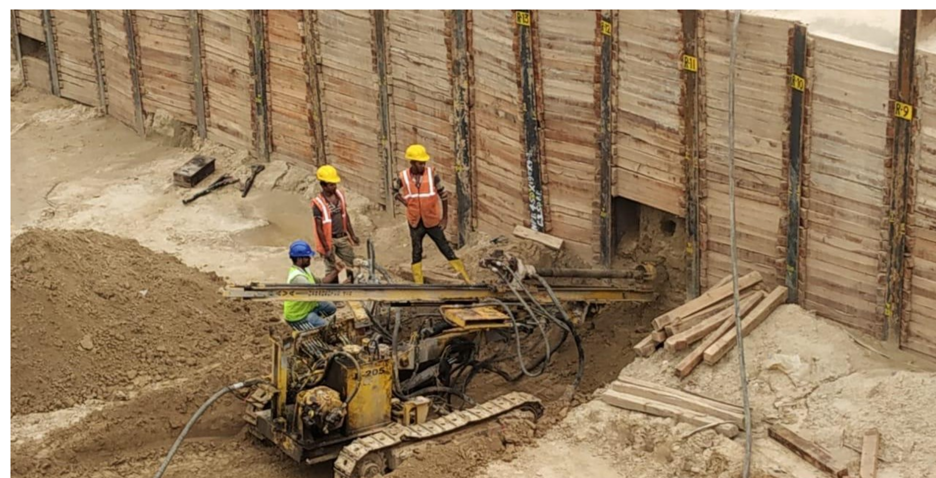


Applications in Retaining Walls = Temporary Active Anchors

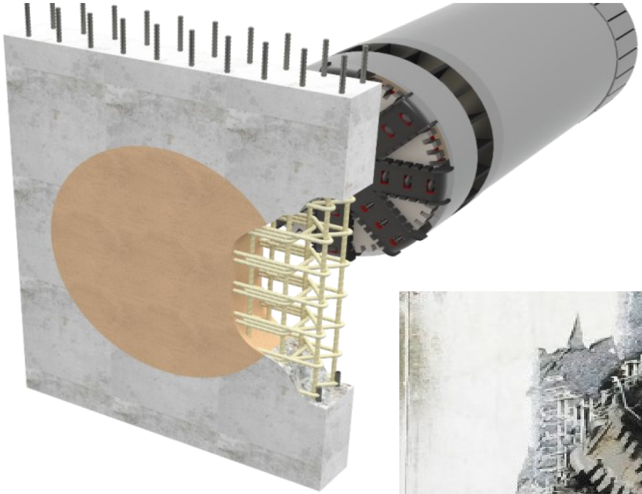




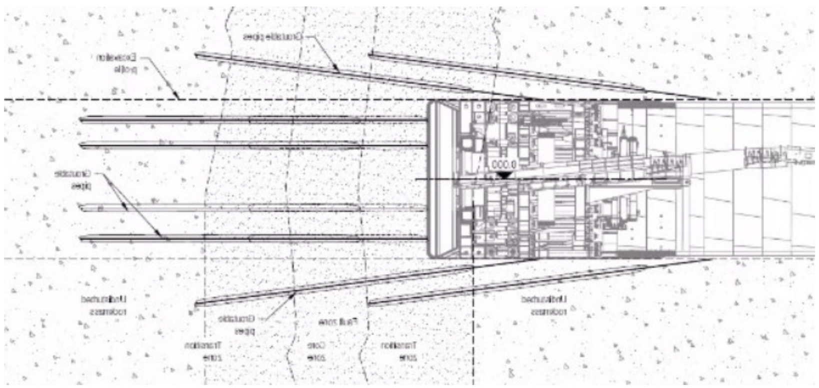
Applications in Retaining Walls = Temporary Active Anchors

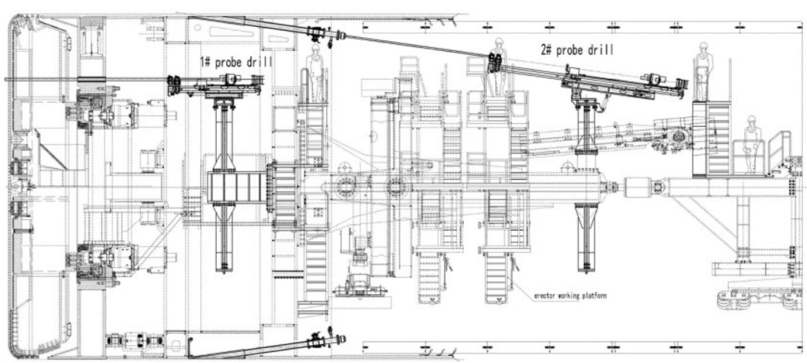


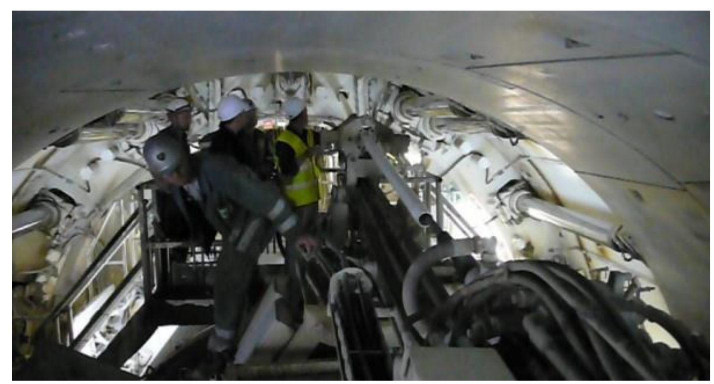
Applications in TBM Tunnels = GFRP Soft-Eyes



Applications in TBM Tunnels = GFRP Injection / Fore-piling Pipes (OD=76mm)

