FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

“Advances in concrete reinforcement”

August 8-9, 2024 - Toronto, Ontario

The use of GFRP bars in Transportation and Infrastructure Projects

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PEI Dept. of Transportation and Infrastructure

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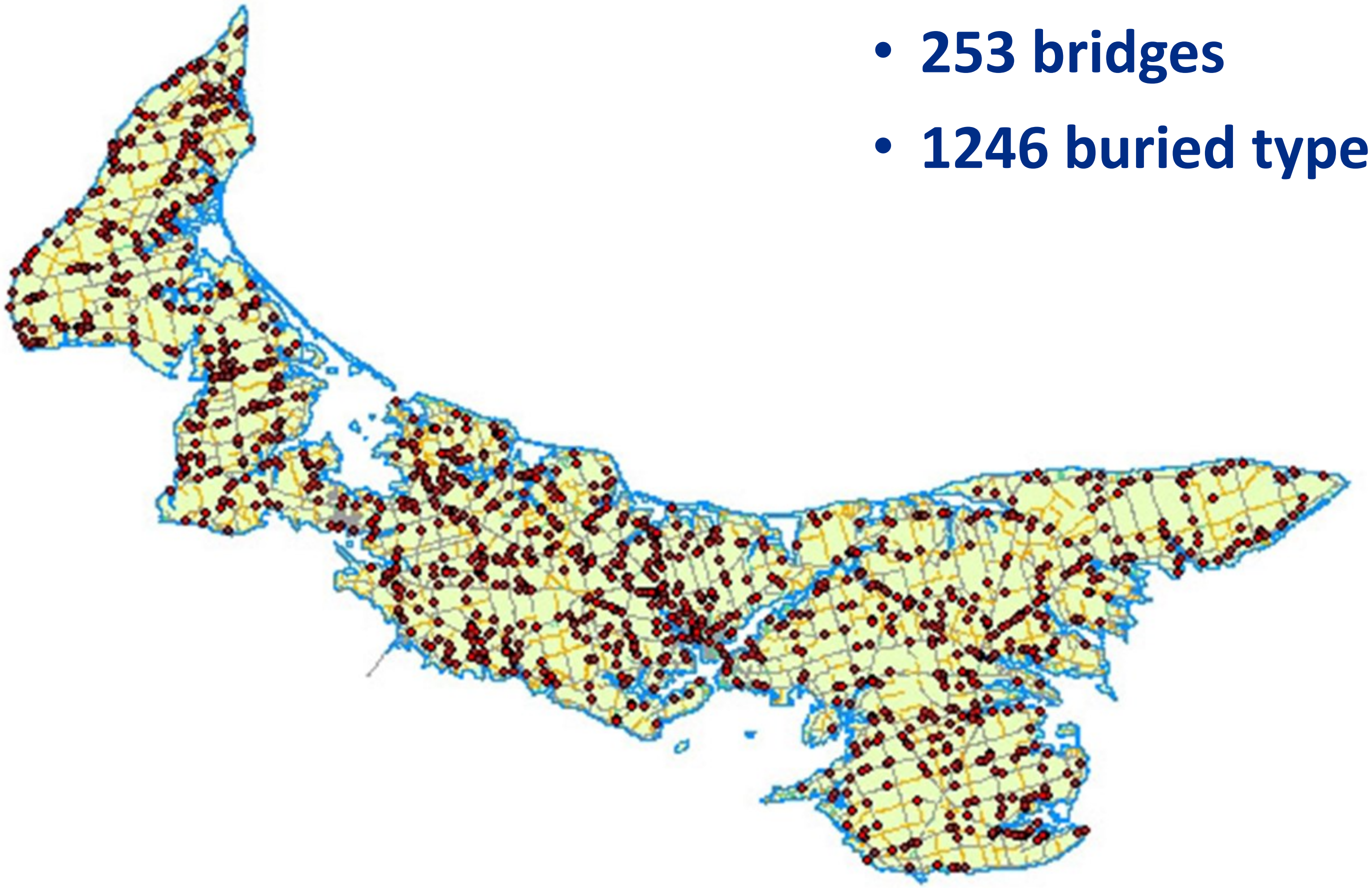
Prince Edward Island

- Here we are on the east coast of Canada.
- Smallest Province.
- 5660 km^2 (2190 mi^2) of land area
- 5600 km (3480 mi) natural waterways
- 5600 km of roadway network.

Structures Map

- 1499 "structures"
- 253 bridges
- 1246 buried type.



Island by Definition

- Surrounded by salt water (about 34 ppt)
- Florida hovers around 36 ppt
- The Dead Sea is 337 ppt.

Seasonal variations

- **Four Seasons**
  - Almost Winter
  - Winter
  - Still Winter
  - Construction
- **Or, in layman's terms**
  - Fall
  - Winter
  - Spring
  - Summer

Fantastic Summer Seasons

- **Up to 30° C (86° F)**
- **Humidex up to 40° C (104 ° F)**

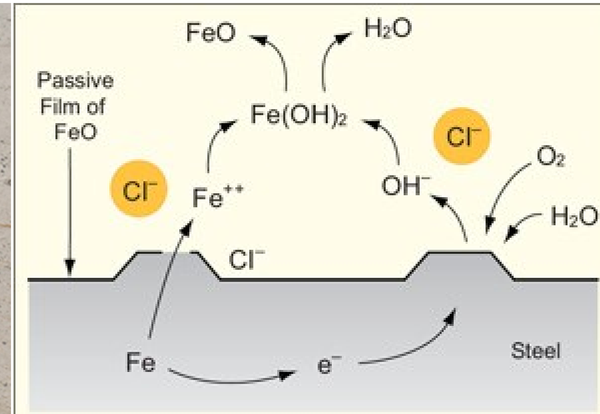
Interesting Winter Seasons too!

- This is 2015
- Total accumulation of 4.5 metres (≈ 15 ft.)
- Down to - 20° C (- 4° F)
- Wind chill down to - 40° C (° F)

Winter Maintenance

- **Salt.**
- **Salt brine, salt pellets, salt/sand blend.**
- **Salt, salt, salt (NaCl).**

All this salt leads to some issues



Carbon steel with passive film failure allowing for corrosion.

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Why would we want to use GFRP?

- To avoid this!





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Started using GFRP as primary reinf. in 2007

How much GFRP Can we stuff into a bridge?

- Just over 70 km of GFRP bar used!

Structures with GFRP Reinf.

Bridge	No. of Spans	Super structure	Horiz. Align.	Total Length (m)	Ft.
Montague Bridge	2	Steel Plate Girder	Curved	60	197
Clarks Mill	1	Steel Plate Girder	Curved	43	141
Montrose Bridge	1	Steel Box Girder	Curved	52	171
Victoria Bridge	1	Steel Plate Girder	Straight	33	108
Kildare Bridge	3	PCC NEBT Girder	Straight	57	187
West River	1	Steel Plate Girder	Straight	48	157
Oak Drive O/P	4	AASHTO Type III	Straight	59	194
Darnley Bridge	4	PCC NEBT Girder	Straight	137	449
Ross' Corner	1	Steel Box Girder	Curved	47	154
St. Peter's	1	PCC NEBT Girder	Straight	28	92
Cardigan	1	Pre-Cast Box Girder	Straight	24	79
Marie	1	PCC NEBT Girder	Skewed	26	85
Huntley	1	PCC NEXT Girder	Skewed	20	66
North Lake	3	PCC NEBT Girder	Curved and Skewed	75	246
Souris	4	PCC NEBT Girder	Straight	128	420
Cornwall Rd O/P	1	PCC NEBT Girder	Skewed	33	108
Clyde River	2	Steel Box Girder	Straight	132	433
Bannockburn Rd. O/P	1	PCC NEBT Girder	Curved and Skewed	35	115
New Haven Interchange	1	PCC NEBT Girder	Skewed	35	115
Hunter River	1	PCC Voided Slab	Straight	16	52
Oyster Bed Bridge	3	PCC NEXT Girder	Straight	44	144
Little Harbour	1	PCC NEBT Girder	Straight	31	102
Morell	1	Steel Box Girder	Straight	58	190
Bayview	3	PCC NEXT Girder	Straight	56	184
Warren Grove Road	1	PCC NEXT Girder	Straight	16	52
Rusticoville	3	PCC NEXT Girder	Straight	72	236
Bridgetown	1	PCC NEBT Girder	Straight	32	105
Cain's Bridge	1	PCC NEBT Girder	Straight	35	115
		TOTAL DECK LENGTH		**1432**	**4698**

- **Total 27 after 2024 season.**
- **Yellow highlighted areas represent deck and substructure.**
- **Green shaded is full-depth pre-cast deck post-tensioned together (steel PT strands).**
- **Represents about 11% of bridge inventory.**
- **Plan on another 12 bridge structures within the next 5 years.**
- **Orange is currently under construction.**

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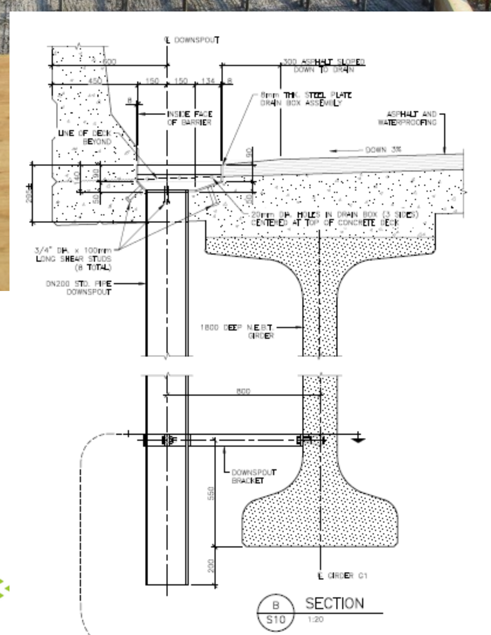
What would we like for the future?

- **Form ties!**
  - Yes, they exist, but industry doesn't favour them.
  - Need to be practical in the field and simple in design.
  - Otherwise, they're expensive (not very heavy) paper weights.

What would we like for the future?

- **PCPS Girder Tie Downs?**
  - Currently steel which have a direct link to PS strands.
  - Maybe not feasible, but something to consider.

What would we like for the future?



- **Deck drains.**
  - Again, we know these exist, but we'd like a larger catchment area.
  - Would they be practical to fabricate?

What would we like for the future?

- **Shear Transfer from Girder to Deck**
  - Difficult to supplement steel in PCC girders.
  - Steel girders aren't going away.
  - How do we get these out of the deck and still achieve composite action?

What would we like for the future?

- **Piles**
  - Practical – *cost effective* solution to piles.
  - Handling, driving, splicing.

What would we like for the future?

- **Buried Structures**
  - Pre-cast reinforcement.
  - Supplement to corrugated metal?

No longer innovative material!

- For us, it's a staple for our decks and concrete substructures.
- Innovation is now in the application, not strength (serviceability & sustainability).
- Practicality – material should be user friendly.
- Engineering – should be transparent and readily available.

Thank you!

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

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DESIGN AND CONSTRUCTION WITH GLASS FIBRE REINFORCED POLYMER (GFRP) REINFORCING BAR AT WEST ST. UNDERPASS OVER HWY 11

Seraj Uddowla, Senior Bridge Engineer

Ministry of Transportation Ontario

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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

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Outline

- MTO Corrosion Protection Policy for Concrete Bridge Components (Reinforcement)
- **West Street Underpass at Hwy 11**
  - Consultation with the Manufacturers for GFRP Bar Detailing and Fabrication
  - Design and Construction
  - Quality Assurance
  - Cost Comparison
  - Summary of Project
  - Acknowledgements

MTO Corrosion Protection Policy for Reinforcement

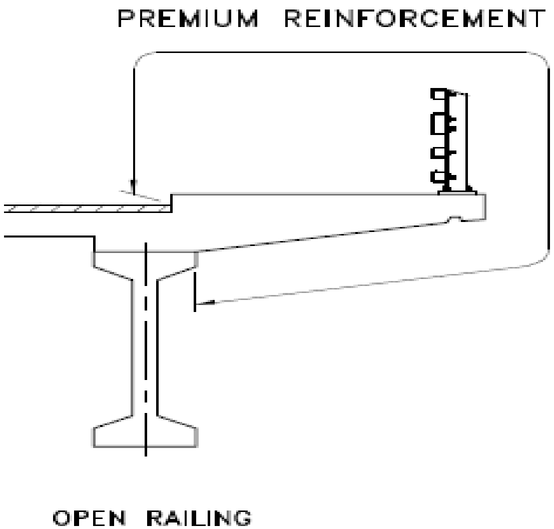
The Basics:

Corrosion Protection Policy is a strategy to mitigate or prevent corrosion.

The Policy: Use Premium Reinforcing in locations vulnerable to salt-induced corrosion where they provide the greatest benefit

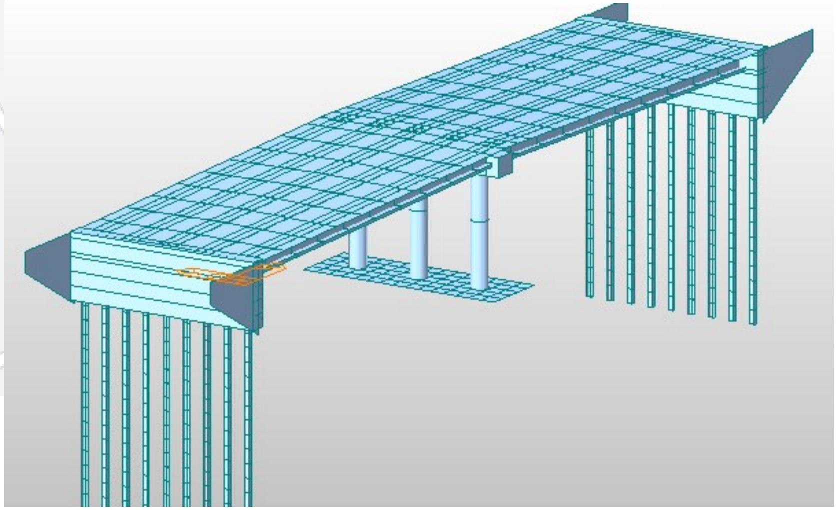
- Applies to new structures
- Applies to rehabilitation of older structures with remaining service life 35 years

- 1978: Epoxy Coated Steel
- 1999: Stainless Steel
- 2005: GFRP
- 2012: Epoxy Coated Steel reinforcement phased out
- 2017: Grade III GFRP



The Location and the Details of the West Street Underpass

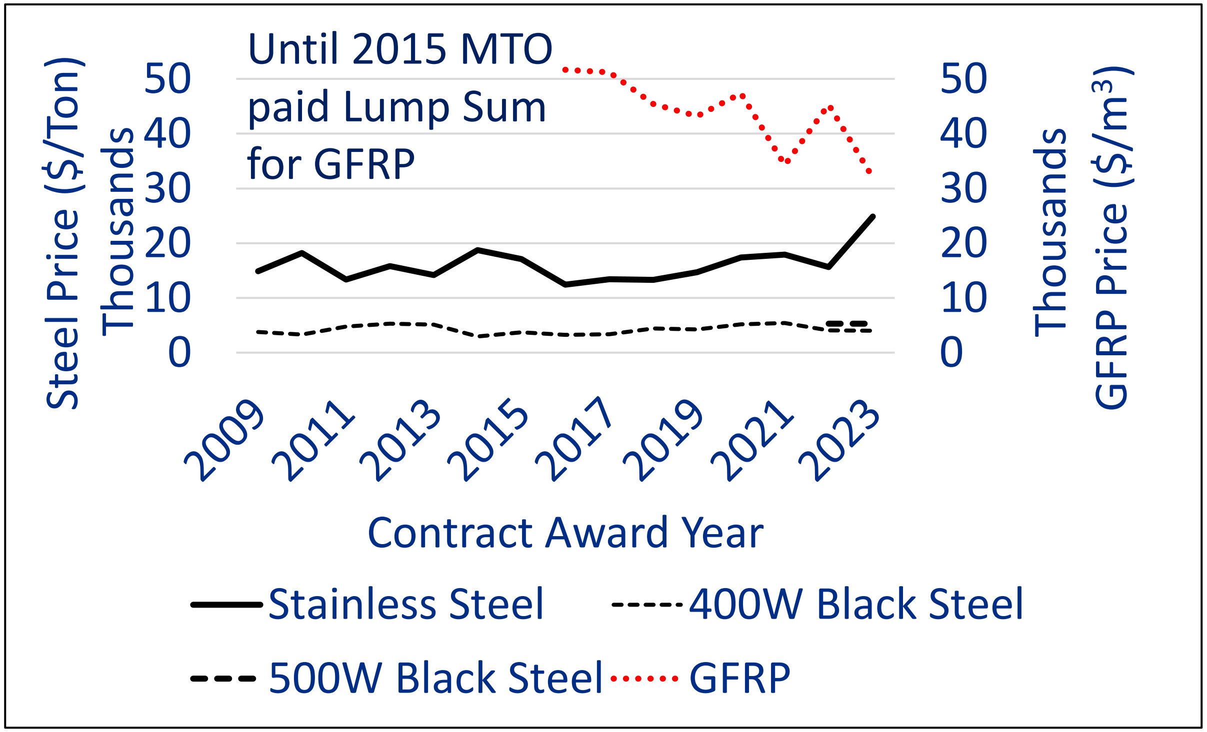
The structure carries West Street (arterial road) over Hwy 11 in Orillia



Consideration of GFRP Reinf. for the Entire Structure

- Ministry is using stainless steel or GFRP reinforcement designated as Premium Reinforcement mixing with black steel which results complexity in the future decision-making process for rehabilitation and the life span of the structures.

- Price Trend of Reinforcing Steel and GFRP in MTO Bridge Projects



Consideration of GFRP Reinf. for the Entire Structure

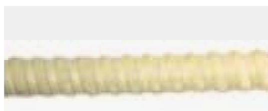
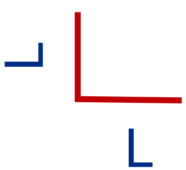
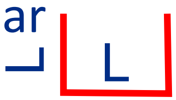
- In the past, the Ministry did not attempt to apply GFRP reinforcement for all the concrete components of any structure considering inadequate research, inferior material properties, additional limitations with production of bent bars and inadequate design guidelines. Strength and stiffness of GFRP bars have been improved and multiple manufacturers are ready in Ontario to supply adequate GFRP bars required for a typical bridge project.