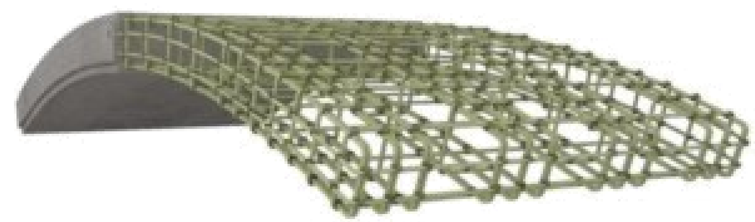






Applications in TBM Tunnels = GFRP Rebars for precast concrete segments

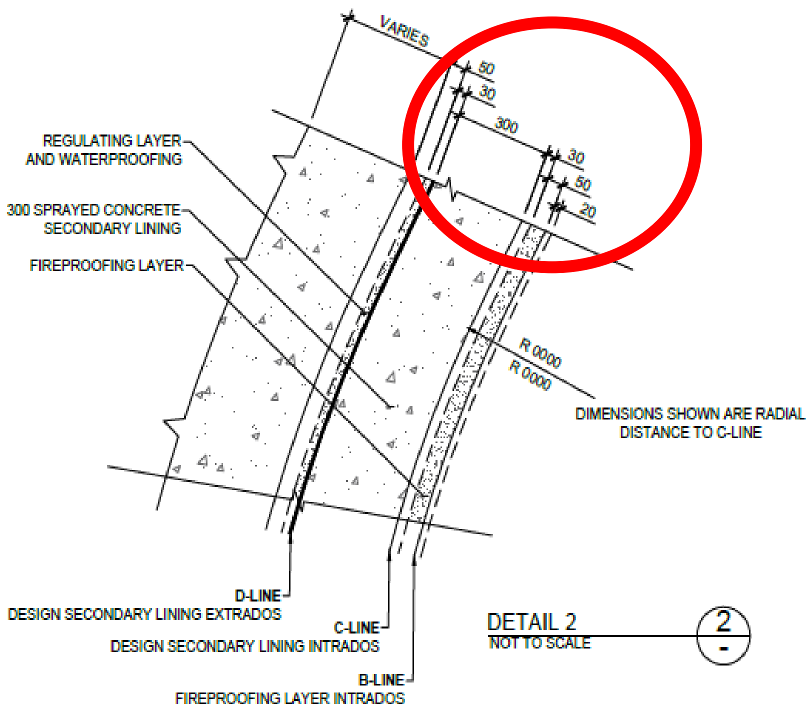


Applications in Tunnels & Caverns = Face Bolts

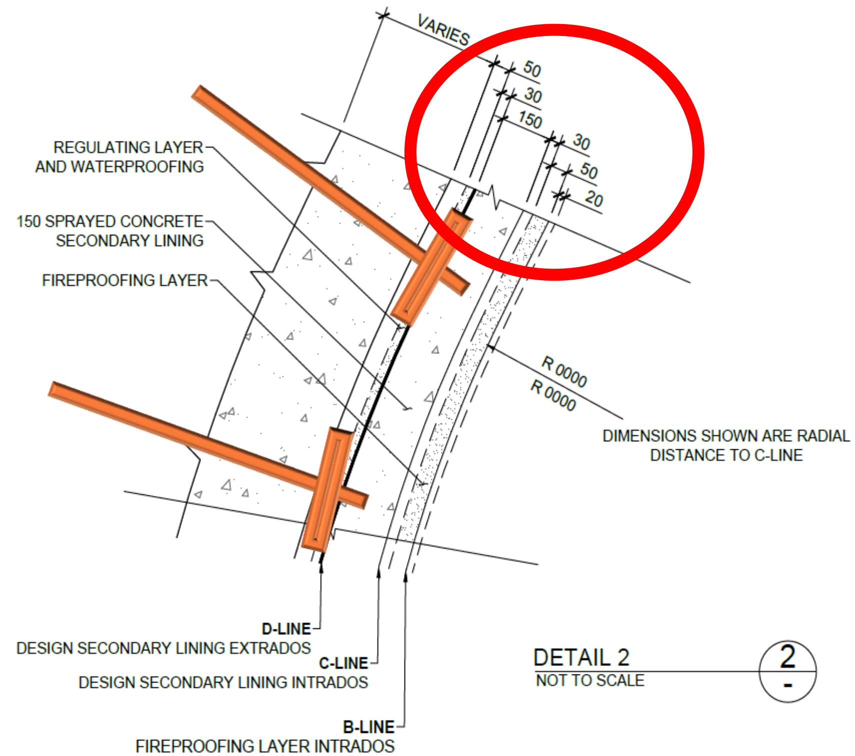
Applications in Tunnels & Caverns = Permanent Bolts

Value Engineering => 2 OPTIONS



OPTION - A Steel temporary bolts

Secondary lining thickness – 300mm



OPTION - B GFRP permanent bolts

Secondary lining thickness – 150mm

Small changes = big savings!!

A — TEMPORARY SN BOLTS
300mm RC SECONDARY LINING

B — PERMANENT GFRP BOLTS
150mm FRC SECONDARY LINING

Option	Spoil	Secondary lining concrete	Steel
A - Traditional	1,306,800 m3	66,660 m3	1,177 t
B – New Design	1,247,400 m3	35,442 m3	265 t
SAVING	**5%**	**47%**	**83%**

Small changes = big savings!!

A — TEMPORARY SN BOLTS
300mm RC SECONDARY LINING

B — PERMANENT GFRP BOLTS
150mm FRC SECONDARY LINING

Option	Good quality rock	Thinly bedded shale	Average
A - Traditional	100m / month	75m / month	87.5m / month
B – New Design	120m / month	90m / month	105m / month
Production Gain	**20% faster (2.4 months/yr)**		

EMBODIED CARBON (CO2)

		Quantity (t)	ECF ($kgCO_2e/kg$)			Embodied Carbon (tCO_2e)		
			A1-A3	A4	A5w	A1-A3	A4	A5w
Reinforced concrete with Steel Rebars	Concrete	159,984	0.12	0.005	0.008	19198.1	799.9	1212.5
	Rebar	1,177	2.28	0.032	0.123	2683.6	37.7	145.3
Reinforced concrete GFRP Rebars	Concrete	85,060	0.12	0.005	0.008	10207.2	425.3	680.5
	Rebar	265	0.7	0.116	0.040	185.5	30.7	10.5

Reinforced Steel Rebars:

	Total EC (tCO_2e) A1-A5w
Concrete	21210.5
Steel Rebars	2866.6
Total A1-A5w:	24077.1

Reinforced GFRP:

	Total EC (tCO_2e) A1-A5w
Concrete	11313.0
GFRP	226.7
Total A1-A5w:	11539.7

REDUCTION OF EMBODIED CARBON:
REINFORCEMENT = 92% - OVERALL = 79%

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Use of GFRP in Middle East & Asia Pacific Regions

Dextra

Pierre Hofmann

Dextra Group

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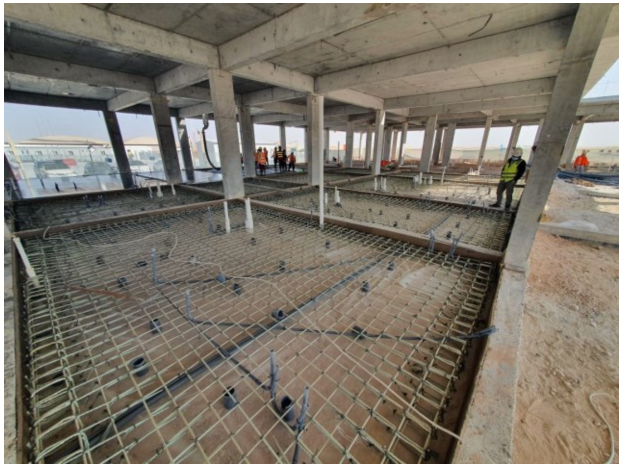
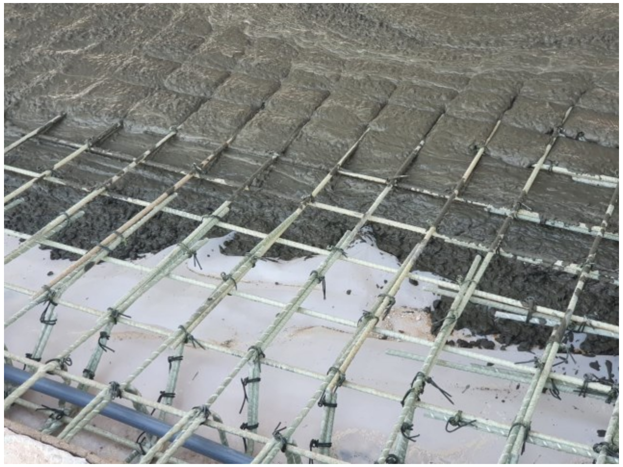
PULTRALL V-ROD FIBERGLASS Innovations ALTAIR MST BAR MAXIMUM STRENGTH GFRP SFTec ACMA American Composites Manufacturers Association FRP Rebar Manufacturers Council

UNIVERSITÉ DE SHERBROOKE NSERC CRSNG UNIVERSITY OF MIAMI Center for Integration of Composites into Infrastructure FDOT

Middle East - Jizan Flood Channel (KSA)

Middle East King Salman Energy Park – SPARK (KSA)




Middle East King Salman Energy Park – SPARK (KSA)

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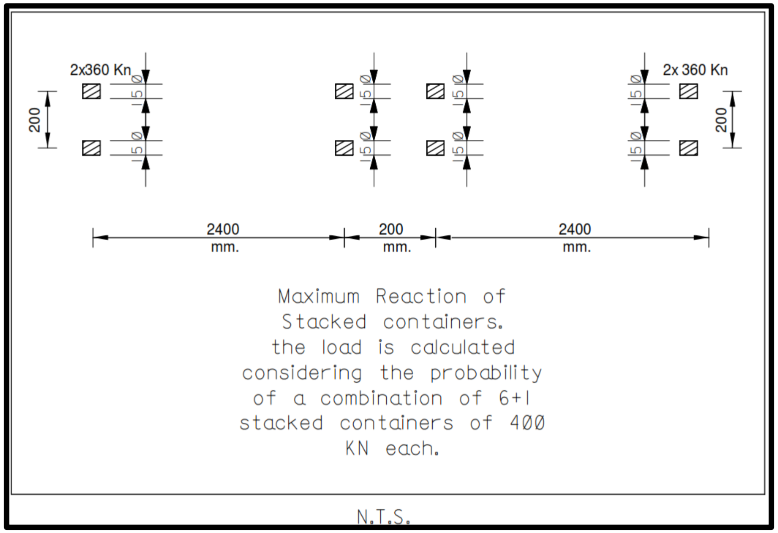
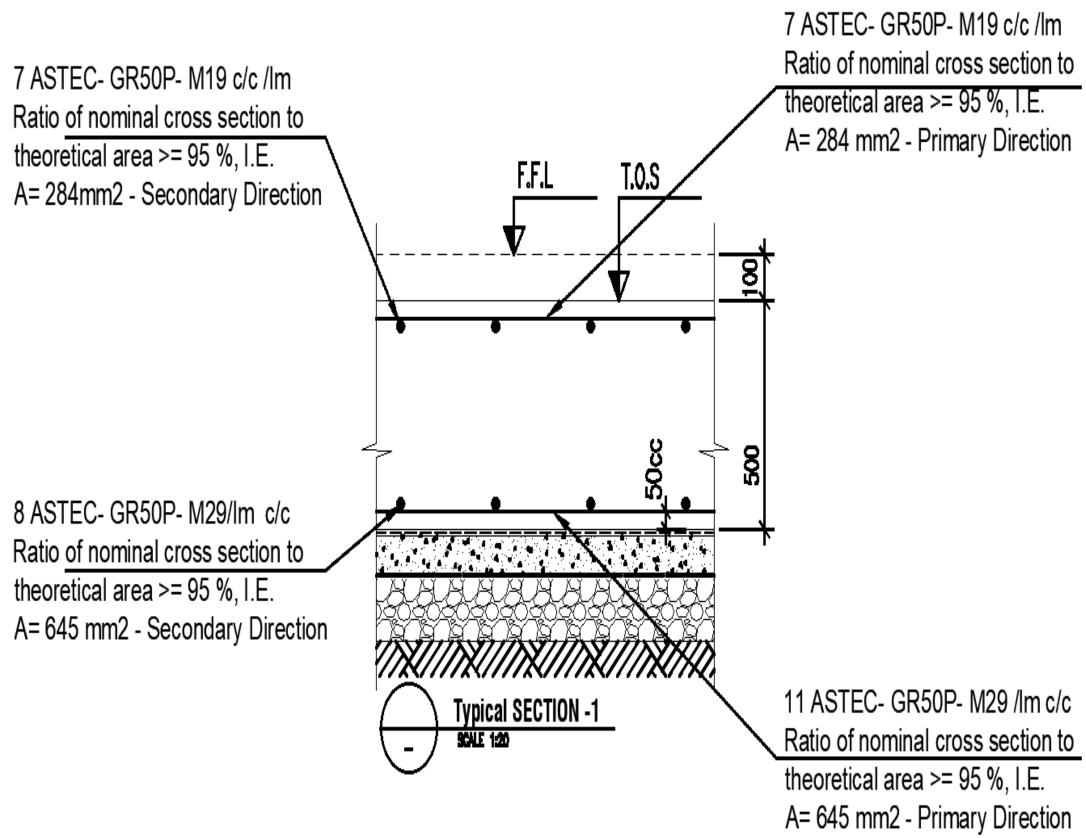
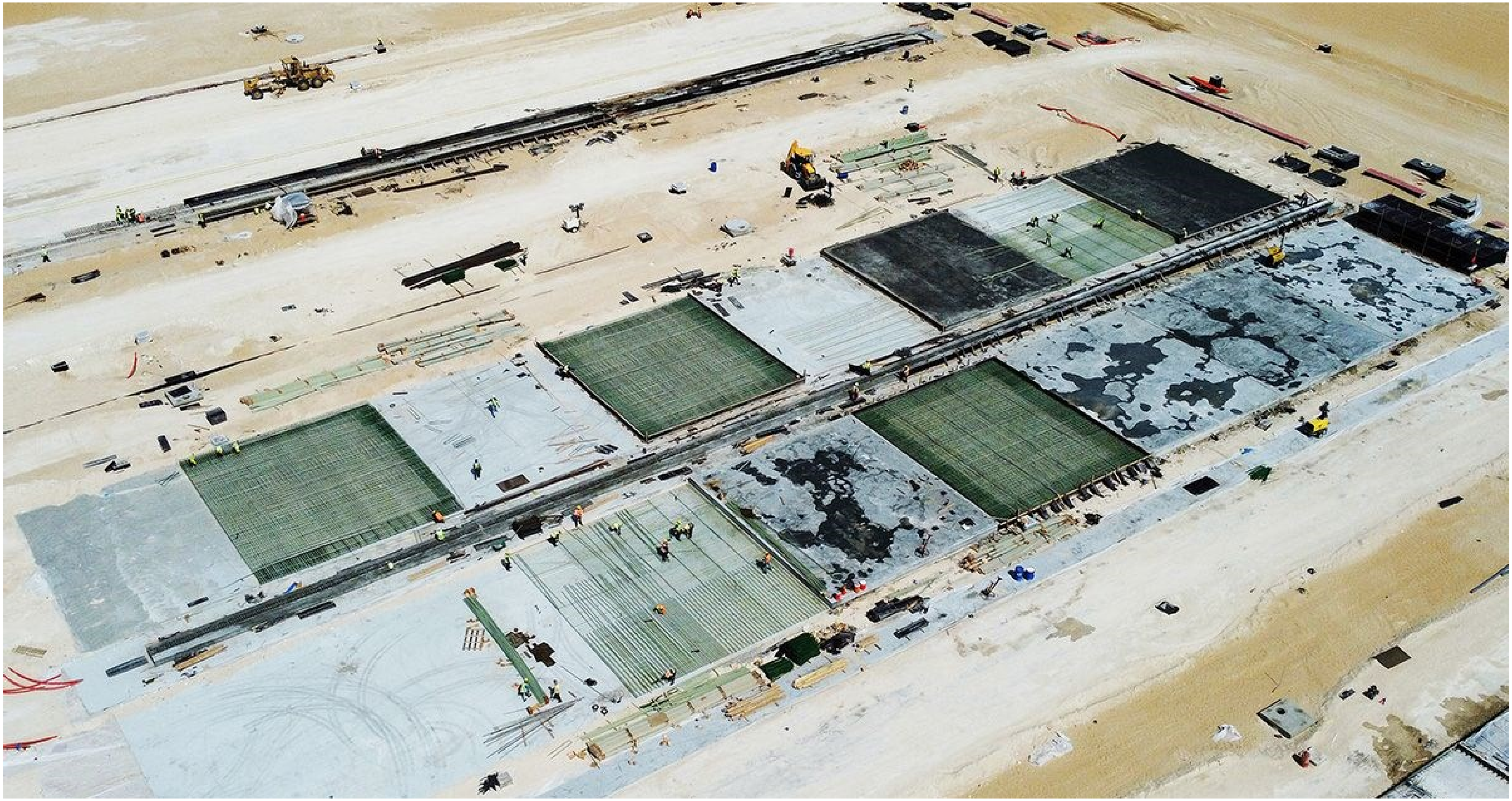
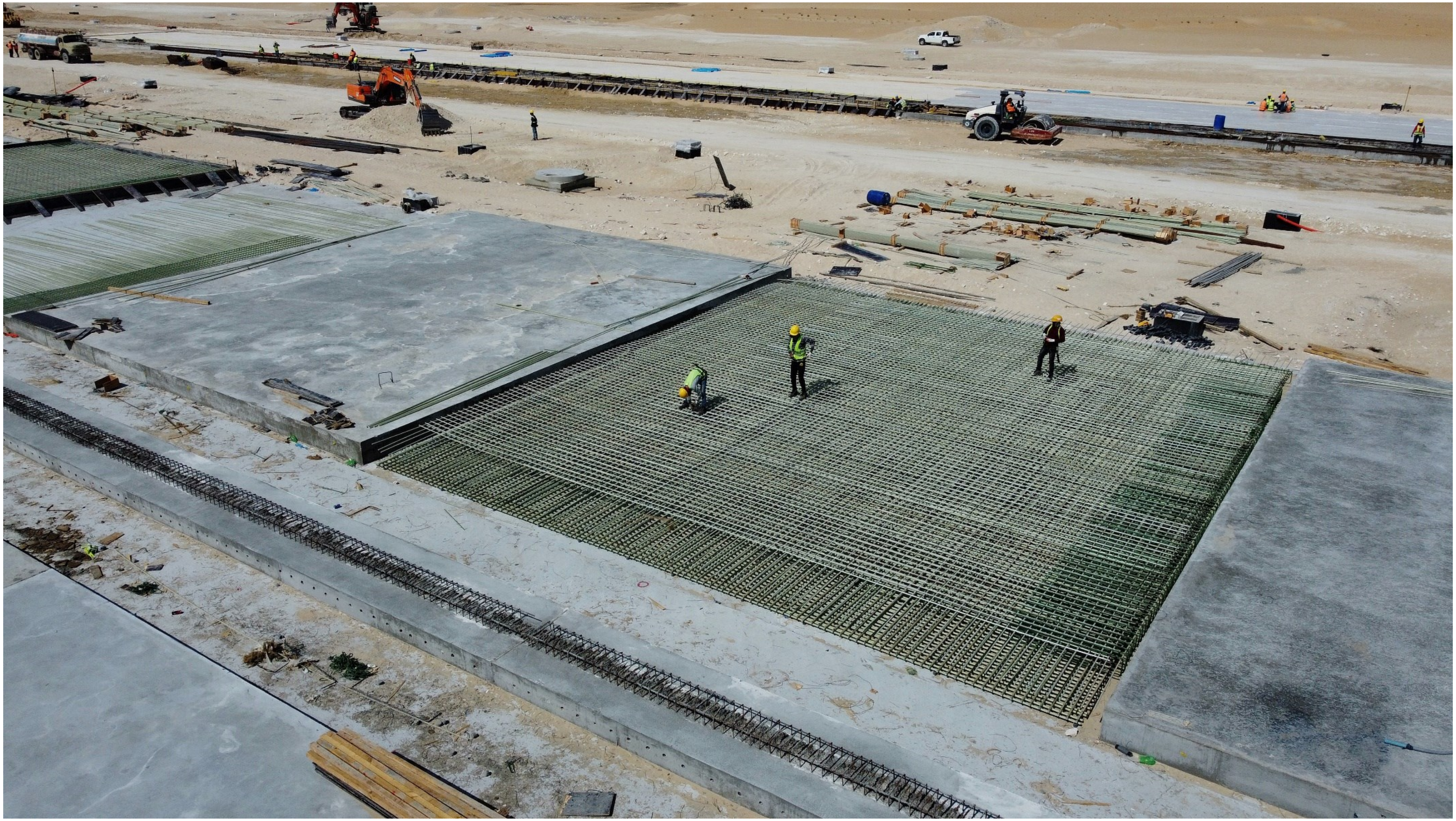