- Other jurisdictions have built bridges in the recent years using GFRP reinforcement in the entire bridge or most of the components successfully.

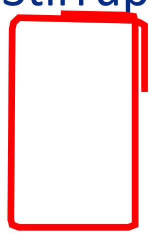
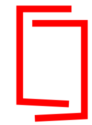
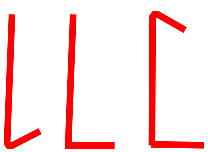
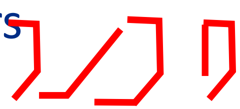
Framework considered for fully GFRP Reinforced Concrete Design in West St Underpass

- Assess design and construction challenges with GFRP.
- Improve our understanding GFRP reinforced concrete design philosophy.
- Prepare contract drawings based on feasible and practical details for GFRP.
- Prepare Special Provision (SP) for GFRP.
- Confirm availability of GFRP reinforcing bar for the project.
- Compare cost of GFRP vs. Steel, cost of GFRP low volume vs. entire structure.
- Execute and evaluate MTO Field Guide for Quality Assurance on site.
- Record and share experience in design and construction of West St Structure project.

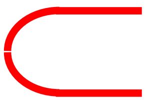
GFRP Bar Detailing and Fabrication

	Bar Shapes	**Comments from GFRP Manufacturers**		
		A	B	C
1	Straight Bar 	Can produce in a timely manner. No limitation in length or size.	Can produce with maximum length 18.0m.	Roughly 3 weeks required for production. Recommended 40' length for regular shipping.
2	L Shaped Bent Bar 	Maximum L = 3.95m. Size of the oven controls L.	Maximum L: 1st leg=2.2 m 2nd leg=1.0 m	Maximum L = 2.75m
3	U Shaped Bent Bar 	Can produce this shape with their maximum dimension for L shape.		

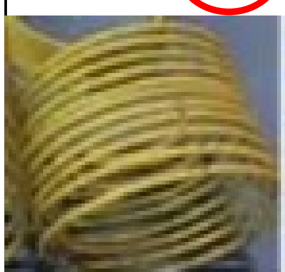
GFRP Bar Detailing and Fabrication

	Bar Shapes	Comments from GFRP Manufacturers		
		A	B	C
4	Closed Stirrup 	Can produce with a limit in the maximum dimension of L shape.	Can produce bar sizes less than 25M. Suggested: 	Can produce with a limit in the maximum dimension of L shape.
5	Bent Stirrup Legs 	Can produce all three shapes	Can produce first two shapes.	Can produce all three shapes
6	Special Bent Bars 	Can produce all four shapes	Can produce first two shapes.	Can produce first two shapes

GFRP Bar Detailing and Fabrication

	Bar Shapes	Comments from GFRP Manufacturers		
		A	B	C
7	Dowels for approach slab 	Can produce		
8	Special bent bar in approach slab and light pole base. 	Can produce	Can not produce. Suggested to split into two bars like below: 	Can produce in two bend diameters. 180mm and 205mm.
9	1.0m dia bar in light pole base 	Can produce	Can not produce. Suggested stainless steel.	Can produce with a closed diameter of drum 1050mm.

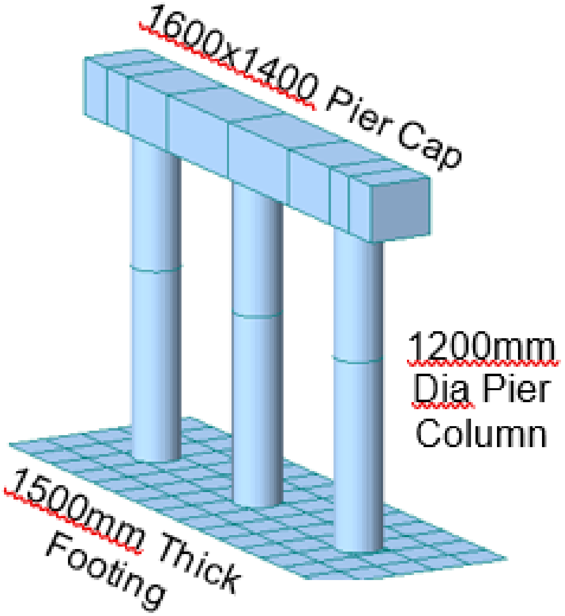
GFRP Bar Detailing and Fabrication

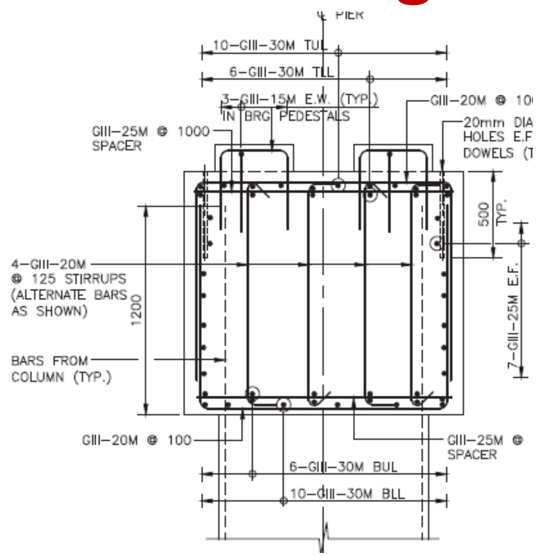
	Bar Shapes	Comments from GFRP Manufacturers		
		A	B	C
10	Z shaped bent bar for sidewalk	Can produce with a minimum bend radius is 60 mm	Can not produce reverse bends. Suggested: 2 bent bars	Can produce
11	Spiral in Circular Columns 	Can produce with maximum length of 18m each piece. Suggested: Anchoring with 1.5 additional turns and splicing with lapping one full turn.		Can produce spirals using their existing drums with internal diameter 1050mm and 1090mm.

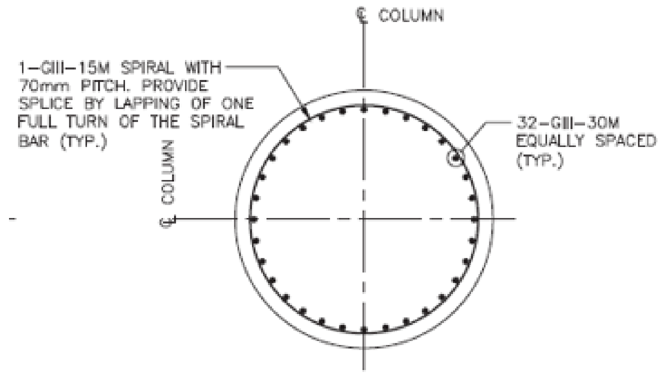
Design and Construction of West St. Underpass

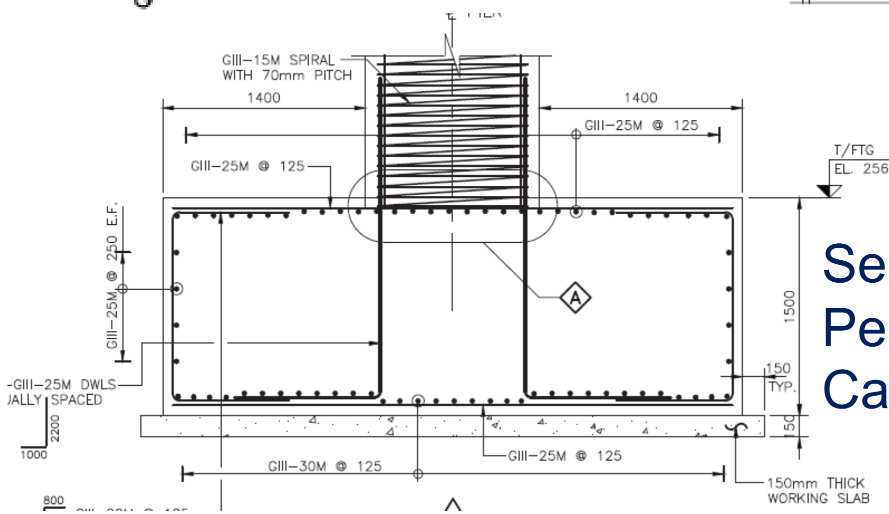
- Pier
- Abutments and Wingwalls
- Deck, Light Pole Base and Parapet wall
- Approach Slabs
- Handling of GFRP Bars on Site

Pier Design







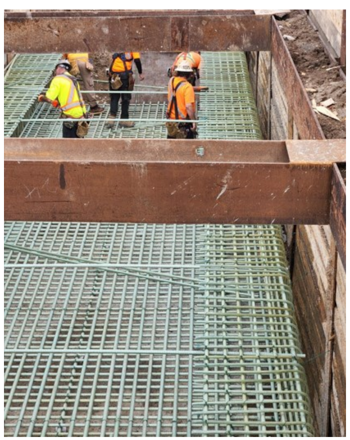


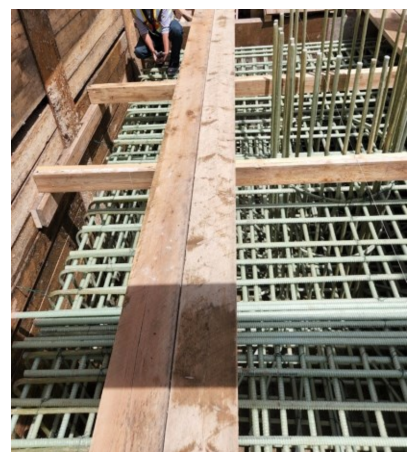
Seismic Performance Category 1

Pier Column Reinforcement:

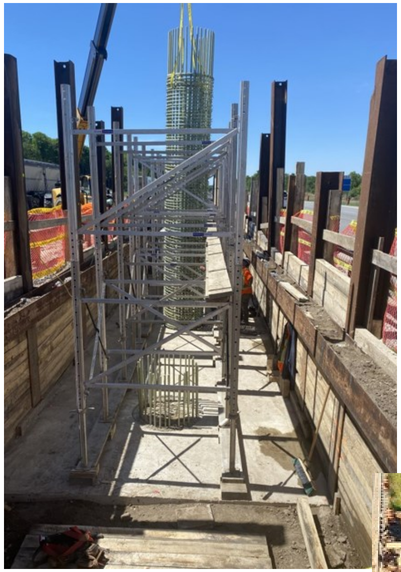
- 32 – 30M GFRP longitudinal bars
- 15M Spiral with 70mm Pitch
- Provide Splice by Lapping one Full Turn

Pier Footing Construction



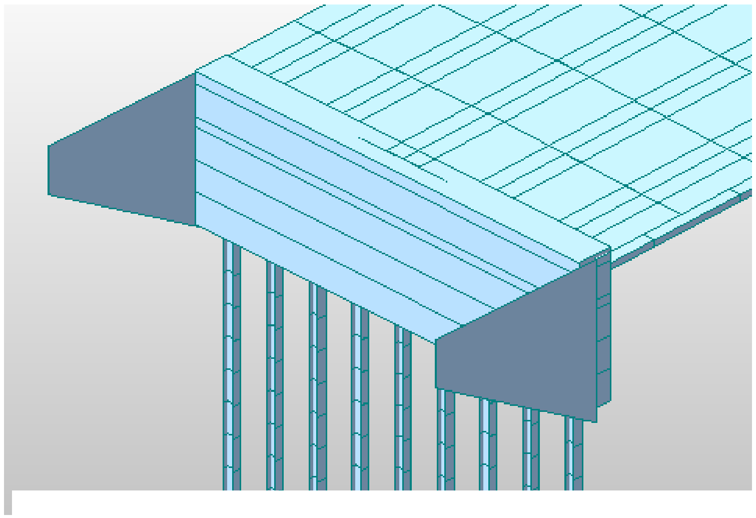


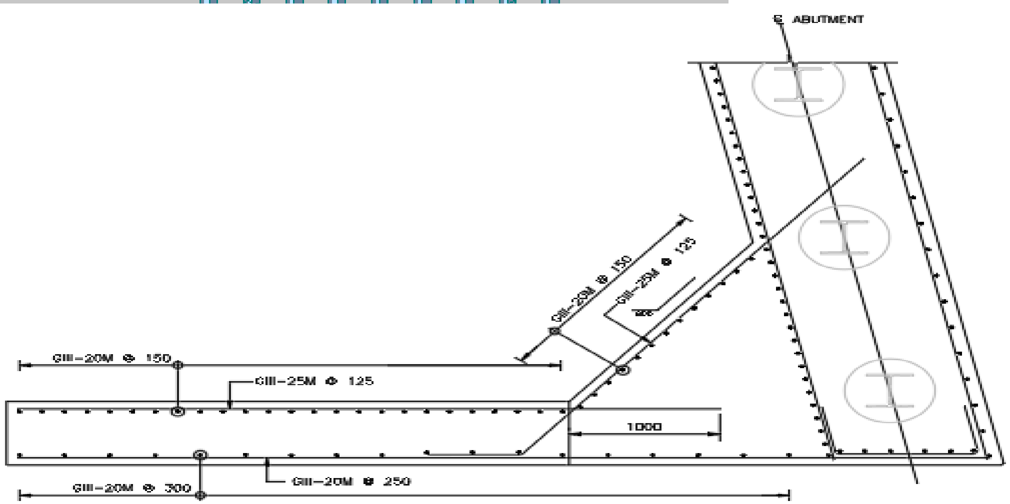
Pier Column Construction

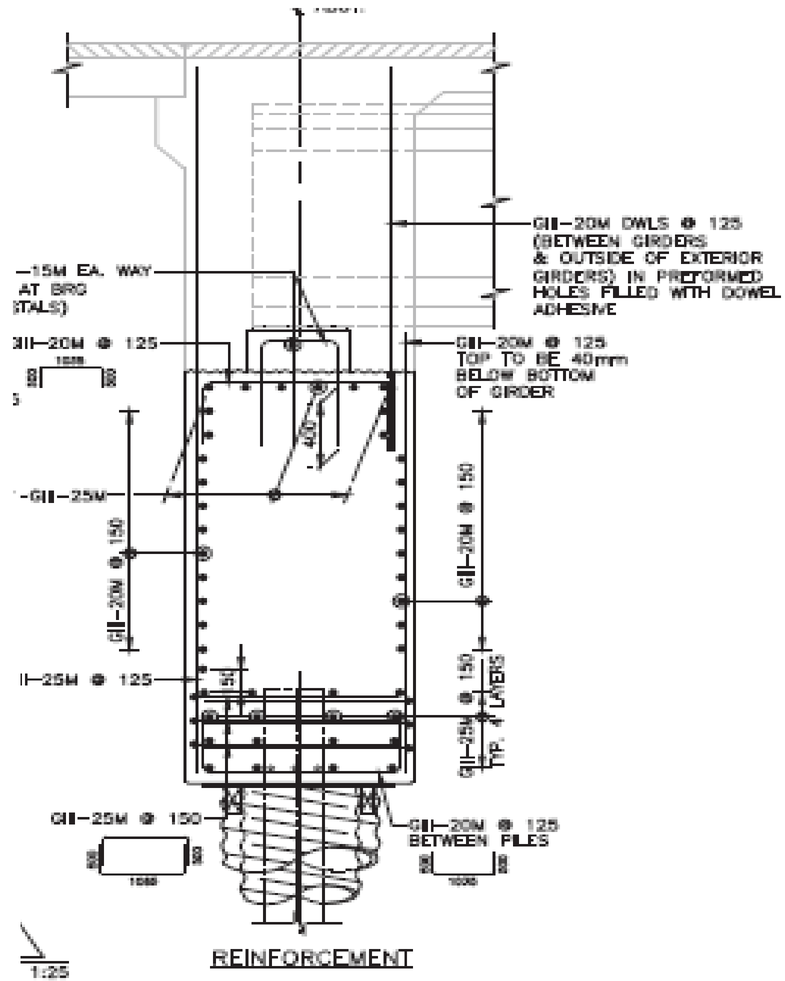


Pier Cap Construction

Abutment and Wingwall Design







Abutment and Wingwall Construction

Stage 1 (Below Bearing Level)

Abutment and Wingwall Construction

Stage 2 (Above Bearing Level)

Abutment and Wingwall Construction

GFRP Bars in the top part of the abutment

Deck Design

Deck Overhang from the Exterior Girder

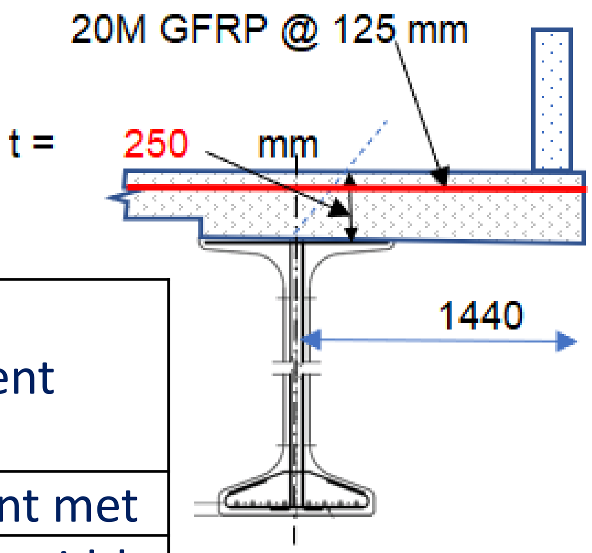
Deck between the girders are designed using empirical method of deck design

At ULS

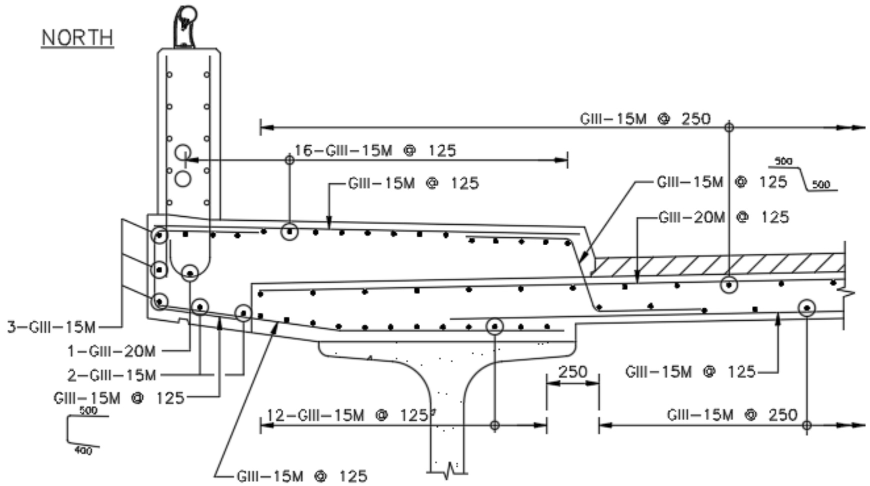
Item	Applied moment, M_{ULS}	Resisting moment, Mr	Failure mode
Flexural moment	81 kN-m/m	149 kN-m/m	Compression