Middle East King Salman Energy Park – SPARK (KSA)



Middle East King Salman Energy Park – SPARK (KSA)



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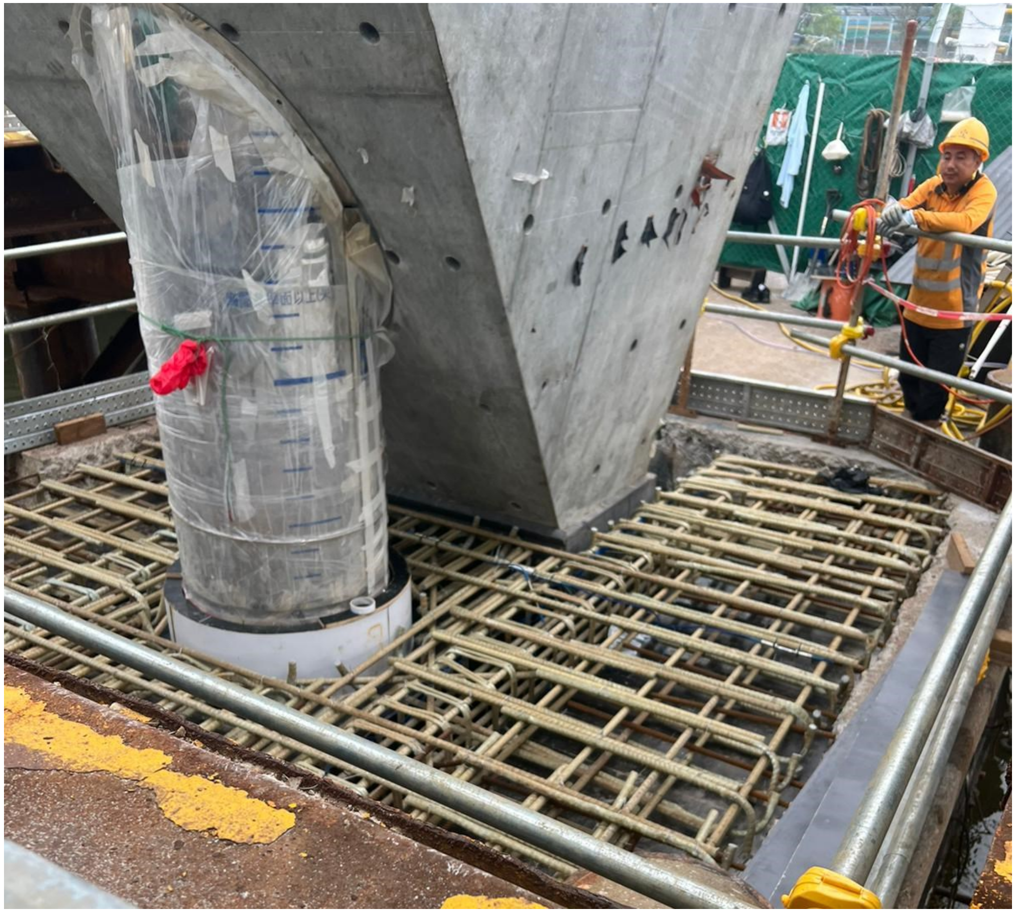
Middle East King Salman Energy Park – SPARK (KSA)

Examples of applications in Asia Pacific (Hong Kong)

Examples of applications in Asia Pacific (Hong Kong)

Examples of applications in Asia Pacific (Hong Kong)



Examples of applications in Asia Pacific (Australia)

DRIVEWAYS

Durabar™

Examples of applications in Asia Pacific (Australia)

SHEDS

Examples of applications in Asia Pacific (Australia)

SWIMMING POOLS

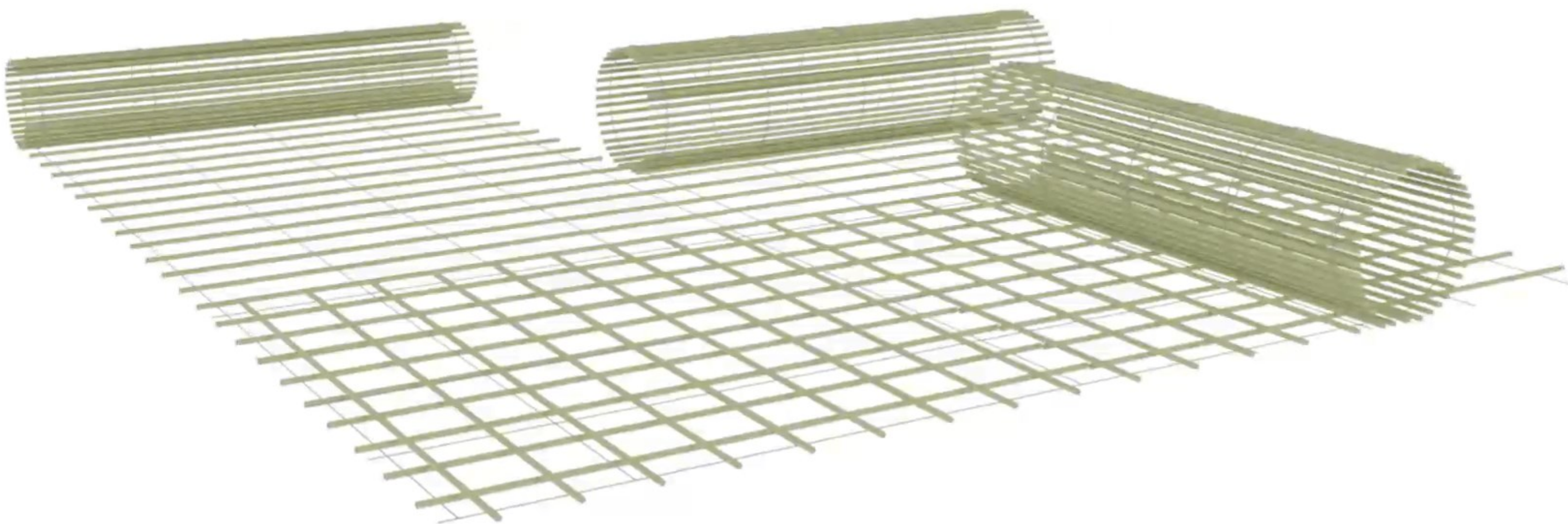
Examples of applications in Asia Pacific (Australia)

ELECTRICAL SLABS / SUB-STATIONS

What is Durabar™ Rollout Carpet

- Durabar™ Rollout Carpet is the latest patented product made from Durabar™ GFRP rebar.
- This revolutionary product is designed for ultimate versatility in construction projects.