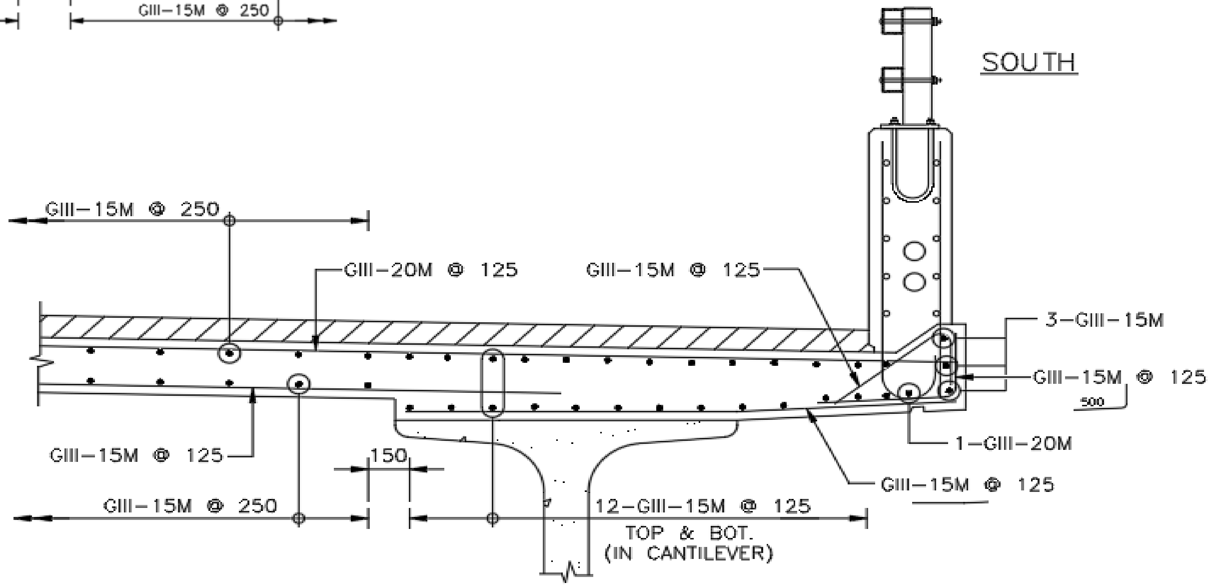
At SLS

Item	Under full-service load	Allowed in the Code	Comment
Stress in GFRP	128 MPa	250 MPa	Requirement met
Strain in GFRP	0.0213	0.00015	Check crack width
Crack width	0.48mm	0.50mm	Requirement met



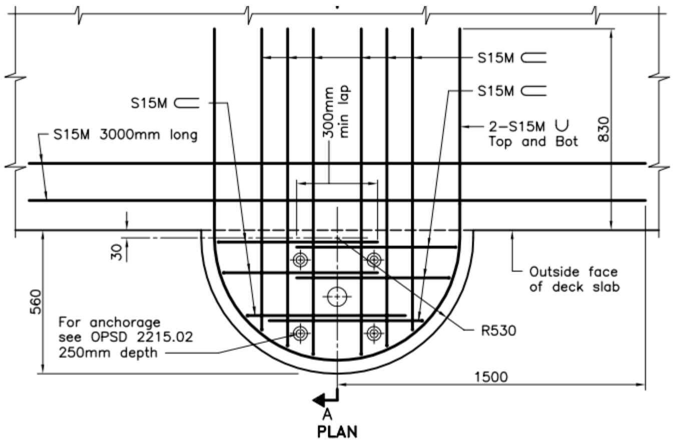
Deck Design


NORTH
GIII–15M @ 250
16–GIII–15M @ 125
GIII–15M @ 125
GIII–15M @ 125
500
500
GIII–20M @ 125
3–GIII–15M
1–GIII–20M
2–GIII–15M
GIII–15M @ 125
500
400
250
GIII–15M @ 125
12–GIII–15M @ 125
GIII–15M @ 250
GIII–15M @ 125


SOUTH
GIII–15M @ 250
GIII–20M @ 125
GIII–15M @ 125
3–GIII–15M
GIII–15M @ 125
500
1–GIII–20M
GIII–15M @ 125
150
GIII–15M @ 125
GIII–15M @ 250
12–GIII–15M @ 125
TOP & BOT.
(IN CANTILEVER)

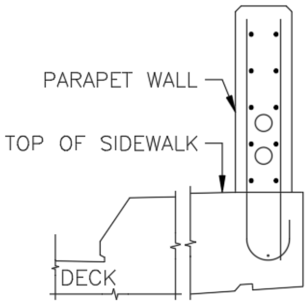
Deck Construction

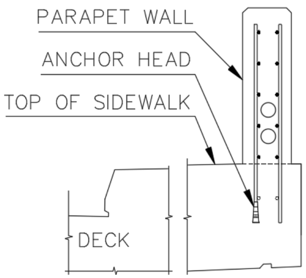
Light Pole Base Construction



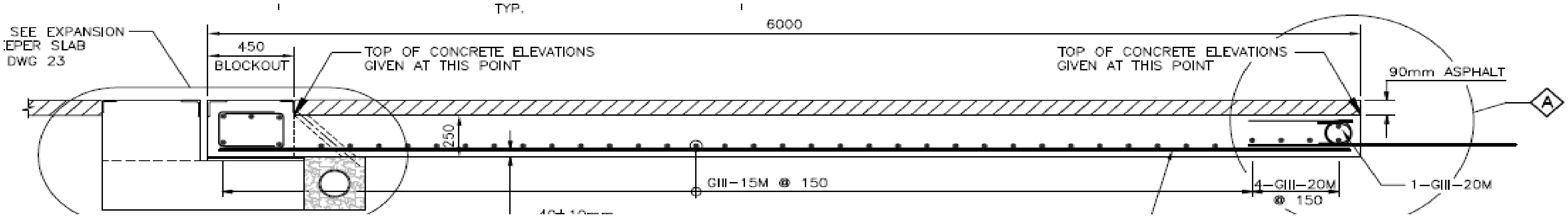
Parapet Wall

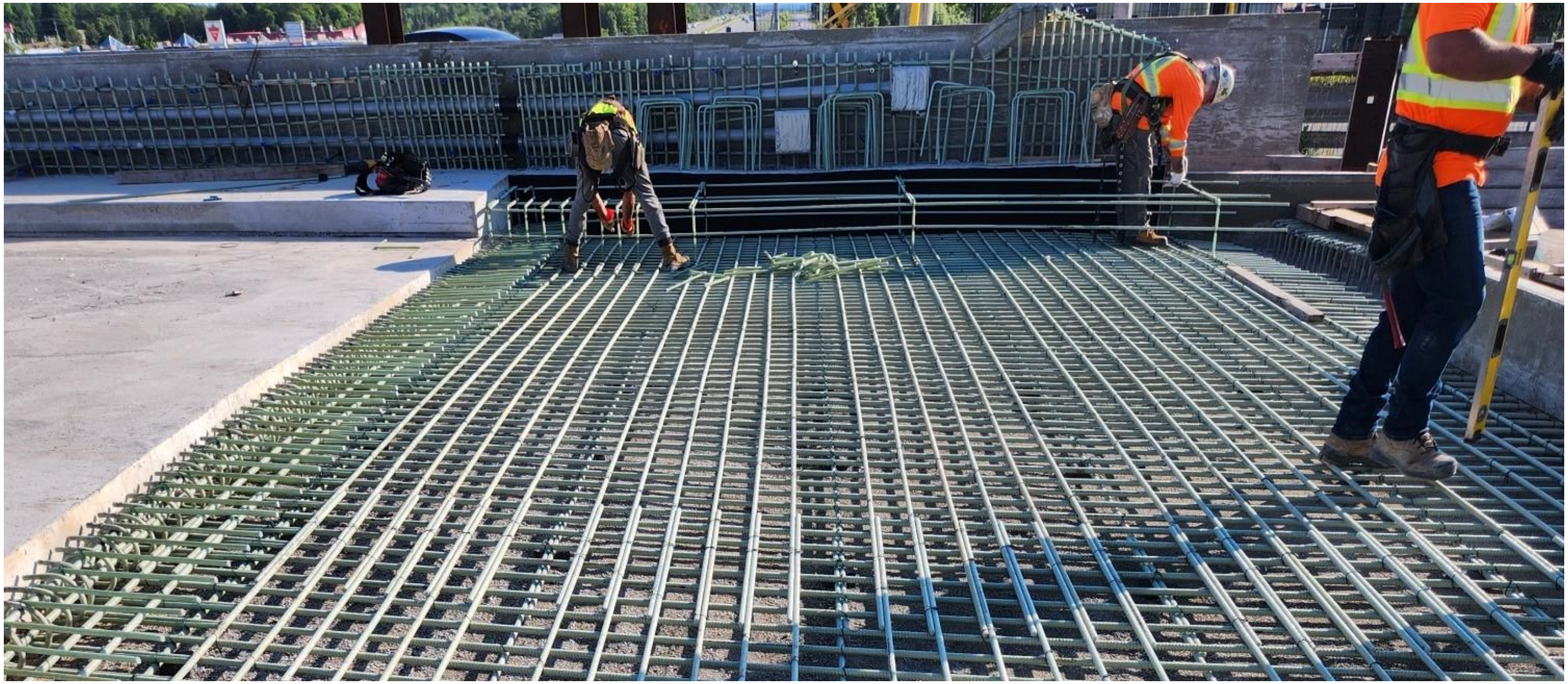
TL-4 Parapet walls with Railings are provided on West St. Bridge Deck.





Approach Slab





Handling of GFRP on Site

GFRP bars are flexible and lighter than steel.




New West St. Underpass Completed in 2023

Quality Assurance of GFRP Bars

Visual Inspections:

- **Bar Surface Condition and Identification on Site**
- **Issues with Bar Installation**
- **Discoloration of the Bars**

Testing of GFRP Bar Samples in the Lab:

- **Tensile Strength, Modulus and Elongation.**
- **Cross Sectional Area**
- Fibre Content
- Water Absorptions (24H and 1 Week)
- Cure Ratio
- Wet Glass Transition Temperature

GFRP Bar Identification on Site

The excess resin observed on bar surface

Bar Identification (OPSS 1640):

(a) Manufacturer's name and symbol,

(b) Type of fibre

(c) Designated bar diameter

(d) Grade designation

(e) Designated modulus of elasticity

(f) Production lot or batch number

Some bars were illegibly stamped or had no markings. Bars with no stamped were fastened with identification tags which lacked information,

Inappropriate Lap Location and Bar Placing

GFRP Bars at the interface of the cleat and wingwall

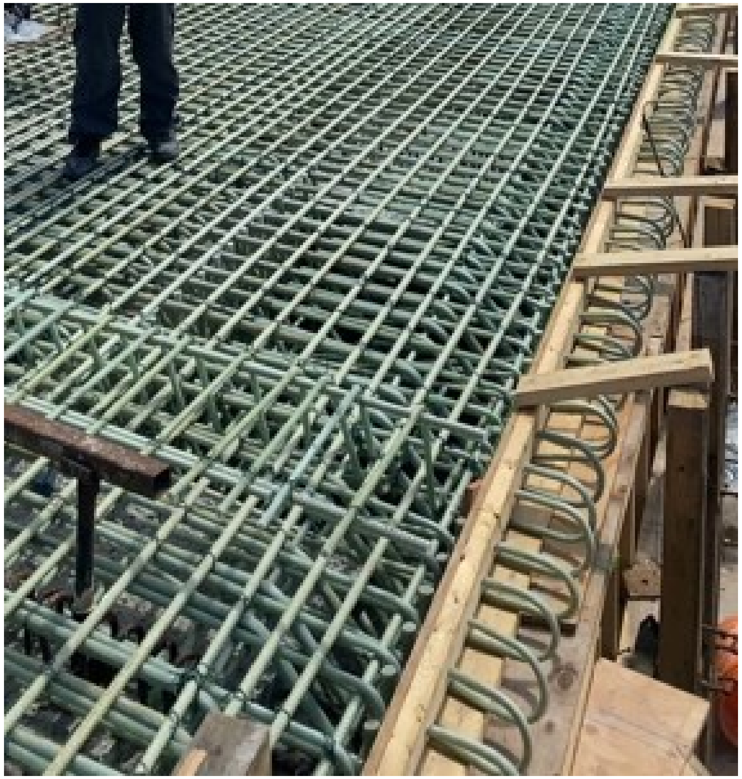
GFRP from Wingwall to Cleat Shorter than Specified

Inappropriate Bar Placing

GFRP Bars at the back of Abutment - Elevation

GFRP Dowels for Approach Slab - Plan

GFRP Bars After Correction



GFRP Dowels for Approach Slab - Plan

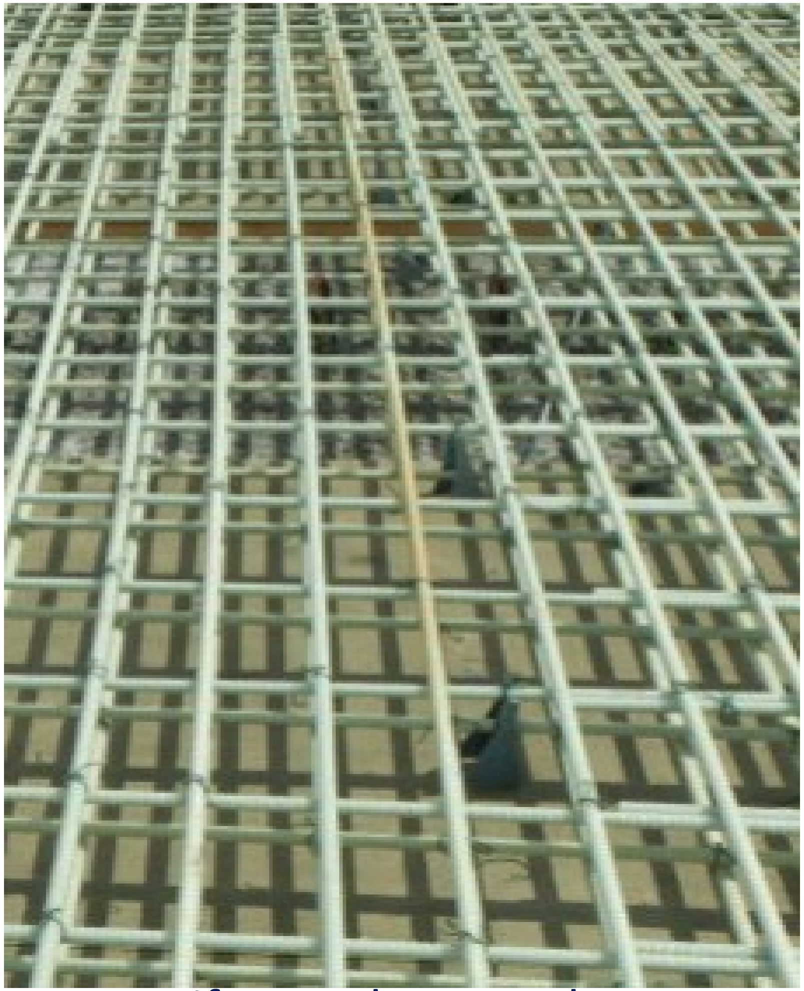
Inappropriate Bar Placing

GFRP Longitudinal bar in the parapet wall around electrical junction box

Color Uniformity of GFRP Bars

Uniform color GFRP bars

Discolored GFRP bars

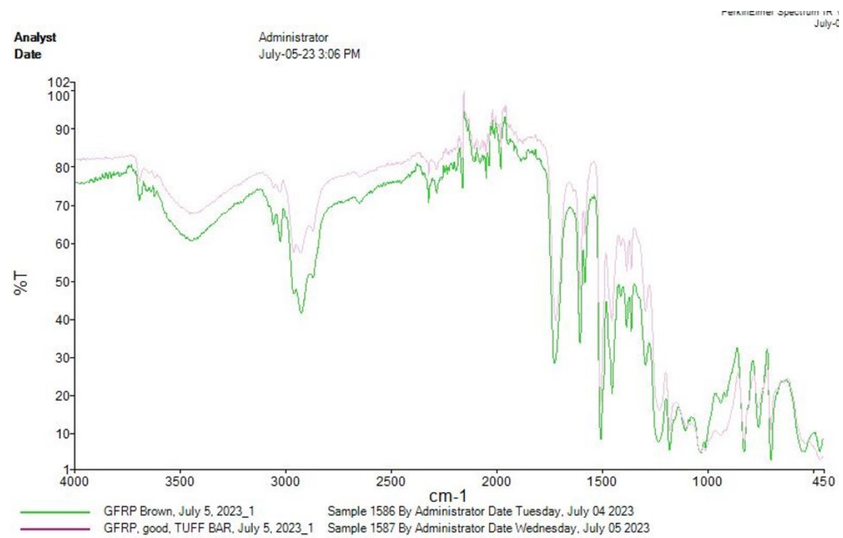


Non-uniform color GFRP bars

Testing Material in the Discolored GFRP Bar

MTO Engineering Material Office initiated an investigation to determine the materials in the discolored GFRP bars.