Durabar™
Carpet



FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Use of GFRP bars in Grand Paris Tunnel Project

Gene Latour

Pultrall V-ROD

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ALTAIR
MST BAR MAXIMUM STRENGTH GFRP
SFTec
ACMA American Composites Manufacturers Association FRP Rebar Manufacturers Council
UNIVERSITÉ DE SHERBROOKE
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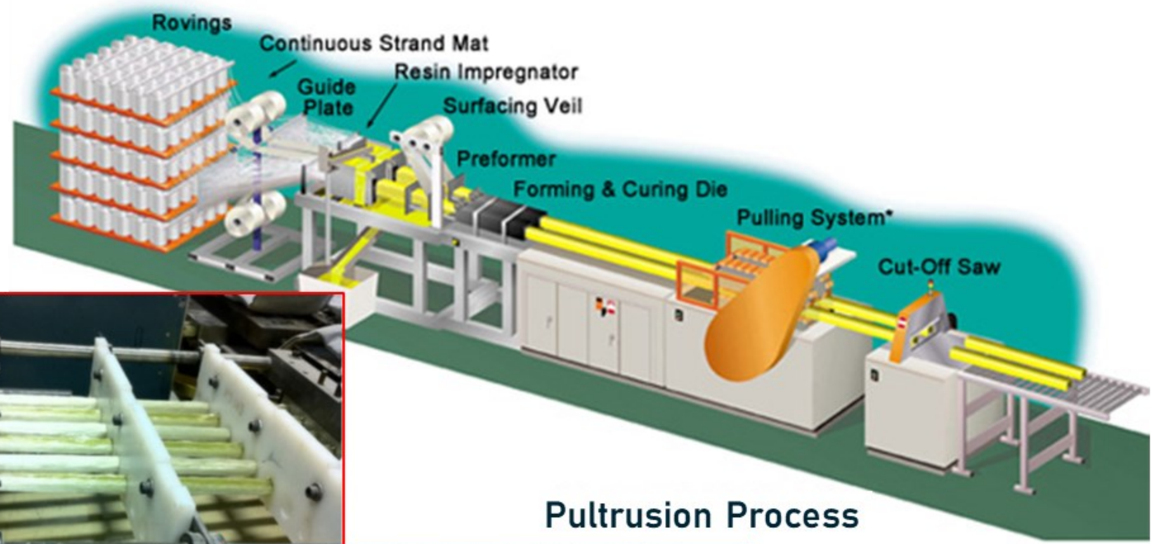
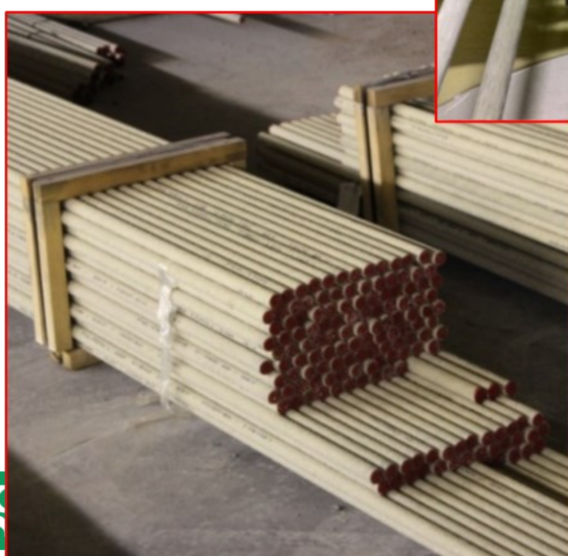
What is GFRP reinforcing

Fiber glass



Pultrusion Process

Matrix

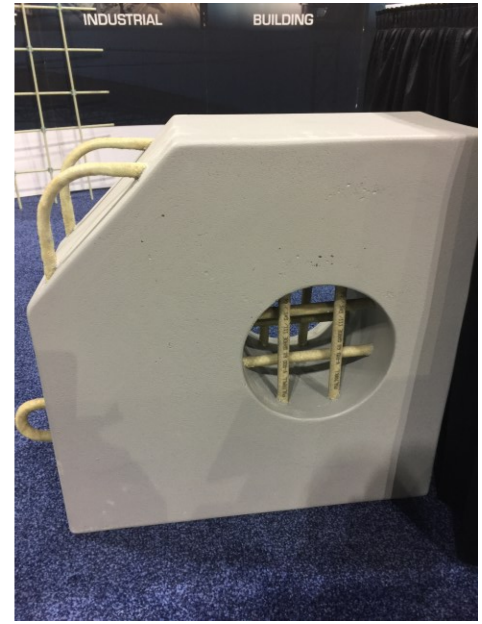


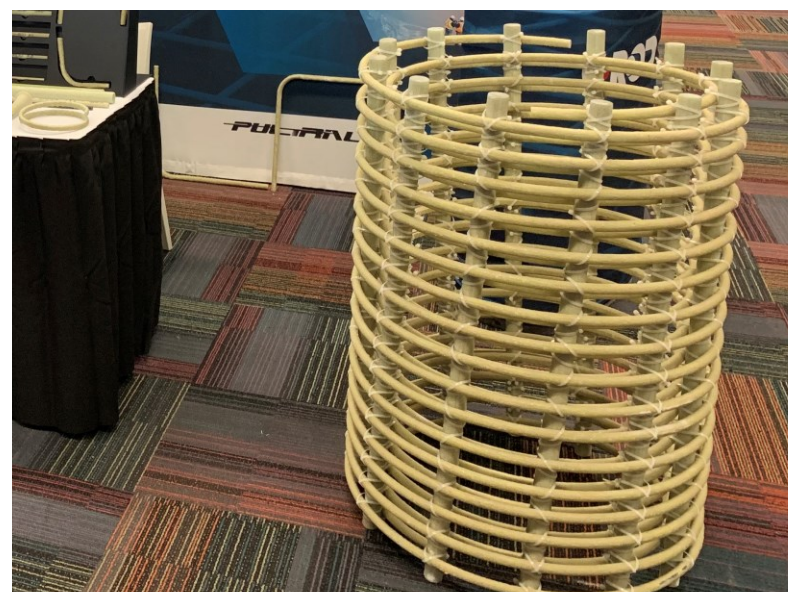
Forming and curing

Why V-ROD GFRP reinforcing

- Superior tensile properties
- Built-in corrosion resistance (non-corrosive)
- Electrically/magnetically neutral (non-conductive)
- One quarter the weight of steel
- Compliant with CSA, ACI, AASHTO codes/standards
- Being extremely resistant in the fiber direction and easily cut in the orthogonal direction, GFRP is highly desirable for reinforcing of soft-eye openings for tunnel boring machines
- Tunneling applications include soft-eye slurry walls; caissons & secant piles; diaphragm walls; temporary soil stabilization; tunnel face threaded anchors; rockbolts


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


INDUSTRIAL
BUILDING



Other Applications

- Bridges: CIP & Precast decks, barriers/parapets, box girders, app slabs, sidewalks/curbs, MSE/RSS walls, columns, pier caps etc
- Transit (LRT/BRT) : structures, platforms, ret walls, track beds, plinths, transformer bases
- Hydro/substations: distribution slabs, chambers/vaults, ductbanks, reactor/transformer bases, manholes
- Parking garages: deck slabs, ramps
- Water treatment/WWTP: base & roof slabs, walls, chlorination tanks, waste facility loading slabs
- Airports: concrete runway/apron slabs, load transfer dowels, secant piles
- Hospitals: MRI's, clean labs and other non-conductive applications
- Marine structures: piers/jetties/harbours, seawalls, secant piles, reef restoration

Design Codes & Specifications - Canada

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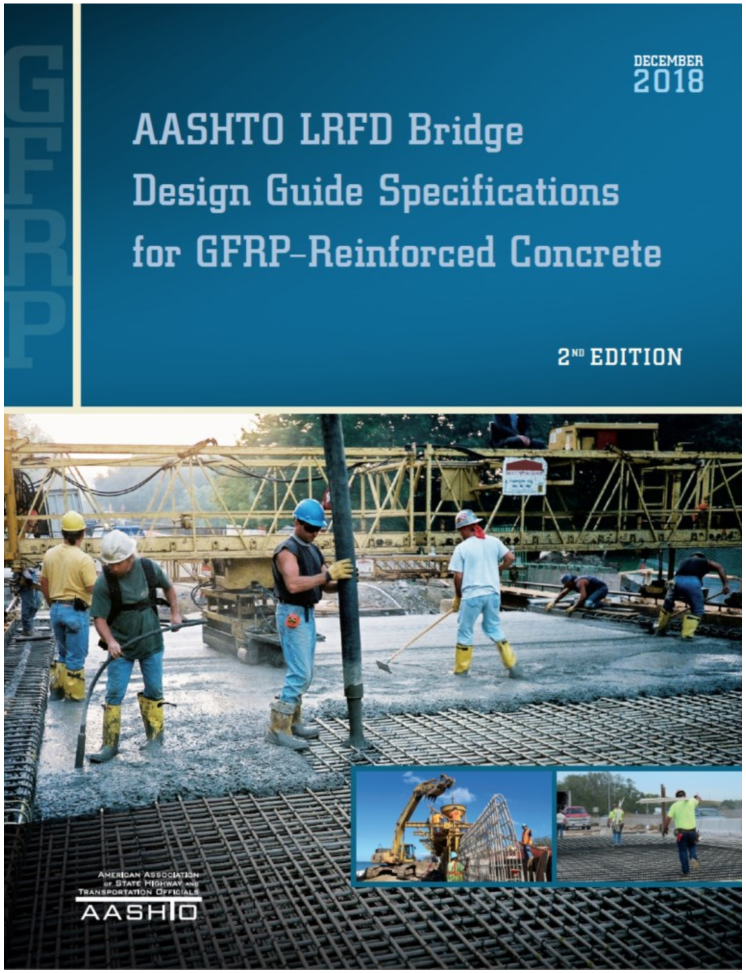
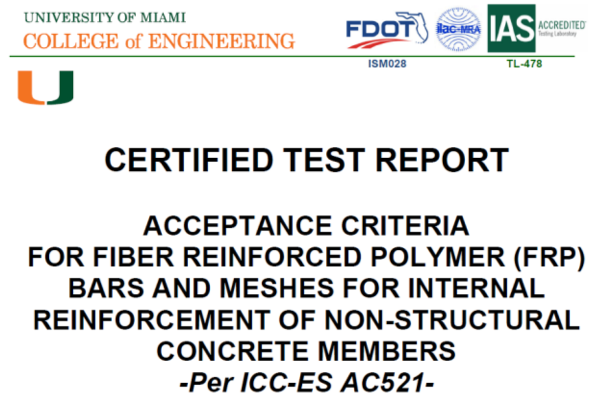
Design Codes & Specifications - USA

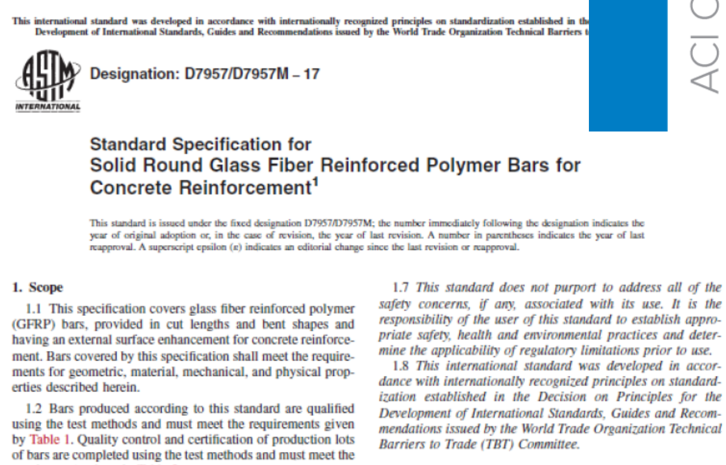




UNIVERSITY OF MIAMI
COLLEGE of ENGINEERING
FDOT
IAS ACCREDITED
ISM028
TL-478

CERTIFIED TEST REPORT

ACCEPTANCE CRITERIA
FOR FIBER REINFORCED POLYMER (FRP)
BARS AND MESHES FOR INTERNAL
REINFORCEMENT OF NON-STRUCTURAL
CONCRETE MEMBERS
-Per ICC-ES AC521-



This international standard was developed in accordance with internationally recognized principles on standardization established in th[e] Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers t[o]

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

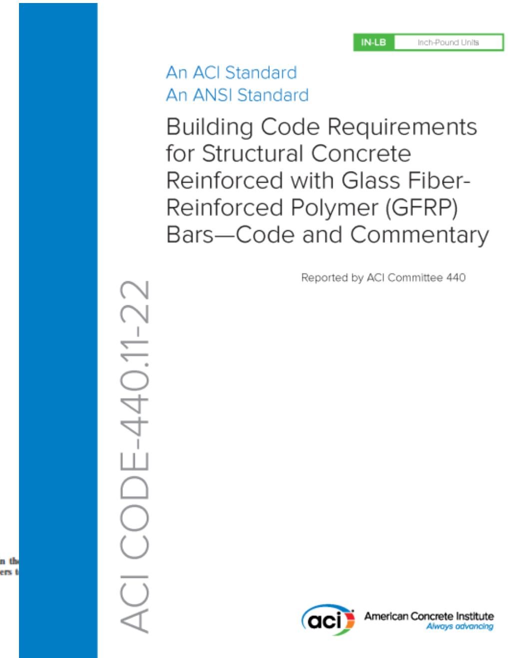
1.1 This specification covers glass fiber reinforced polymer (GFRP) bars, provided in cut lengths and bent shapes and having an external surface enhancement for concrete reinforcement. Bars covered by this specification shall meet the requirements for geometric, material, mechanical, and physical properties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

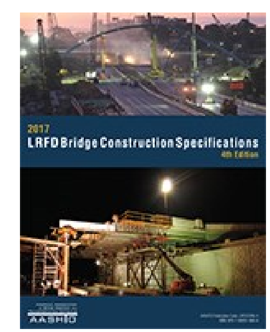
1.2 Bars produced according to this standard are qualified using the test methods and must meet the requirements given by Table 1. Quality control and certification of production lots of bars are completed using the test methods and must meet the requirements given in Table 2.

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.