Cross-section of discolored GFRP Bar

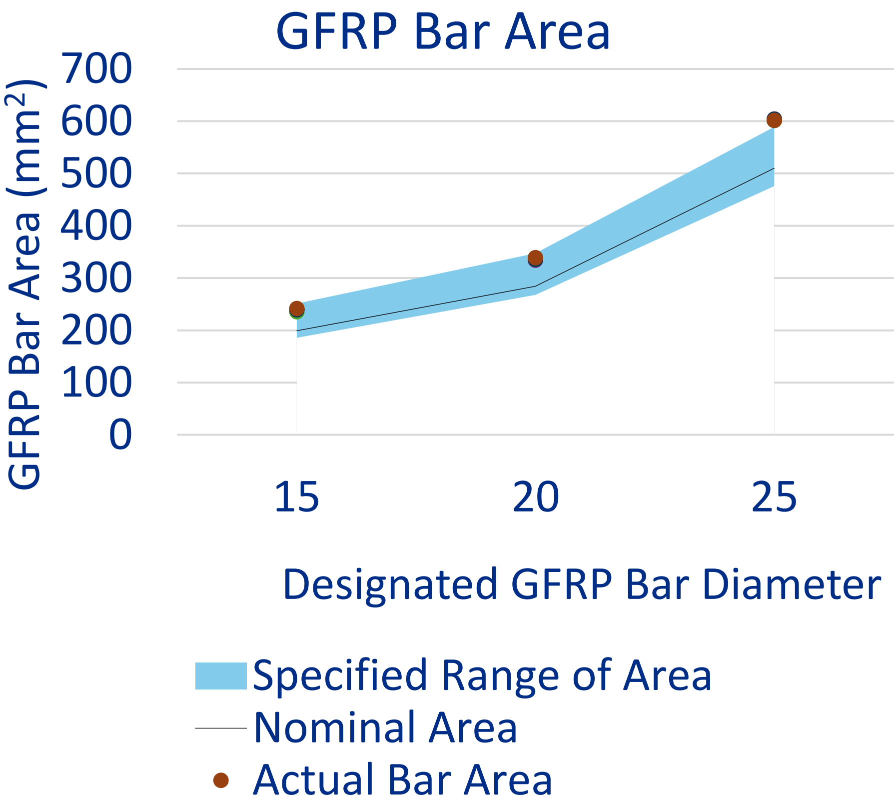


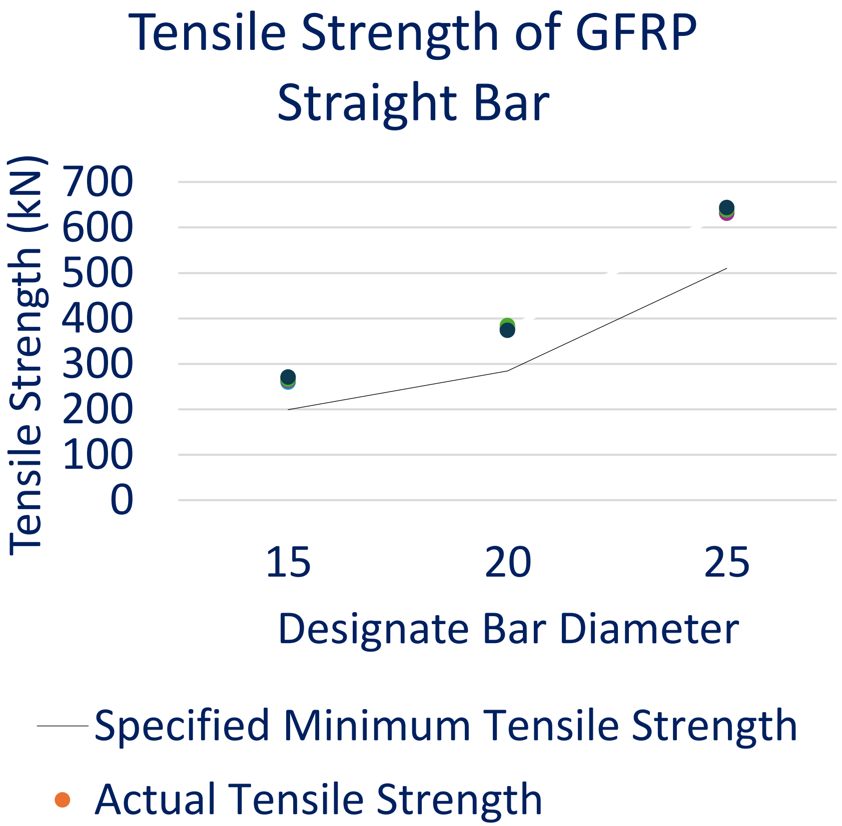
FTIR (Fourier Transform Infrared Spectroscopy) Scan results of a discolored and normal color bar

The FTIR scans revealed, the brown (discolored) and "good" GFRP samples were almost identical and showed that the Vinylester Resin materials were the same.

Cross-sectional Area and Tensile Strength of GFRP Bars

5 Specimens for each GFRP bar sizes 15, 20 and 25 are collected for testing their cross-sectional area and direct tensile strength and the results are plotted in Figures below:

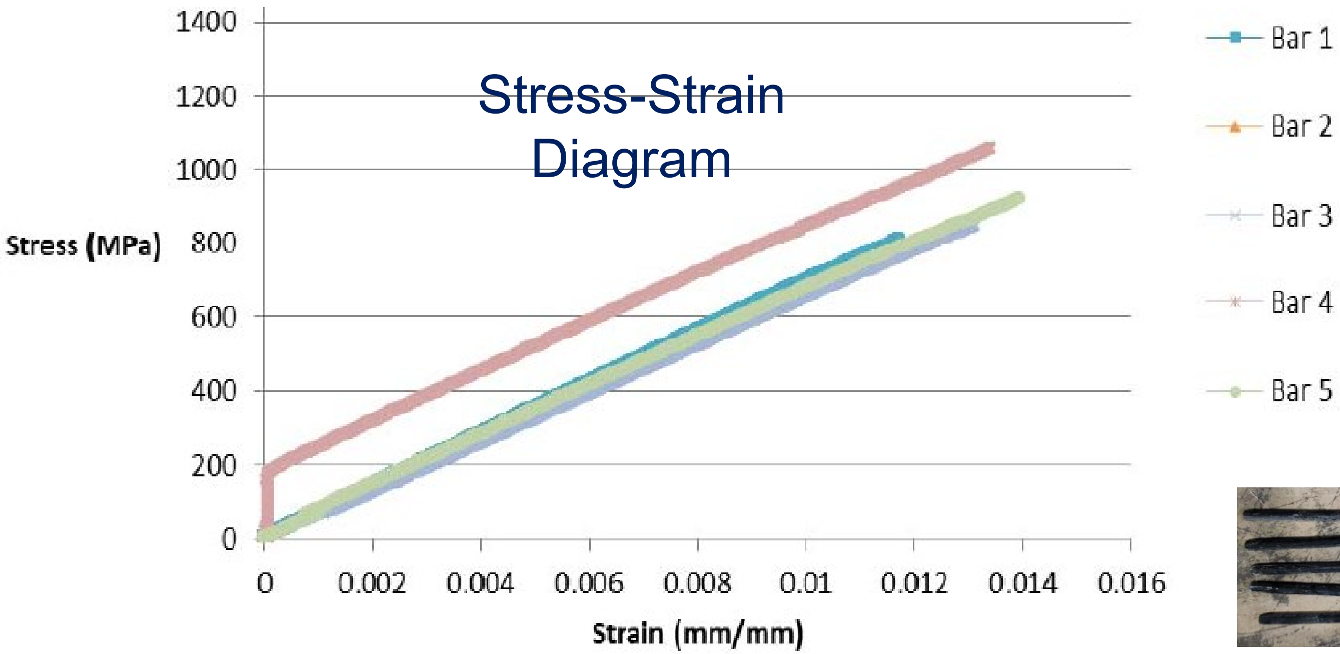




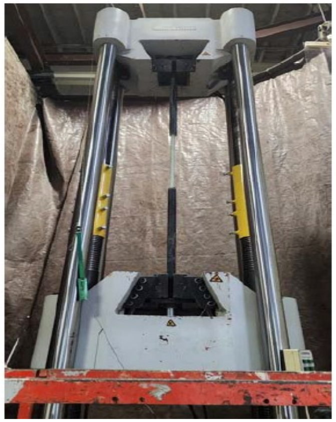
Stress-Strain and Tensile Modulus of GFRP Bars

5 GFRP test samples of size 20 bar from the project were tested to create stress strain diagram for investigating their modulus and ultimate elongation.

The calculated Modulus of elasticity from the stress strain diagram found 66.74 GPa with a minimum value 65.72 GPa which is greater than specified modulus of elasticity 60 GPa.



Test Setup



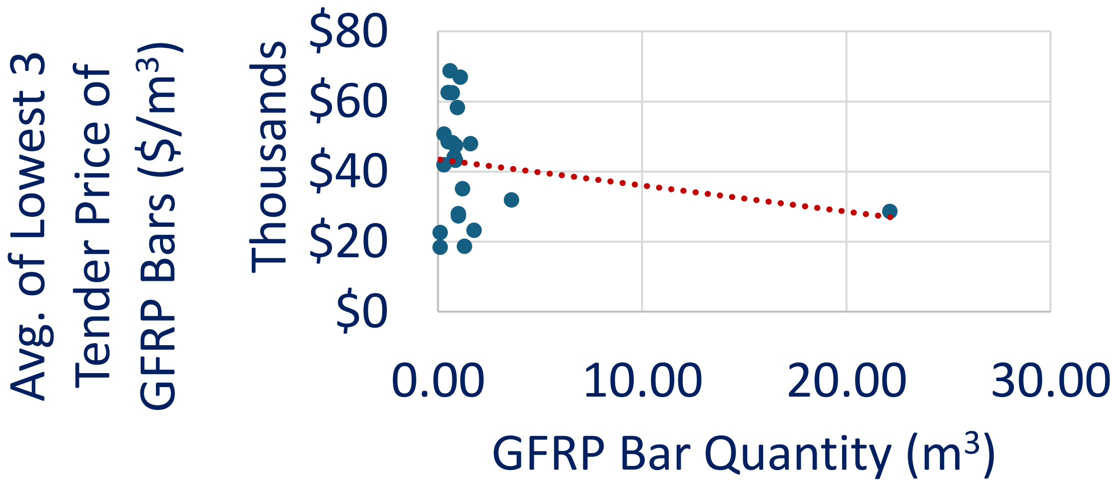
Cost Comparison

- Quantity and Cost of GFRP Bars on West St. Bridge and in Other Projects
- Cost Comparison of GFRP with Steel in Similar Bridges

Quantity and Cost of GFRP Bars in West St. Bridge and in Other Projects

Total Quantity of GFRP bar used in West St. Underpass =	22.14 m^3
Average Tender Price from 3 Lowest Bidder =	$635,000
Unit Price of GFRP=	$28,679/$m^3$

Cost of GFRP in 18 projects awarded in 2020 - 2022

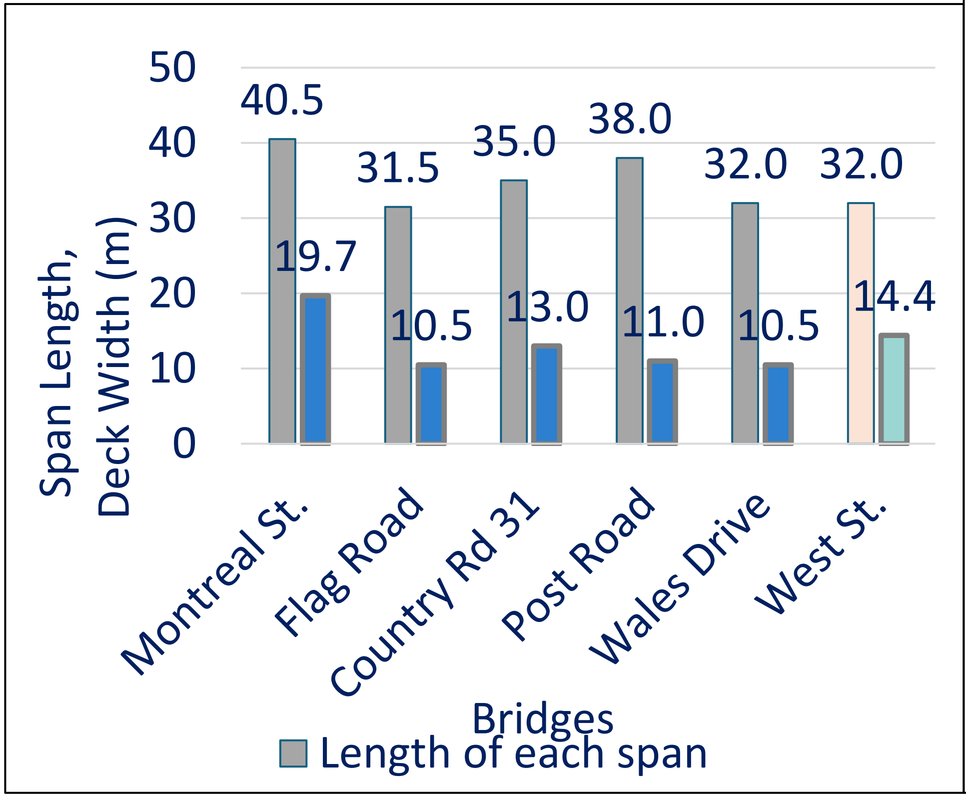


Average Cost of GFRP in Other MTO Projects = 17 Projects awarded in 2020-2022 (Quantities < 2.0 m^3)	$42,000/$m^3$

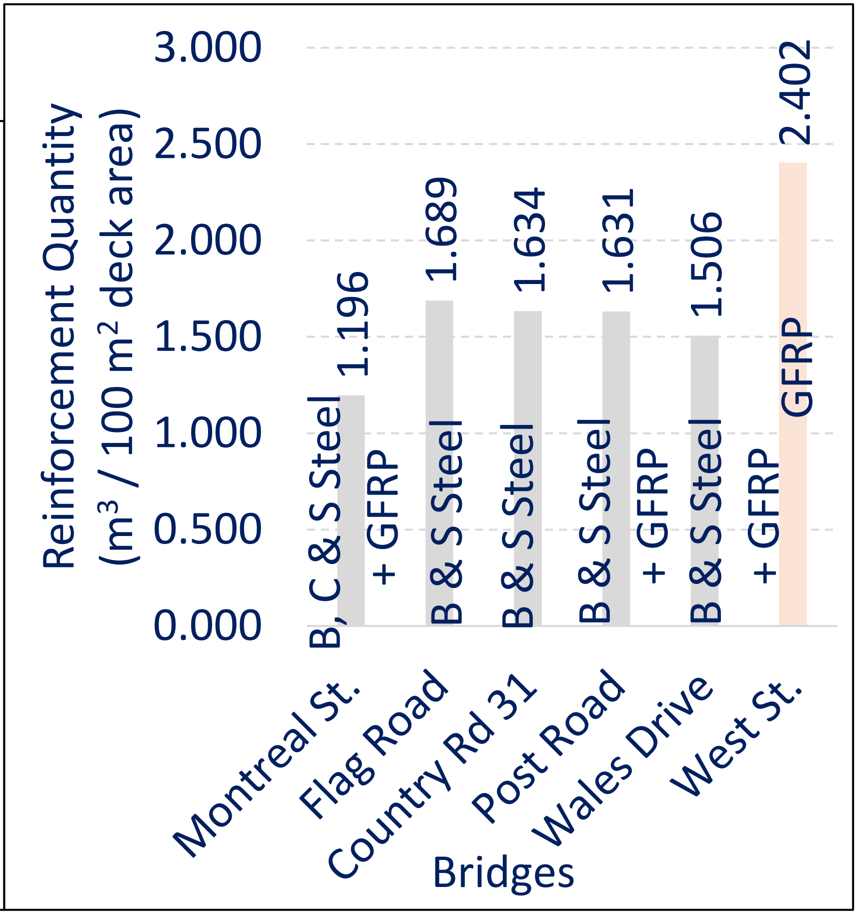
Cost Comparison of GFRP with Steel in Similar Bridges

Five Similar Underpasses on Hwy 401 Constructed in the Recent Years are compared with West St. Underpass.

Spans and the Width of the decks

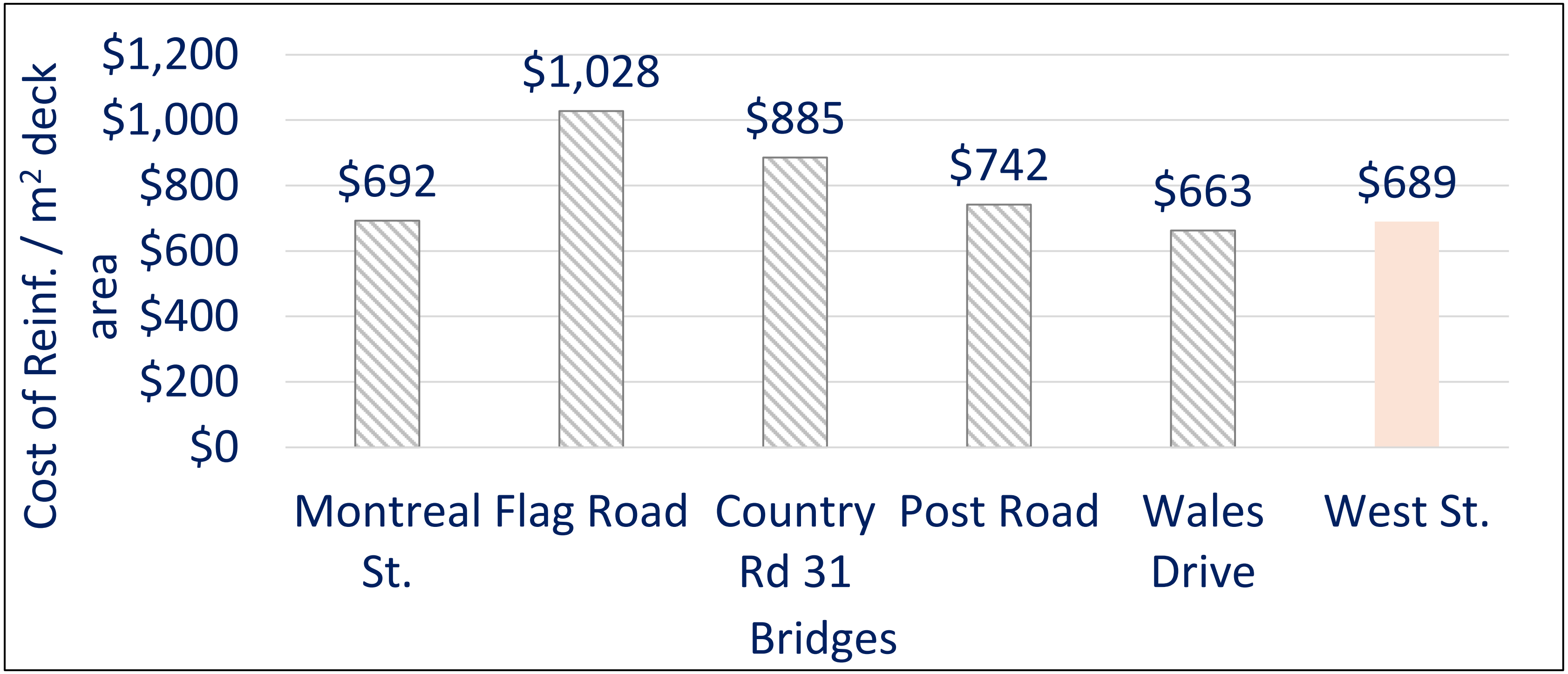


Type of Reinforcement Used



Cost Comparison of GFRP with Steel in Similar Bridges

For cost comparison, actual material quantities from the five projects and the average tender price of the different reinforcement types paid in 2021 are used. The cost of the GFRP in the West St. Underpass shown in the figure below is the actual.