2. Referenced Documents





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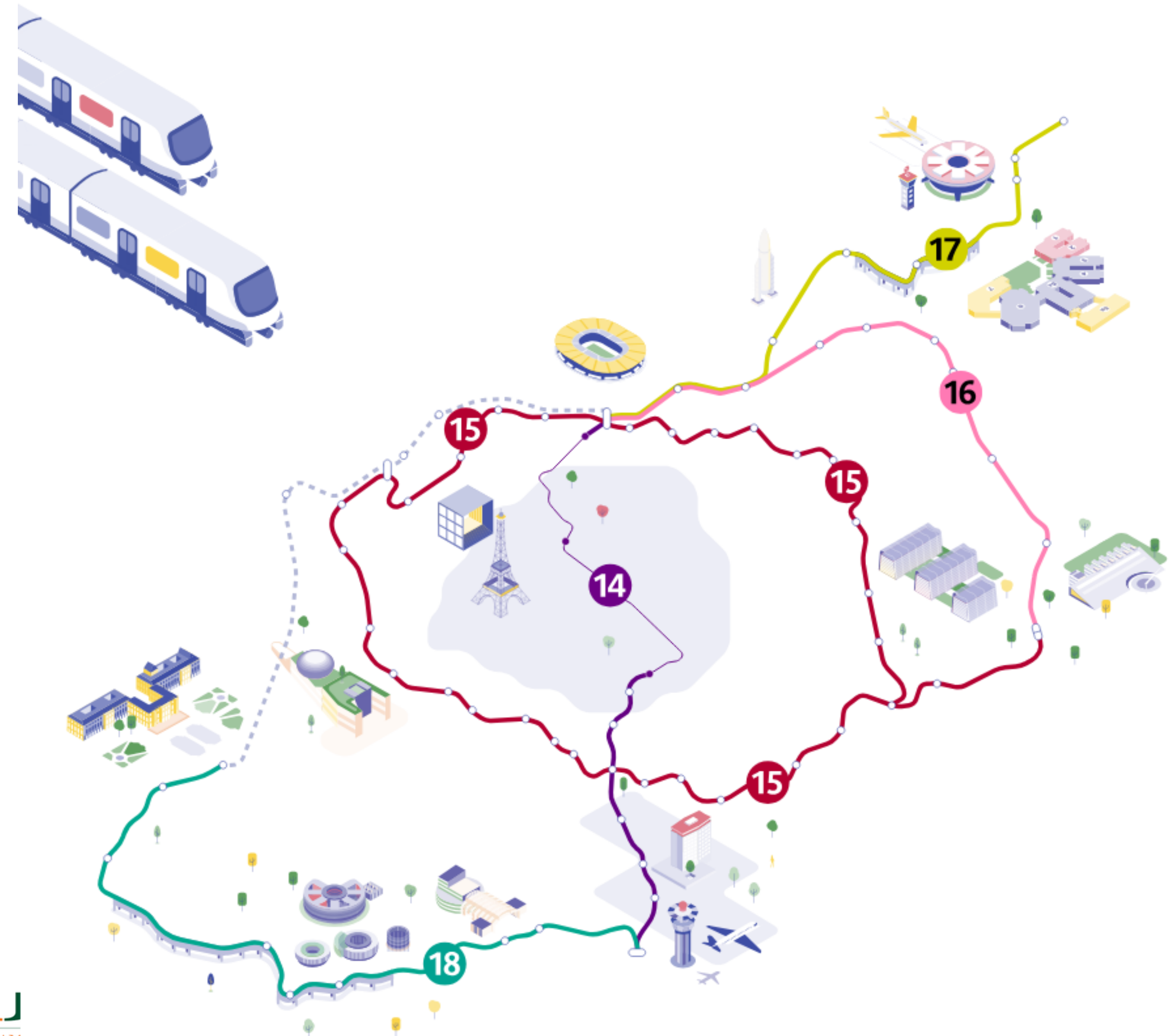
Overview of Grand Paris Express

- The Grand Paris Express is the new metro that will connect the main places of life and activity in the suburbs without going through Paris.
- Currently the largest transport project underway in Europe
- 200km, 68 station automated railway network
- Ring route around Paris (line 15) and three additional lines (16,17,18) connecting adjacent neighborhoods

Overview of Grand Paris Express



Overview of Grand Paris Express

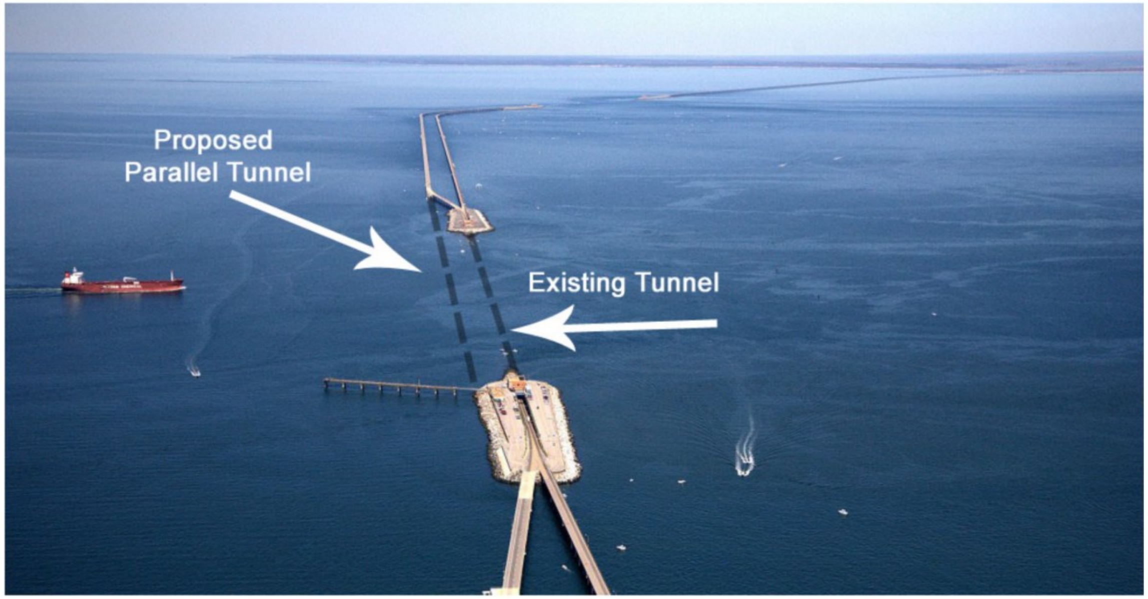
V-ROD GFRP in soft-eye cages

V-ROD GFRP in soft-eye cages

- Craning V-ROD GFRP cages on site. Steel sections are lapped to GFRP

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

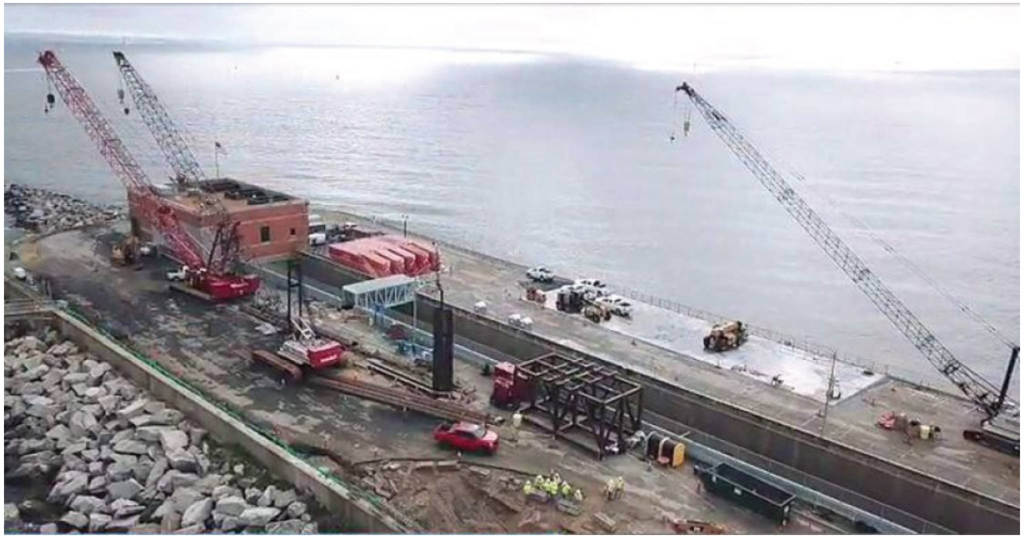


Project Description

The Parallel Thimble Shoal Tunnel Project will construct a new two-lane tunnel under Thimble Shoal Channel. When complete, the new tunnel will carry two lanes of traffic southbound and the existing tunnel will carry two lanes of traffic northbound.

Chesapeake Bay/Thimble Shoals Tunnel
Owner – Chesapeake Bay Tunnel Commission
Designer – Mott MacDonald
Contractor – Chesapeake Tunnel JV (Dragados USA/Schiavone Construction)

The Parallel Thimble Shoal Tunnel Project will construct a new two-lane tunnel under Thimble Shoal Channel. When complete, the new tunnel will carry two lanes of traffic southbound and the existing tunnel will carry two lanes of traffic



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FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

The **I-64 Hampton Roads Bridge-Tunnel (HRBT)** in southeastern Virginia is at the beginning of an expansion project to help ease congestion in the area. The project, which comes with a price tag numbering in the billions, is the Virginia Department of Transportation's largest in history.