Summary

1. Due to low elastic modulus of GFRP and SLS design requirements, higher reinforcement ratio with GFRP was required in bridge components compared to the steel reinforcement and it results some bar congestions.
2. Design – details with GFRP reinforcement requires additional effort due to limited bent bar sizes and shapes of GFRP bar fabrication.
3. Additional Structural Standard Drawing (SSD)with GFRP to be required.
4. No additional lead time required for GFRP fabrication and delivery for the project since consultation and confirmation of bar details have gone through during design process. It is recommended designer should follow similar process for future GFRP design projects.
5. After successful completion of West St project, it is found that GFRP manufactures in the DSM list can supply for most of GFRP reinforcement in any typical bridges when entire structure with GFRP reinforcement is built.

Continue…….

Summary

7. GFRP spirals cannot be manufactured with 90 degrees bent to anchor and splicing like steel. Anchoring and splicing GFRP spirals are provided by adding additional turn which can create bar congestion. Maximum bar length of 18.0 m is fabricated for spirals which can cover about 5 spiral circles in 1.2 m dia. column. This results in many splices in column spirals and causes bar congestion.
11. Some bridge components such as pier cap with demanding closely spaced shear stirrups may require larger section because strength and stiffness of GFRP bent bars is less than its straight bars.
12. Some field staff raised safety and health concerns due to exposure for airborne fine fibers of the bars when dealing with the material.
1. Larger volume on GFRP bars in a project can reduce unit cost of GFRP.
2. It is noticed the entire structure with GFRP can be built in reasonable cost.

Acknowledgements

- Structures Office, MTO
- Structural Section, PD, Construction, QA, EMO, Central Region, MTO
- WSP, Project delivery including Hwy, foundation design
- GIP, General Contractor
- MST Rebar Inc., GFRP supplier
- Salit Steel, Rebar fabricator and installer
- DECAST, NU girder supplier
- Consor, CA

Thank You

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Quality Assurance Testing of GFRP in MTOs' Contracts

Martin Krall, Senior Bridge Engineer

Ministry of Transportation Ontario

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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

Overview

Quality Assurance Testing

- For MTO: Owner conducted material testing for product acceptance and contract payment purposes.
  - Project-by-project, and lot-by-lot
- QA testing generally repeats QC testing
  - QC testing is done by the contractor/supplier before supply to the project

Outline

- CSA S807 Test Methods
- Commercial Laboratory Challenges
- Owner Challenges

CSA S807 QA/QC Tests

Mechanical Properties

- Tensile Strength and Modulus
- Bend Strength
- Transverse Shear Strength
- Apparent Horizontal Shear Strength

Physical/Thermal Properties

- Cross-sectional Area
- Fibre Content
- Water Absorption
- Cure Ratio
- Glass Transition Temperature

Commercial Laboratory Challenges 1

Finding & Identifying Commercial Laboratories

- In 2014 & 2018, MTO sought potential labs for testing
  - 70 candidates were identified
- In 2019, 23 labs expressed that they either:
  - Were capable of doing at least some of the tests, or
  - Were interested in becoming capable

2019 QA Pilot Project

- 4 bids received; only 2 were compliant
- Awarded and implemented testing of all properties

Since 2019

- QA testing has been done on an ad hoc basis since 2021 though larger/routine construction materials QA testing contracts

Commercial Laboratory Challenges 2

Commercial Laboratory Concerns

- Typically, labs decline to bid because:
  - 1) Cost of testing equipment makes bid prices non-competitive
  - 2) Inability to recover equipment costs on low quantity of tests
- Other concerns:
  - Labs inexperienced with FRP testing must identify and accept risk
  - Lack of knowledgeable staff to oversee and conduct tests

Prime and Sub Lab Arrangements

- A 'one lab' solution is typically a network of laboratories, with on acting as the prime and the others as sub-contracted labs
  - Mechanical Tests: industrial lab setting
  - Physical Tests: clean lab setting

Owner Challenges 1

QA Bar Sample Lengths

Nominal Bar Diameter mm	Sample Lengths				
	Group 1 Tests mm	CA Test mm	AHS Test mm	Tensile Test mm	Total All Tests mm
13	401	1740	91	1270	**3502**
15	401	870	105	1737	**3113**
20	401	290	140	2423	**3254**

Group 1 Tests have fixed length specimens: Cure Ratio, Glass Transition Temperature, Fibre Content, Water Absorption, & Transverse Shear Strength
CA: Cross-sectional Area; AHS: Apparent Horizontal Shear Strength

- Required length of sampled bars is too long for owner QA
- Supplied bars also can be too short and similar when cutting specimens from bent bars (standard hooks or stirrup shapes)
- Owners must choose to do reduced or limited QA testing from what is available to sample and can be shipped to the lab

Owner Challenges 2

Coordination of Proprietary Data for Tests

Transverse Shear Blades

- Outside diameter of bar is different for each manufacturer and bar type they make.
- No. of blade sets =

  [n suppliers] x [n bar diameters] x [2 (bent or straight)] x [n grades]
- For MTO effectively 15 sets: 3 suppliers, 5 bar sizes, 1 grade
- Similar issue for Apparent Horizontal Shear Strength cradles

Enthalpy of Polymerization (Cure Ratio Test)

- Measure of energy per mass for complete cure, in denominator
- Some suppliers consider this a trade secret and additional effort is needed for confidentiality when sharing with QA labs for testing and reporting

- **Questions?**

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

Ministry of Transportation Ontario (MTO) GFRP Material and Construction Standards

James Combe, Senior Bridge Engineer

Ministry of Transportation Ontario (MTO)

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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

OPS Specifications

Purpose

- **A specification defines each item in a Contract that the Contractor agrees to construct in a Contract.**
- **The specifications form a part of the Contract Document and are considered legal documents.**
- **Specifications should:**
    - Contain reference to or a description of the essential parts/characteristics of the item.
    - Establish requirements/attributes and measurable properties for payment.
    - Provide the Contractor with a definite basis for preparing a bid.
    - Inform all representatives of the Owner of the work the Contractor is obligated to do.
    - Describe equipment and contractual procedures.
    - State the basis for acceptance and rejection of the completed work, including sampling and testing methods.
    - Provide rules for decision on matters referred to the Contract Administrator.

OPS Specifications (Objectives)

Technical Considerations

- Performance
- Durability
- Cost Effectiveness

Spelling / Grammar Rules; Agency Conventions; Documentation Options

- Consistency
- Clarity
- Efficiency
  - For the Design Team, Contract Administrator, Contractor

OPS Specifications

OPSS Categories

- **There are three types of Ontario Provincial Standard Specifications (OPSS's).**
- **These are not three sets of independent specifications; they are different types of OPSSs with common elements for use in different business environments:**
    - Provincial-oriented (PROV) OPSSs. These are developed to reflect the administration; testing; and payment policies, procedures, and practices of the Ontario Ministry of Transportation.
    - Municipal and provincial common (Common) OPSSs. These are for both provincial and municipal oriented Contracts.
    - Municipal-oriented (MUNI) OPSSs. These are for municipalities in Ontario.

Common and MUNI required coordination between MTO and the Municipal Engineers Association. MTO still meets to discuss specifications, but no longer has direct input into MUNI specifications. Common specifications have generally been discontinued.

OPS Specifications

MTO Documentation Types

Standard Documentation	Non-Standard Documentation

• Ontario Provincial Standard Specification (OPSS) — OPSS 950, OPSS 1640 (Nov. 2023)
• Ontario Provincial Standard Drawing (OPSD)
• MTO Drawing (MTOD)
• MTO Structural Standard Drawing (SSD)
• MTO Standard Special Provision (SSP)
SSP 999S02 (2017-2023)
	• Non-Standard Special Provision (NSSP)
	  • Provincial Office NSSP — BRDG0001 (July 2016)
	  • Regional Office NSSP
	  • Project Specific NSSP
	• Non-Standard Drawings
	  • Contract Drawing Books
	  • Modified Standard Drawings
	• Modified SSP, OPSD, MTOD

OPSS Details (General 100 and Construction 200-900)

Layout and Numbering

Section	Construction Specification	Material Specification
1	Scope	Scope
2	References	References
3	Definitions	Definitions
4	Design / Submission Requirements	Design / Submission Requirements
5	Materials	Materials
6	Equipment	Equipment
7	**Construction**	**Production**
8	Quality Assurance	Quality Assurance
9	**Measurement for Payment**	~~Owner Purchase of Material~~
10	**Basis of Payment**	~~Designated Sources Requirements~~

OPSS.PROV 950

- Aligned language with OPSS 905 (Steel Reinforcement for Concrete)
- Updates from recent standards (e.g., CSA S807-19)
- No more references to steel standards
- Separate construction requirements from 999S02
- Permissible damage limits / standard repair method

950.02 REFERENCES

This specification refers to the following standards, specifications, or publications:

Ontario Provincial Standard Specifications, Material

OPSS 1640 Glass Fibre Reinforced Polymer (GFRP) Reinforcement for Concrete

Ontario Ministry of Transportation Publications

Guidelines for Inspection and Acceptance of Glass Fibre Reinforced Polymer (GFRP) Reinforcing Bars, September 2022

950.07.07 Bar Defects, Deficiencies and Damage

950.07.07.01 General

All bars shall be inspected for any defects and deficiencies up to the date of completion of the placement of concrete.

Any damage to a bar resulting in visible fibres, other than at cut ends; or any cut or defect greater than 0.7 mm deep for bars of size 15 or less and 1.0 mm deep for larger bars shall be cause for rejection and the bar shall not be incorporated into the Work.

950.07.07.02 Repair of Bar Defects, Deficiencies and Damage

All visible damage to the bars exceeding 2% of the surface area per 300 mm length of bar (2% x circumference of bar x 300 mm) and not resulting in rejection by the Contract Administrator shall be repaired by lap splice of a new bar adjacent to the damaged portion. The appropriate lap length shall be provided on either side of the damage according to the Contract Administrator.

OPSS.PROV 1640

- Number selected to mirror steel (1440). Aligned language with OPSS 1440.
- Updates from recent standards (e.g., CSA S807-19)
- Only reference to steel is RSIC Manual for tolerances
- Separate material/fabrication requirements from 999S02
- Bent/Anchor bar identification by paint and tags

1640.07.03.02 Spirals, Bent and Anchor Headed Bars

1640.07.03.02.01 General

Where it is not practical to stamp spirals, bent or anchor headed bars, they may be identified with bar tags and paint.

1640.07.03.02.02 Bent and Anchor Headed Bar Tags

Bar tags shall contain information according to the Identification subsection, the identifiable paint marking colour code, and include the shape description. Tags shall be maintained legible and clearly visible on the bars until the bars are placed in the structural component.

1640.07.03.02.03 Paint Marking

The paint used to mark the bars shall not have any detrimental effects on the bars. The paint shall be durable to maintain legibility within a construction environment and be both insoluble in water and resistant to ultraviolet (UV) degradation and discolouring.

Each sublot shall be identified by a colour according to AMS-STD-595A that can be easily distinguished from other sublots and the bar's own colour. The colour shall be applied to each bar tag, and both ends of all bars in the sublot. Sublot colour shall be identified in the GFRP quality control report.

NSERC CRSNG MIAMI FDOT

What isn't covered? / Future Need

- **Post-installed adhesive anchorages**
  - Interested in 'dowels'; MTO has conducted and collaborated in some research, but not fast enough to keep up with the state of practice for steel
  - Anticipated future is qualified systems which will need a partnership between adhesive and FRP bar manufacturer; e.g., ACI 355.4, ICC-ES AC308 system qualification
  - Design criteria

TMU

GFRP Field Inspection Guidelines

- Replaces previous versions which were intended for Quality Assurance (QA) staff
- Formal publication posted to MTO Technical Publications (gov.on.ca)
- Additional examples of acceptable and not acceptable product condition

Ontario

Ministry of Transportation
Standards and Contracts Branch
Structures Office Report

Guidelines for Inspection and Field Acceptance of Glass Fibre Reinforced Polymer (GFRP) Reinforcing Bars

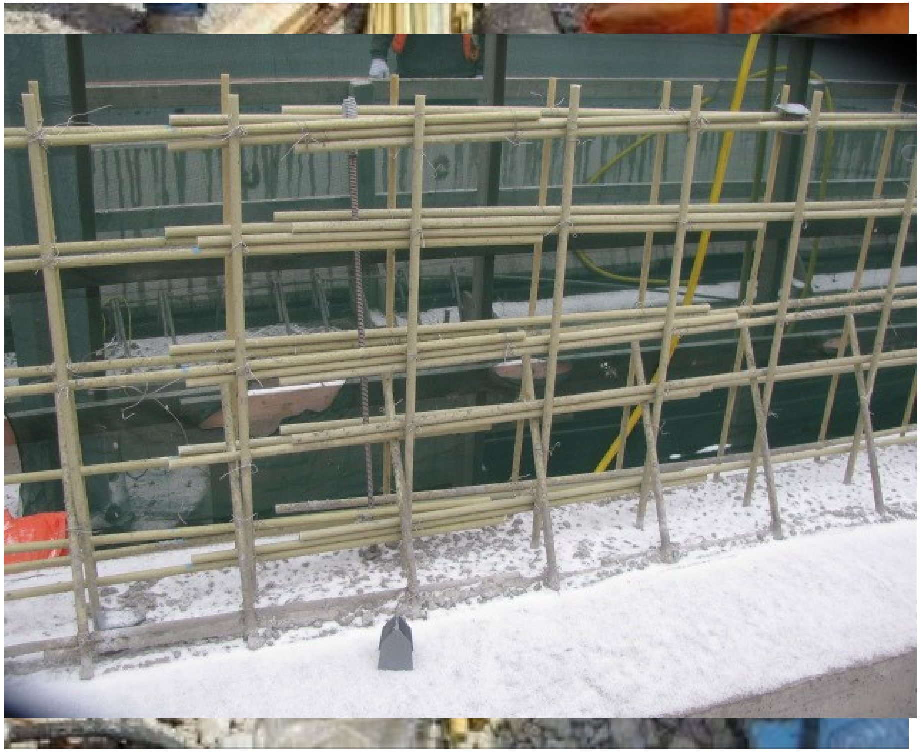
What isn't covered? / Future Need

- Storage on site. How much UV exposure is acceptable without additives?

HIIFP with University of Waterloo to investigate common construction snags

- Sandblasting components near installed bars (e.g., concrete joints typically at barriers, expansion joints, staged construction)
- Contaminants (concrete spatter, form oils/grease, etc.)

UNIVERSITY OF WATERLOO | FACULTY OF ENGINEERING



NSERC CRSNG MIAMI FDOT

FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

"Advances in concrete reinforcement"

August 8-9, 2024 - Toronto, Ontario

GFRP Qualification Testing for Acceptance of Qualified Suppliers

Erum Mohsin, Lead Bridge Engineer

Martin Krall, Senior Bridge Engineer

Ministry of Transportation, Ontario

SPONSORED BY:

MTO Qualification

The MTO lists pre-qualified products (suppliers) on its Designated Sources for Materials (DSM) list

- For use on MTO highway construction and maintenance contracts
- Reduces risks for products that may involve time-consuming and/or expensive testing
- Increases confidence that supplied product will be as specified in the construction contract
  - Product Acceptance/Approval is done at site on a per-project basis through QA testing

Qualification is:

- Proof of capability of production of a product to specific standards and from the specific facility listed on the DSM
- A baseline for later comparison with routine project testing
- Continuous monitoring of product quality and checks
- Suppliers to adhere to the qualification criteria for which approval is granted

Qualification Overview

Qualification of GFRP bars is:

- Described in MTO's "DSM Structural Division Criteria for Approval" document
  - Requires facilities to have ISO 9001 certification
- Done to testing described in:
  - CSA S807 "Specification for fibre-reinforced polymers"
  - MTO's active GFRP material specification: OPSS 1640
- Done to visual quality criteria described in:
  - MTO's "Guidelines for Inspection and Field Acceptance of Glass Fibre Reinforced Polymer (GFRP) Reinforcing Bars", September 2022
  - MTO's active GFRP construction specification: OPSS 950

Qualification Testing

Qualification of GFRP bars requires a lot of testing

- One grade of typical sizes of straight and bent bars tests 23 different properties using ~2130 individual specimens
  - 6 properties use conditioned specimens (thermal, alkali, etc.)
  - 8 require long-term commitments (creep-rupture, water absorption to saturation, most conditioned specimens)
  - Straight sizes: 13, 15, 20, 25 (+340 Specimens for size 10)
  - Bent sizes: 15, 20 and (+340 specimens for size 25)
- Testing done by approved 3rd party laboratories
- Suppliers become qualified within 1 to 3 years
  - Done in stages; occasional product revision and re-testing

Qualification Testing Review

MTO reviews qualification submissions for "completeness" and "correctness"

- Completeness:
  - All required properties & samples (No. of specimens, production lots, etc.)
  - All "products" (straight, bent, anchor head, grades, etc.)
- Correctness:
  - Proper test methods used
  - Results are reported correctly
  - Calculations performed correctly with appropriate parameters
  - Limits and standard values are calculated/reported/used correctly
  - Results meet the limits
- Other rational checks
  - Does it make sense, is it realistic, is it consistent?

MTO Qualified Products

In General

Current DSM is:

- only Grade III, high durability (D1) GFRP Bars
- No other FRPs
- No other grades

Previous Qualifications

- Included Grade I
- Up to 7 suppliers

MTO's Current DSM Suppliers

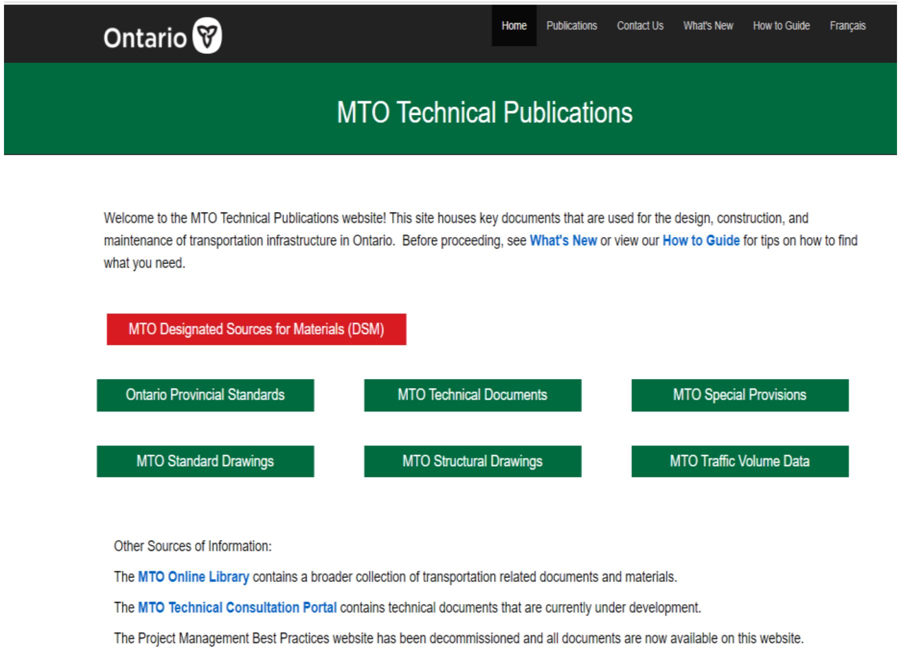
MST Rebar Inc.

- Straight, bent, anchor headed

Pultrall Inc.

- Straight, bent, anchor headed

MTO Qualified Products



- https://www.library.mto.gov.on.ca/SydneyPLUS/TechPubs/Portal/tp/TechnicalPublications.aspx

THANK YOU

Quebec's current practice for the use of FRP reinforcement in road infrastructure

4th International Workshop on FRP Bars for Concrete Structures
August 8th, 2024

Marc-Antoine Loranger, Eng.
Ministère des Transports et de la Mobilité durable (MTMD)

Votre gouvernement

Québec

Presentation outline

- MTMD Current Applications
- Qualification of GFRP Bars
- Conclusions & Focus Areas for the Future

MTMD current applications

Internal reinforcement of bridge deck slabs

Products

- Straight and bent GFRP bars.
  - Compliant with CSA S807 and MTMD 15101.

Application

- Top transverse and longitudinal reinforcement mats only.
- Single-span bridges not located on the Strategic network (RSSCE).
- Structures Office needs to be consulted before project preparation.
- Numerous projects completed.
- Expected lifespan > 75 years.

P-02164, Saint-Léon-de-Standon, 2019

Votre gouvernement

MTMD current applications

Barrier walls

Products

- Straight, anchor-headed and bent GFRP bars.
  - Compliant with CSA S807 and MTMD 15101.

Application

- Alternative to galvanized steel reinforcement.
  - Types 201 et 201M → straight and bent bars.
  - Types 301, 301M et 311B → straight bars with and without anchor heads.
- Structures Office needs to be consulted before project preparation.
- Numerous projects completed.
- Very relevant application.
- Expected lifespan > 75 years.

P-15590, Québec, 2016

MTMD current applications

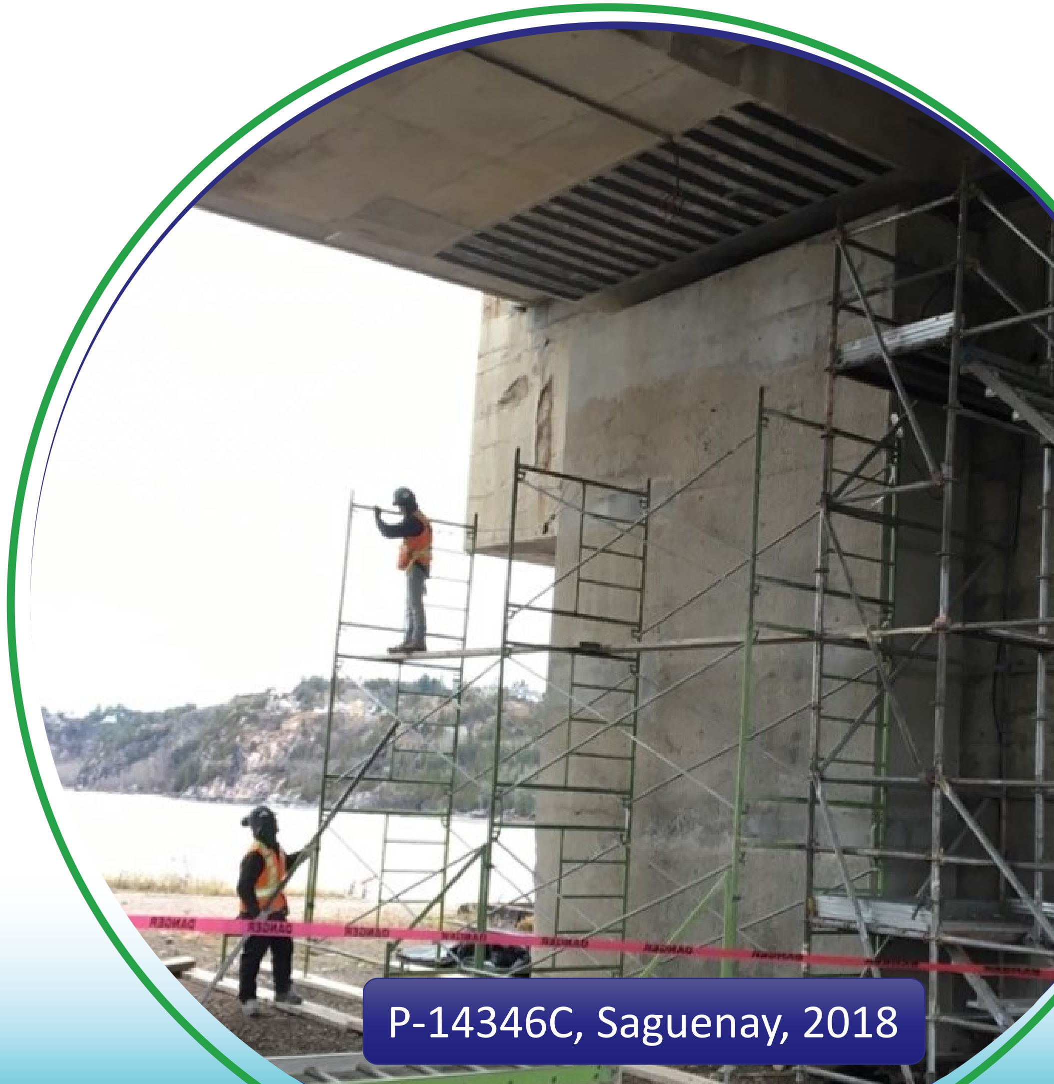
External reinforcement of concrete members

Products

- Wet layup composite systems (GFRP, CFRP) and pre-cured CFRP plates.
  - Compliant with CSA S808.

Application

- Structural intervention.
  - Shear reinforcement.
  - Flexural reinforcement.
- Structures Office needs to be consulted before project preparation.
- Standard specifications have been developed by the Structures office.



P-14346C, Saguenay, 2018

MTMD current applications

Homologated retaining walls

Products

- Straight GFRP bars.
  - Compliant with CSA S807 and MTMD 15101.

Application

- Reinforced concrete walls.
  - Alternative to steel reinforcement.
- A few pilot projects completed.
- Use of GFRP added to our 2024 Retaining Wall Certification Program.

P-19996, Saint-Fulgence, 2023

MTMD current applications

Concrete pavements

Jointed plain concrete pavement (JPCP)

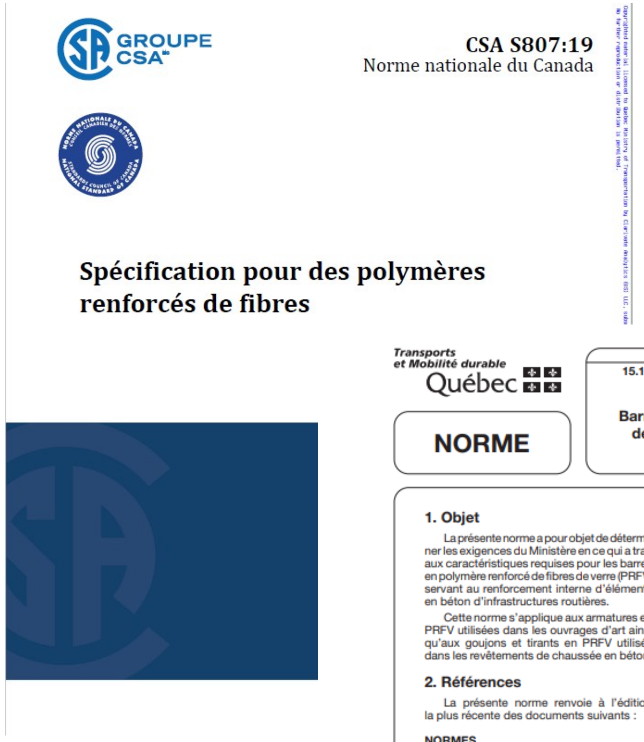
- GFRP tie rods and dowels.
  - Compliant with CSA S807 and MTMD 15101.
- Test sections on highways since 2008.
  - Long-term behavior monitoring.
- Now regulated since 2024 by the Ministry's Specifications (CCDG).
  - Choice between GFRP or steel bars left to the contractor.

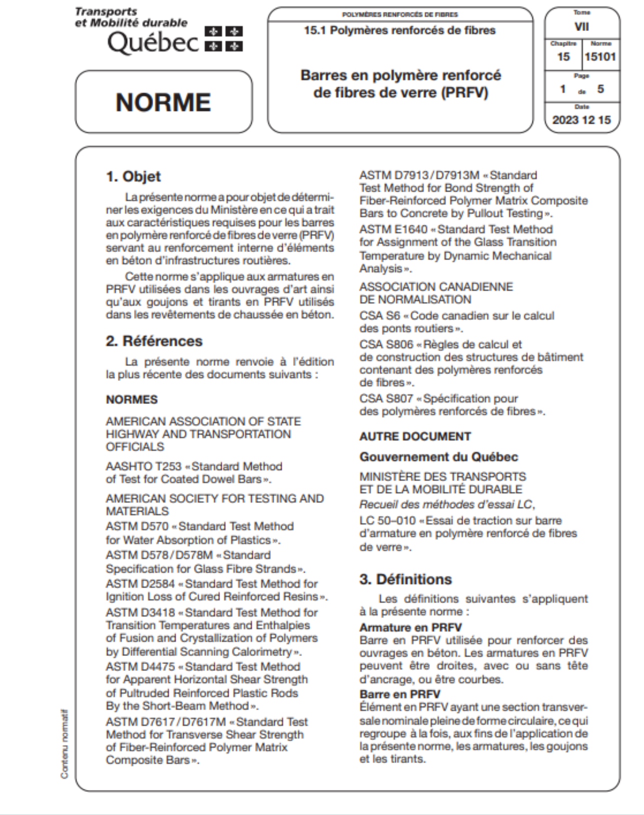
Continuously reinforced concrete pavement (CRCP)

- Test sections on highways since 2006.
- Ongoing research project with Université de Sherbrooke (UdS) to optimize design.

Qualification of GFRP bars

- MTMD qualification of GFRP bars is based on :
  - CSA S807;
  - MTMD 15101 (GFRP Bars Specification).
- Samples needed for in-house testing.
  - Fully equipped laboratory to assess the performance and quality of GFRP materials.
  - Able to conduct all the owner's QA tests required by CSA S807.





Transports et Mobilité durable Québec

NORME

POLYMÈRES RENFORCÉS DE FIBRES

15.1 Polymères renforcés de fibres

Barres en polymère renforcé de fibres de verre (PRFV)

Tome VII | Chapitre 15 | Norme 15101 | Page 1 de 5 | Date 2023 12 15

1. Objet

La présente norme a pour objet de déterminer les exigences du Ministère en ce qui a trait aux caractéristiques requises pour les barres en polymère renforcé de fibres de verre (PRFV) servant au renforcement interne d'éléments en béton d'infrastructures routières.

Cette norme s'applique aux armatures en PRFV utilisées dans les ouvrages d'art ainsi qu'aux goujons et tirants en PRFV utilisés dans les revêtements de chaussée en béton.

2. Références

La présente norme renvoie à l'édition la plus récente des documents suivants :

NORMES

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

AASHTO T253 « Standard Method of Test for Coated Dowel Bars ».

AMERICAN SOCIETY FOR TESTING AND MATERIALS

ASTM D570 « Standard Test Method for Water Absorption of Plastics ».

ASTM D578/D578M « Standard Specification for Glass Fibre Strands ».

ASTM D2584 « Standard Test Method for Ignition Loss of Cured Reinforced Resins ».

ASTM D3418 « Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry ».

ASTM D4475 « Standard Test Method for Apparent Horizontal Shear Strength of Pultruded Reinforced Plastic Rods By the Short-Beam Method ».

ASTM D7617/D7617M « Standard Test Method for Transverse Shear Strength of Fiber-Reinforced Polymer Matrix Composite Bars ».

ASTM D7913/D7913M « Standard Test Method for Bond Strength of Fiber-Reinforced Polymer Matrix Composite Bars to Concrete by Pullout Testing ».

ASTM E1640 « Standard Test Method for Assignment of the Glass Transition Temperature by Dynamic Mechanical Analysis ».

ASSOCIATION CANADIENNE DE NORMALISATION

CSA S6 « Code canadien sur le calcul des ponts routiers ».

CSA S806 « Règles de calcul et de construction des structures de bâtiment contenant des polymères renforcés de fibres ».

CSA S807 « Spécification pour des polymères renforcés de fibres ».

AUTRE DOCUMENT

Gouvernement du Québec

MINISTÈRE DES TRANSPORTS ET DE LA MOBILITÉ DURABLE

Recueil des méthodes d'essai LC,

LC 50–010 « Essai de traction sur barre d'armature en polymère renforcé de fibres de verre ».

3. Définitions

Les définitions suivantes s'appliquent à la présente norme :

Armature en PRFV
Barre en PRFV utilisée pour renforcer des ouvrages en béton. Les armatures en PRFV peuvent être droites, avec ou sans tête d'ancrage, ou être courbes.

Barre en PRFV
Élément en PRFV ayant une section transversale nominale pleine de forme circulaire, ce qui regroupe à la fois, aux fins de l'application de la présente norme, les armatures, les goujons et les tirants.

Contenu normatif

Conclusions

So far...

- Satisfactory in-service performance.
- Well-regulated and standardized use.

Focus areas for the future

- Consider the use of FRP bars for other relevant applications.
- Repair techniques for GFRP bars.
- Training for laboratories and practising engineers.
- More environmentally friendly FRP bars (local, recyclable, or reusable materials).