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Guadalajara Subway

Other pile projects

Bern train station

Schöneicht motorway tunnel project

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Other pile projects

Gotthard Tunnel, Switzerland

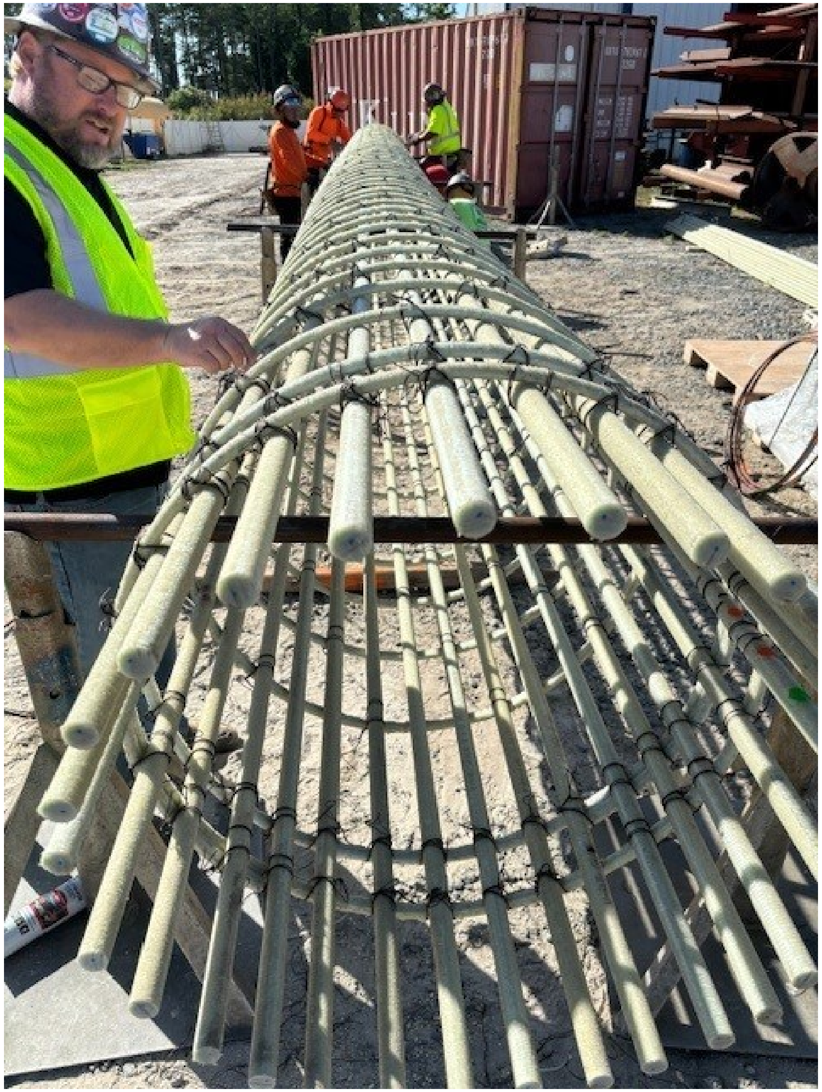
Altrheinduker Mannheim project

Other pile projects

Flagler Beach Seawall, Florida DOT

Other pile projects

Flagler Beach Resiliency project, Florida DOT



Other pile projects

Portlands waterfront dev'p - Toronto

TTC North Tunnels – Toronto, Canada


SHAFTSPACER
SYSTEMS

Eglinton Crosstown LRT – Toronto, Canada

Kicking Horse bridge – BC MoTi

Rapid replacements – MTO East Region

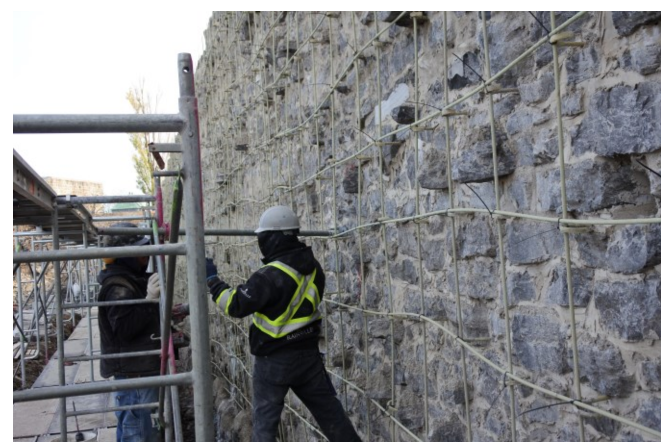

ROYAL LEPAGE
Travelodge
Hotel
WATERPARK OPEN

MTO project – Toronto, ON

Kipling Ave – Toronto, ON

Nipigon cable stayed bridge, MTO NW

Rehabilitation projects



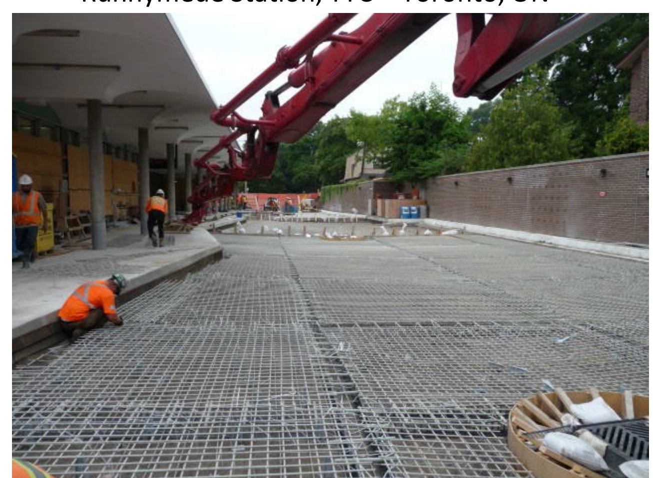
Various transit projects

Ottawa LRT

VIVA Next BRT – Toronto, ON

Winnipeg Southwest Transitway

Runnymede Station, TTC – Toronto, ON

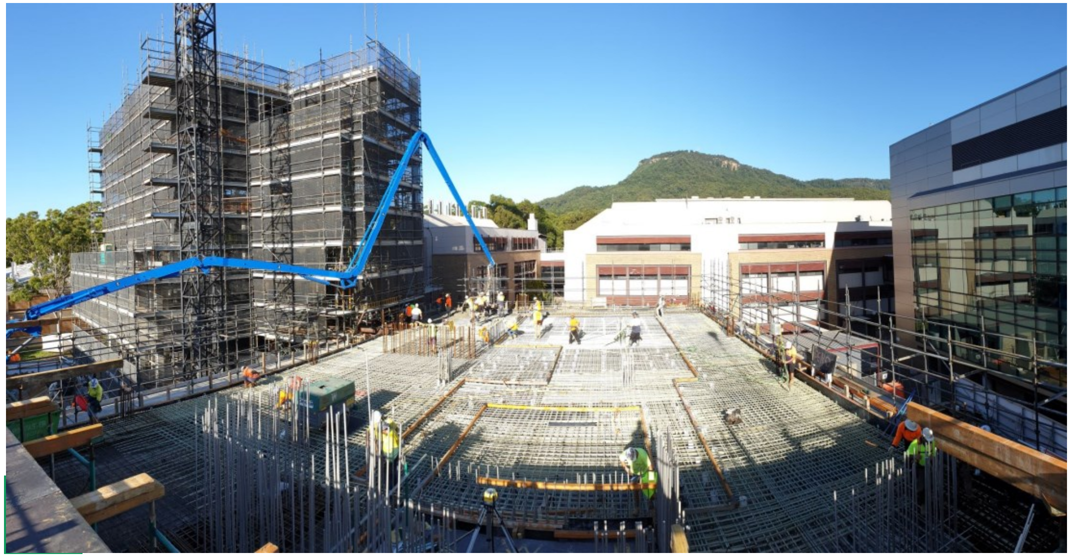


Clean labs and MRI's

MaRS project – Toronto, ON

IPL clean labs, Waterloo, ON

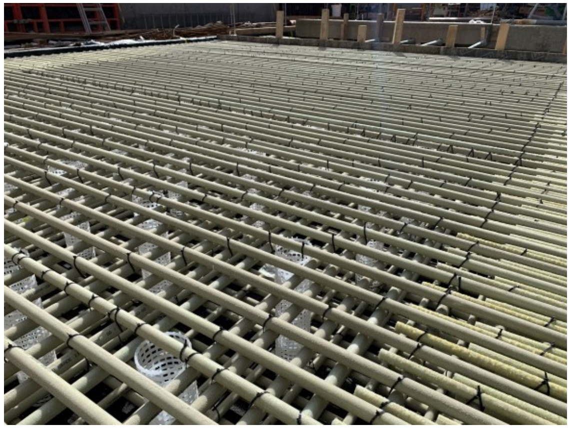
Wollogong University, AU



Clean labs and MRI's

Compass U fusion reactor, Czech Republic

City University, Zurich, Switzerland



Paul Scherrer Institute, Switzerland

Waste water treatment plants

Parking garages