Votre gouvernement

Questions

Contact me

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Votre gouvernement

Québec

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

SPONSORED BY:

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

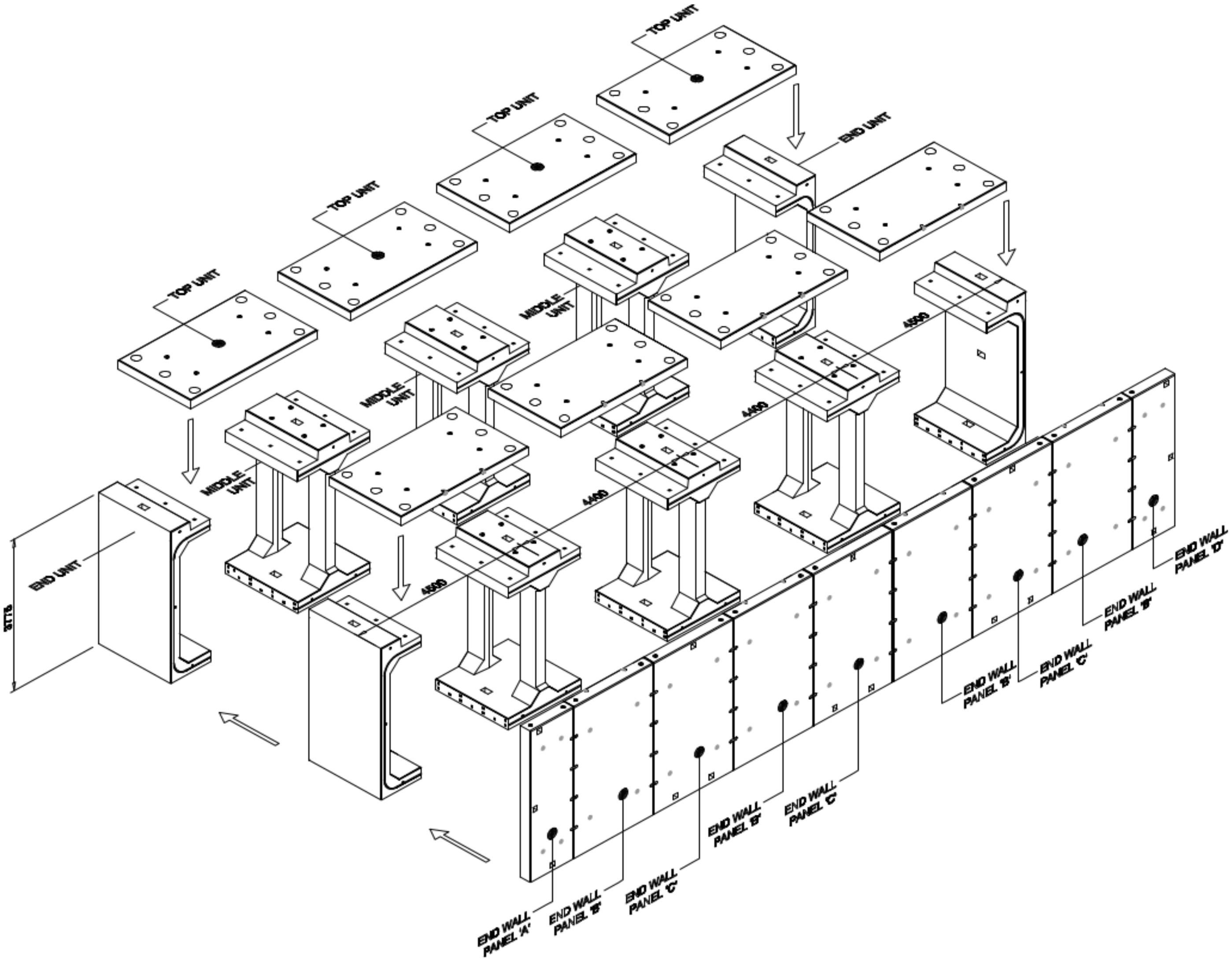
UNIVERSITY OF MIAMI

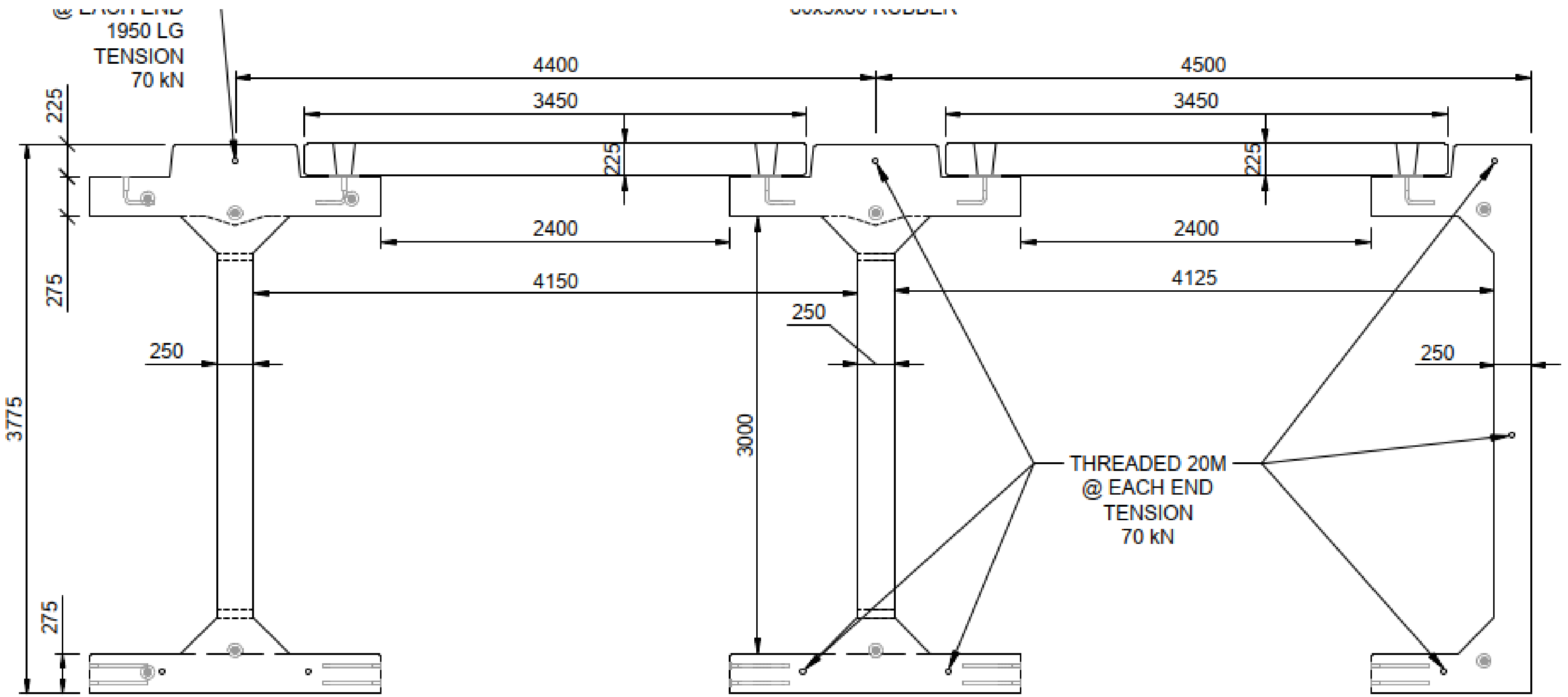
Center for Integration of Composites into Infrastructure

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'



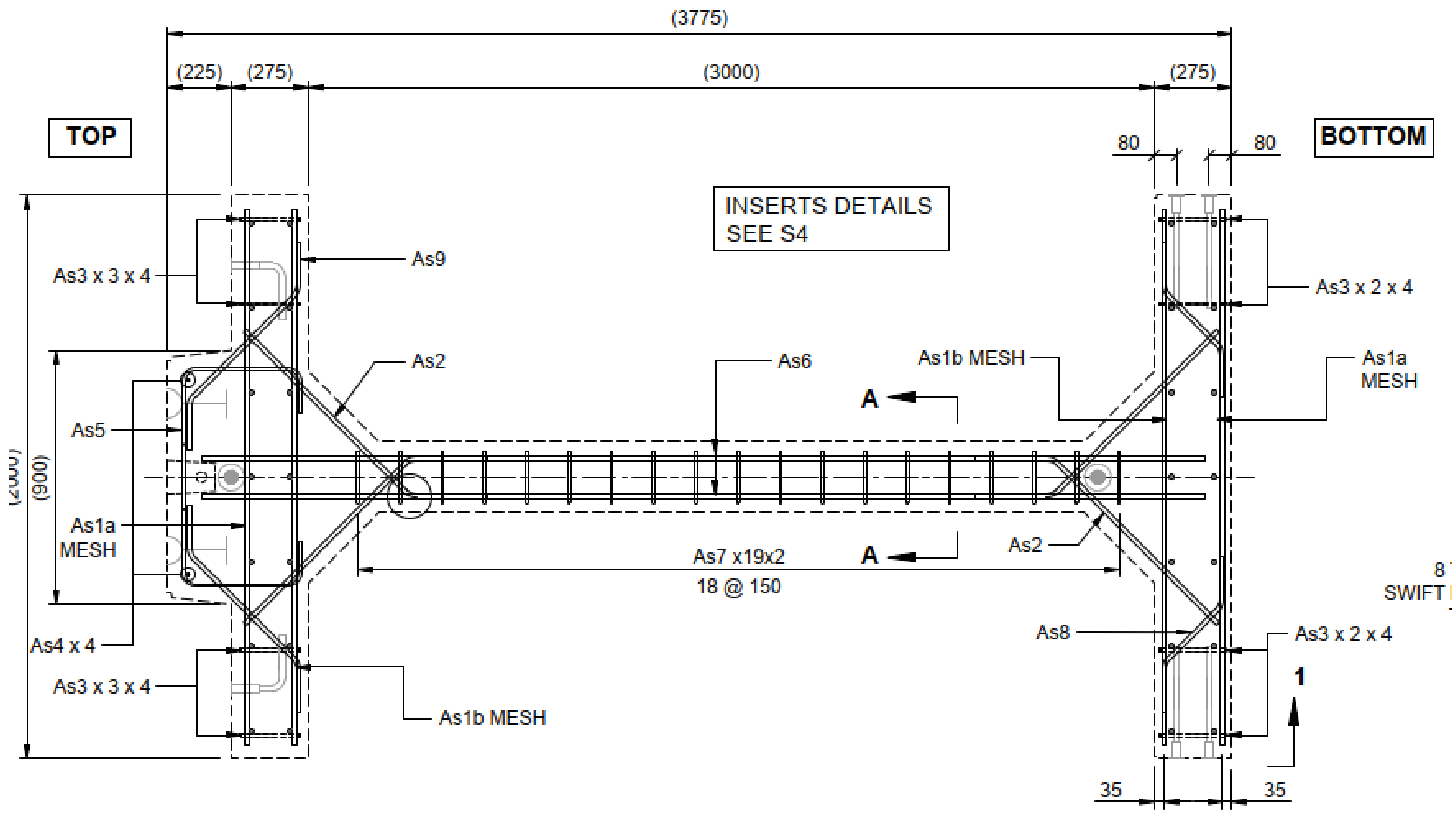
TYPICAL UNIT CONNECTION
SCALE 1:50

Design challenges

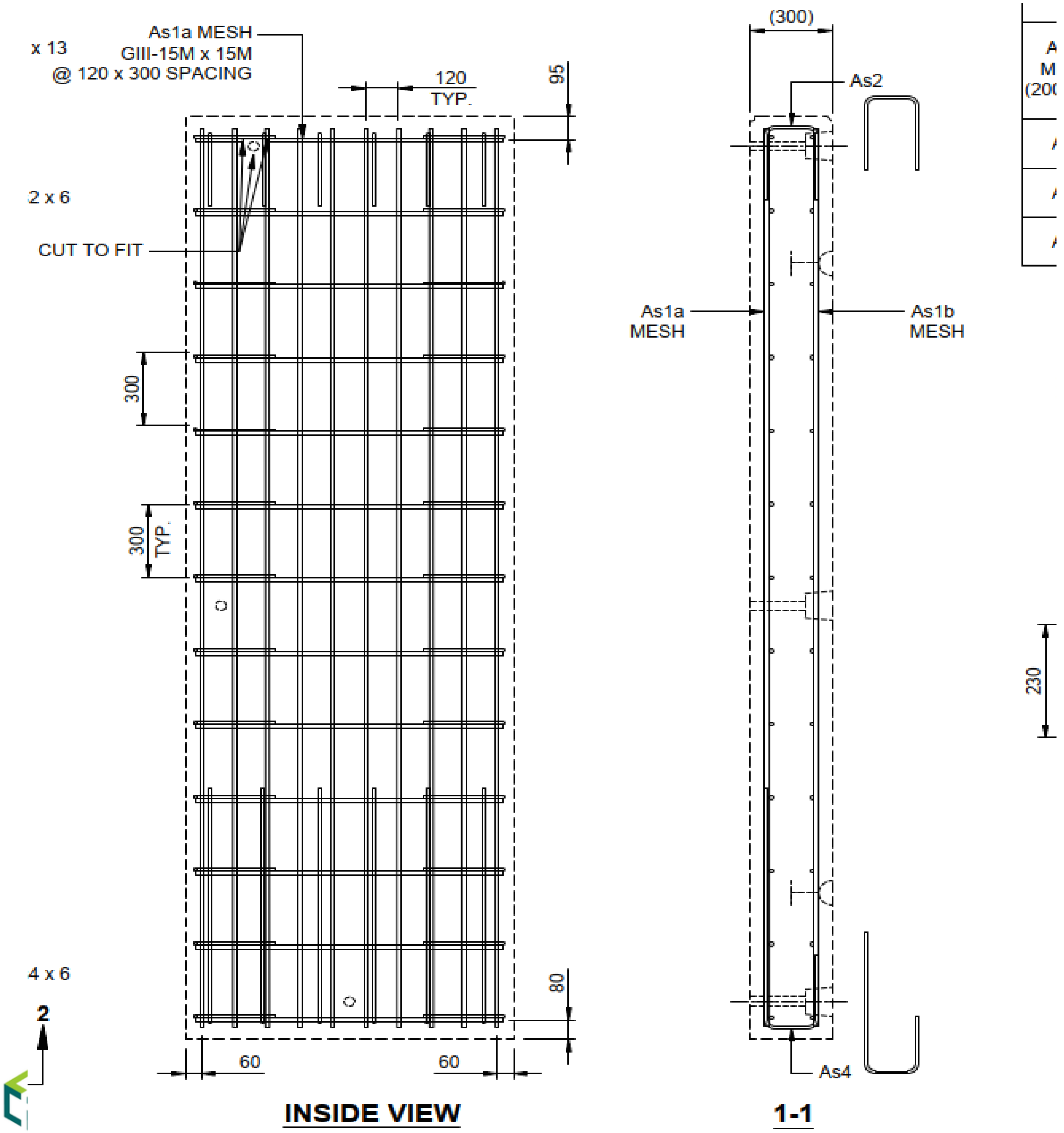
- Design for worst case with 3.5m of fill on top
- Current provisions for shear according to CSA S806 impose a significant reduction in Vc compared with steel
- Due to high sustained load, need to limit SLS stress to 25% Fu
- Top slab only 225mm thick sustains very high shear
- Supporting corbel designed 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
As3 x 2 x 4
As4 x 4
As3 x 3 x 4
1
As1b MESH
35
35

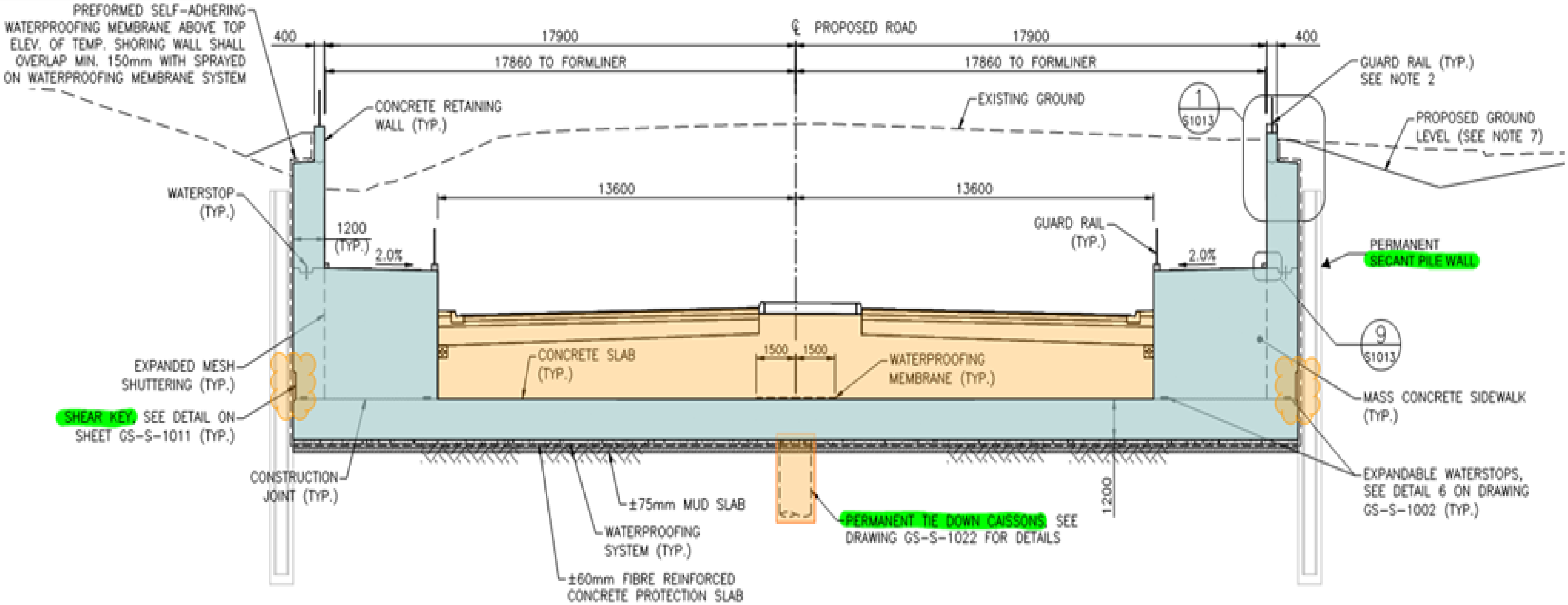
PLAN VIEW


As1a MESH
x 13
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
CONCRETE SLAB (TYP.)
1500
1500
WATERPROOFING MEMBRANE (TYP.)
9 S1013
EXPANDED MESH SHUTTERING (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.

$$A_{frp} = (400 / 60000)\ A_g$$
$$= 0.0067\ A_g$$

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 **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.

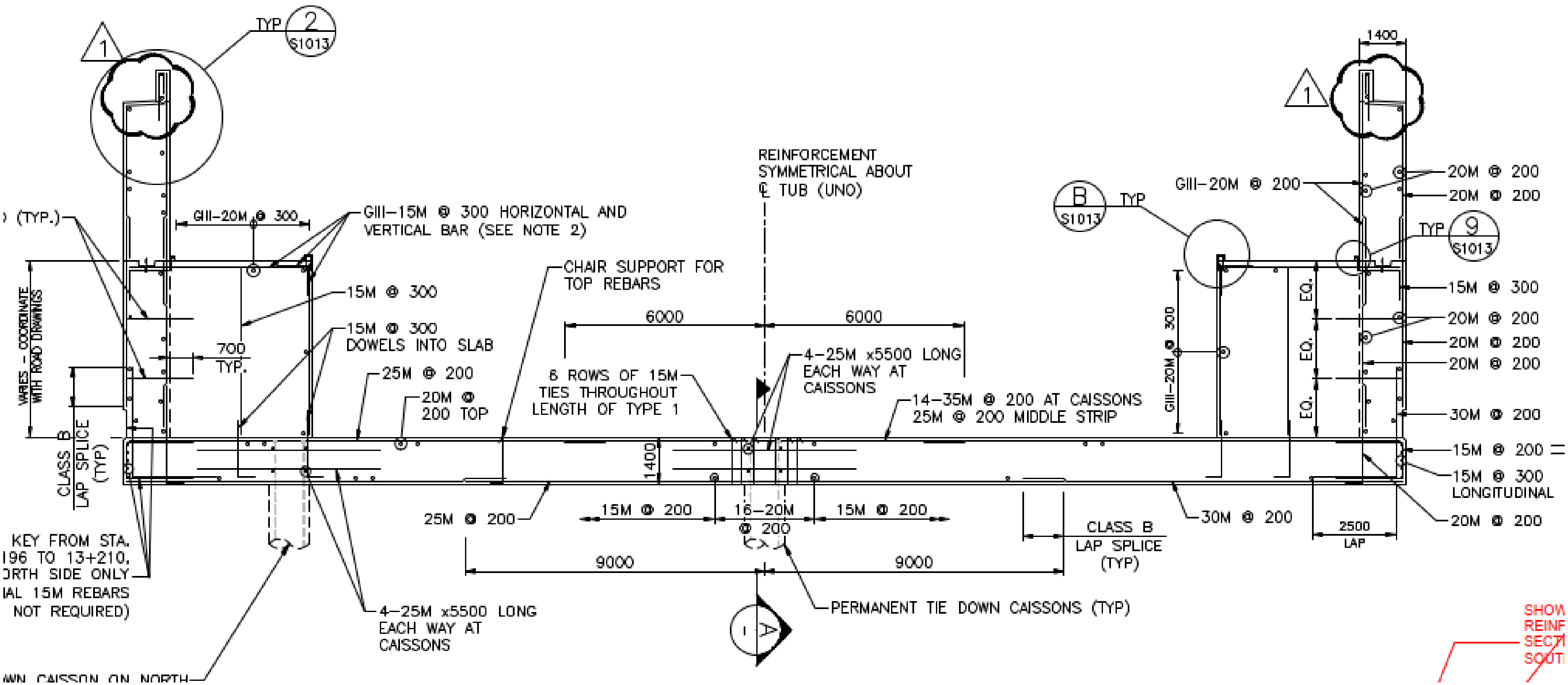
TABLE 7.12.2.1—MINIMUM SHRINKAGE AND TEMPERATURE REINFORCEMENT

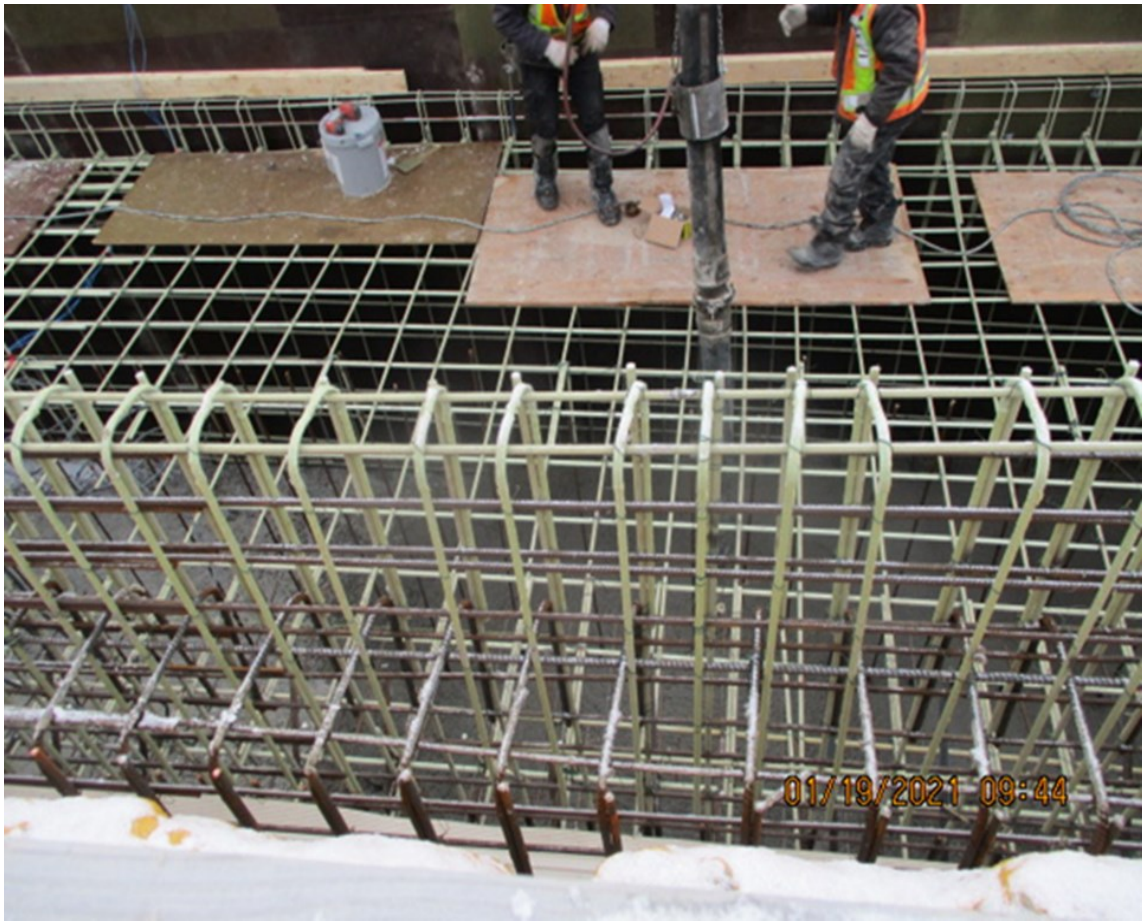
Length between movement joints, ft	Minimum shrinkage and temperature reinforcement ratio	
	Grade 40	Grade 60
Less than 20	0.0030	0.0030
20 to less than 30	0.0040	0.0030
30 to less than 40	0.0050	0.0040
40 and greater	0.0060*	0.0050*

*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
1
GIII-20M @ 300
GIII-15M @ 300 HORIZONTAL AND VERTICAL BAR (SEE NOTE 2)
15M @ 300
15M @ 300 DOWELS INTO SLAB
700 TYP.
25M @ 200
20M @ 200 TOP
CHAIR SUPPORT FOR TOP REBARS
6000
6000
REINFORCEMENT SYMMETRICAL ABOUT ℄ TUB (UNO)
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
1400
20M @ 200
20M @ 200
TYP 9 S1013
15M @ 300
20M @ 200
20M @ 200
20M @ 200
30M @ 200
15M @ 200
15M @ 300 LONGITUDINAL
20M @ 200
GIII-20M @ 300
EQ.
EQ.
EQ.
VARIES - COORDINATE WITH ROAD DRAWINGS
CLASS B LAP SPLICE (TYP)
1400
25M @ 200
15M @ 200
16-20M @ 200
15M @ 200
30M @ 200
CLASS B LAP SPLICE (TYP)
2500 LAP
9000
9000
PERMANENT TIE DOWN CAISSONS (TYP)
4-25M x5500 LONG EACH WAY AT CAISSONS
A
(TYP.)
KEY FROM STA. 196 TO 13+210, ORTH SIDE ONLY IAL 15M REBARS NOT REQUIRED)
WN CAISSON ON NORTH

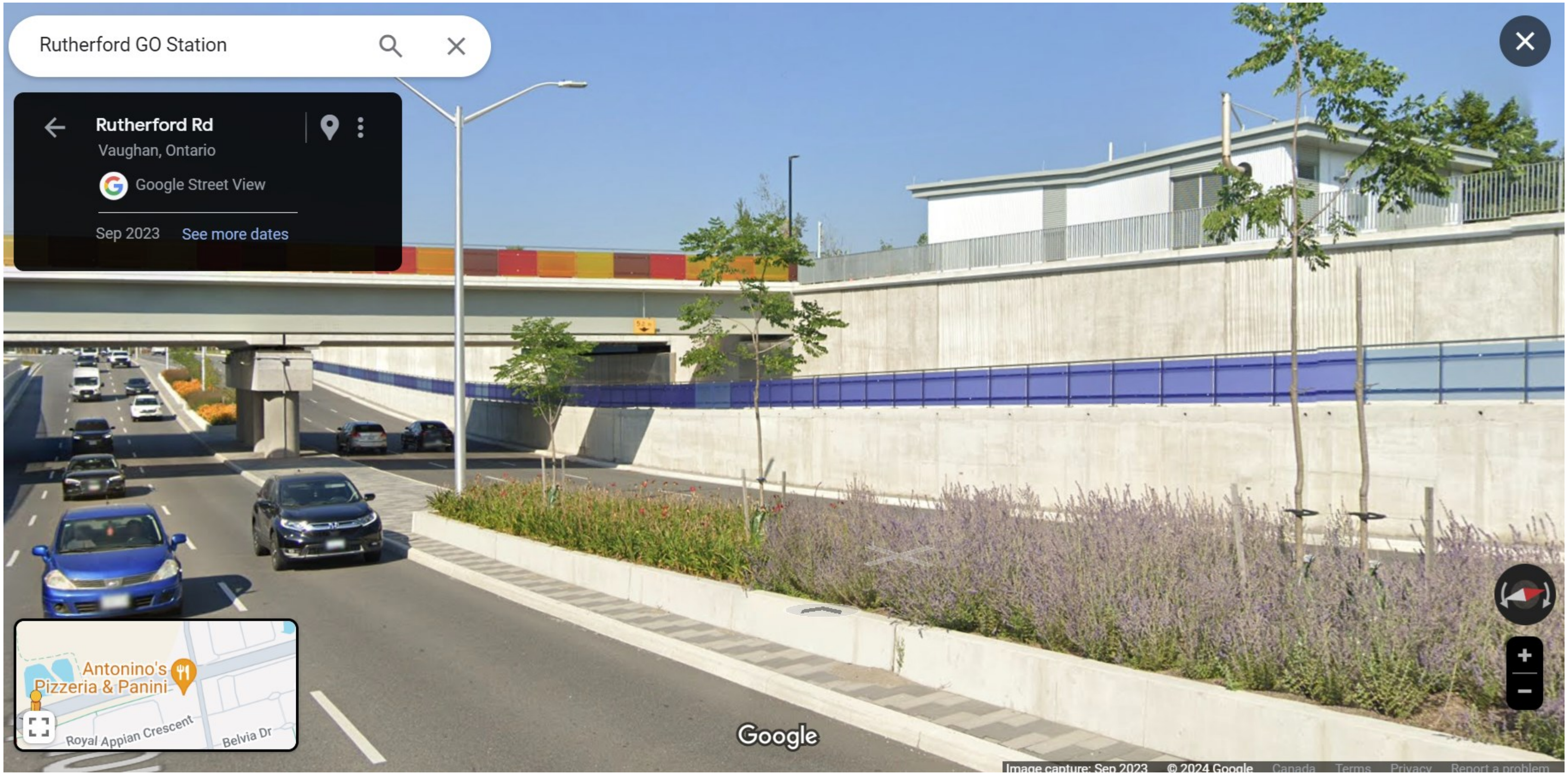


Mass concrete MUP with GFRP reinforcement

-Increase dead weight to counteract buoyancy

-Reduce bending and shear of retaining walls

Final product and observation



FOURTH INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURES

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August 8-9, 2024 - Toronto, Ontario

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

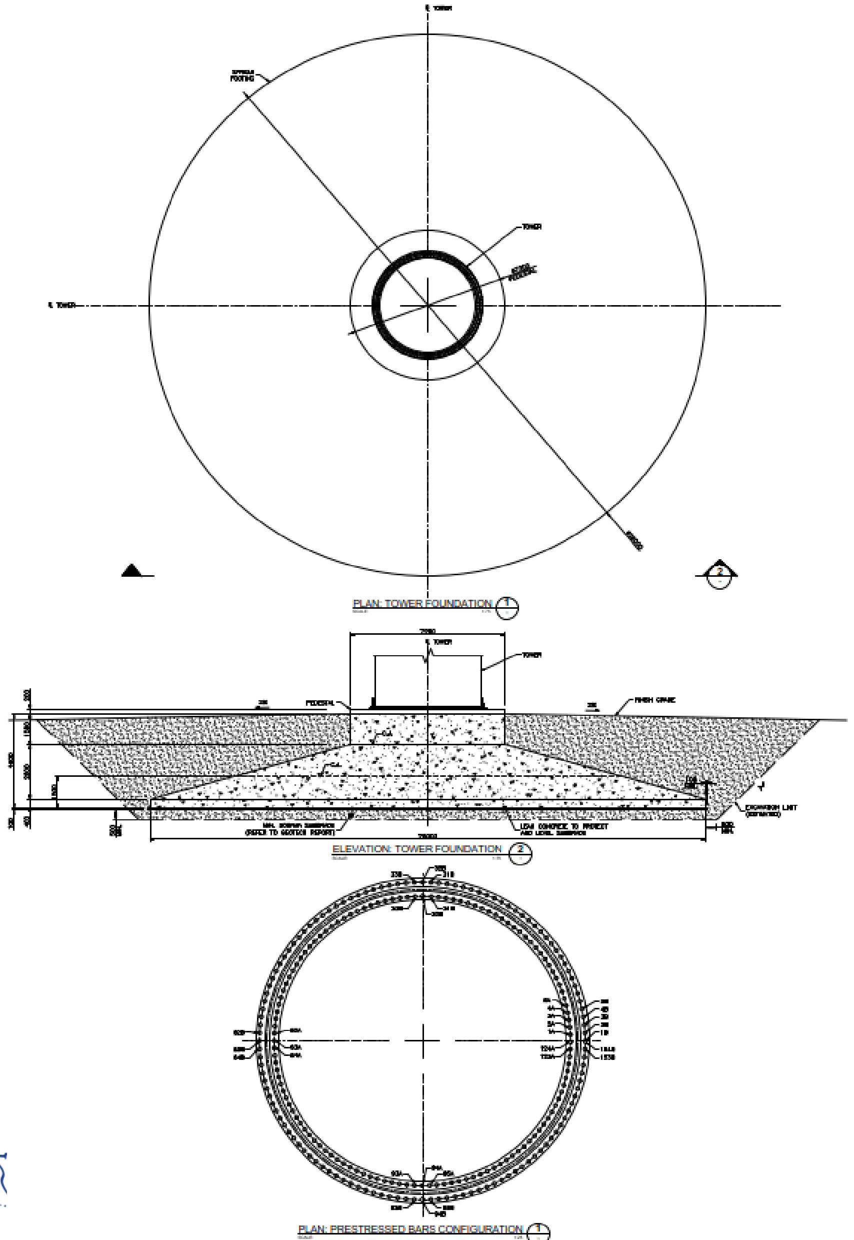
SPONSORED BY:

Wind turbine foundation for NEOM

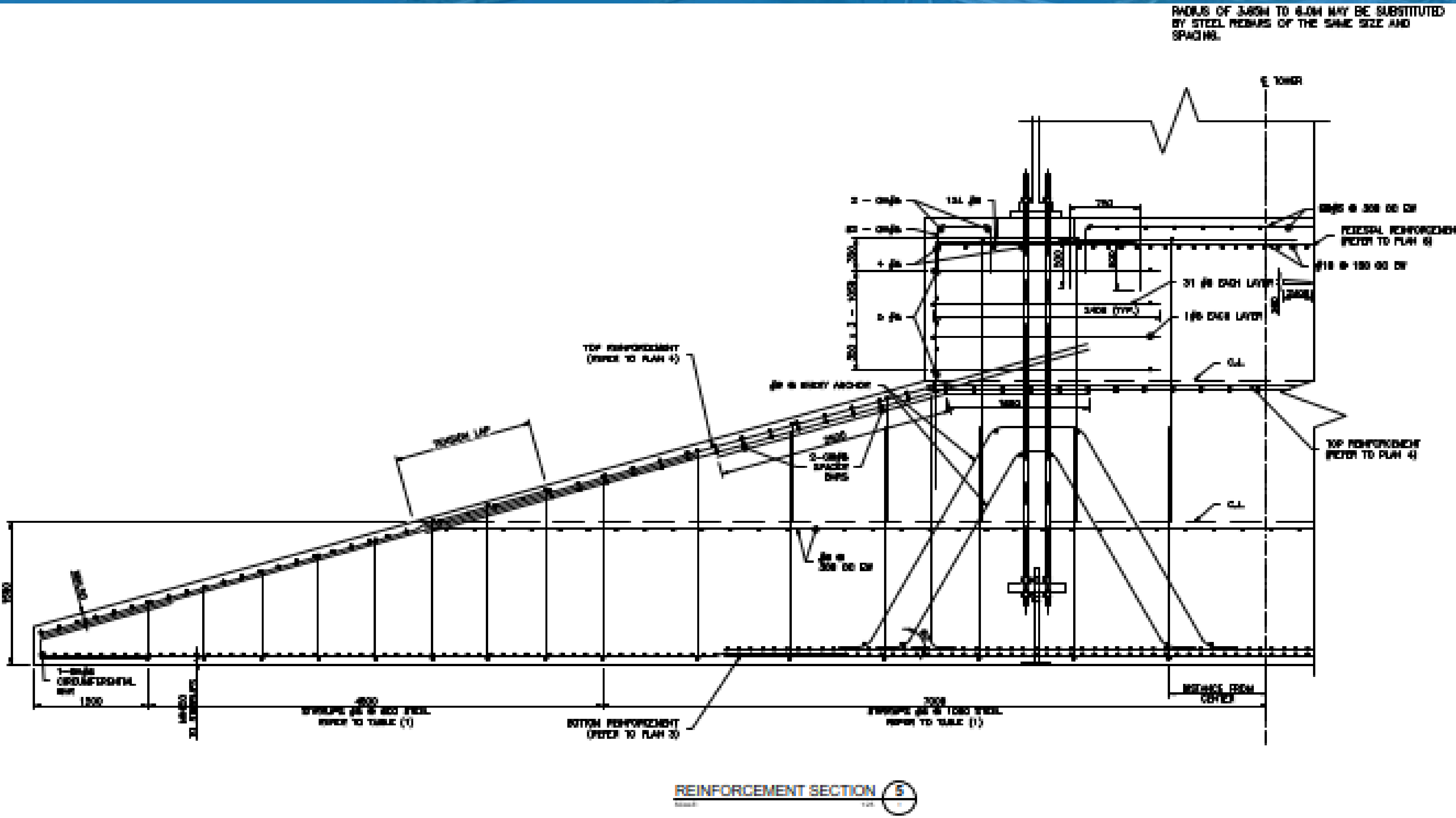
- WSP Canada was retained by NEOM to carry out a feasibility study on the use of GFRP reinforcement for wind turbine foundations, and if found feasible, develop a pilot design.
- Project objectives:
  - Use of green technologies
  - Maximize use of local resources
  - Availability and development of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



NSERC CRSNG
MIAMI
FDOT

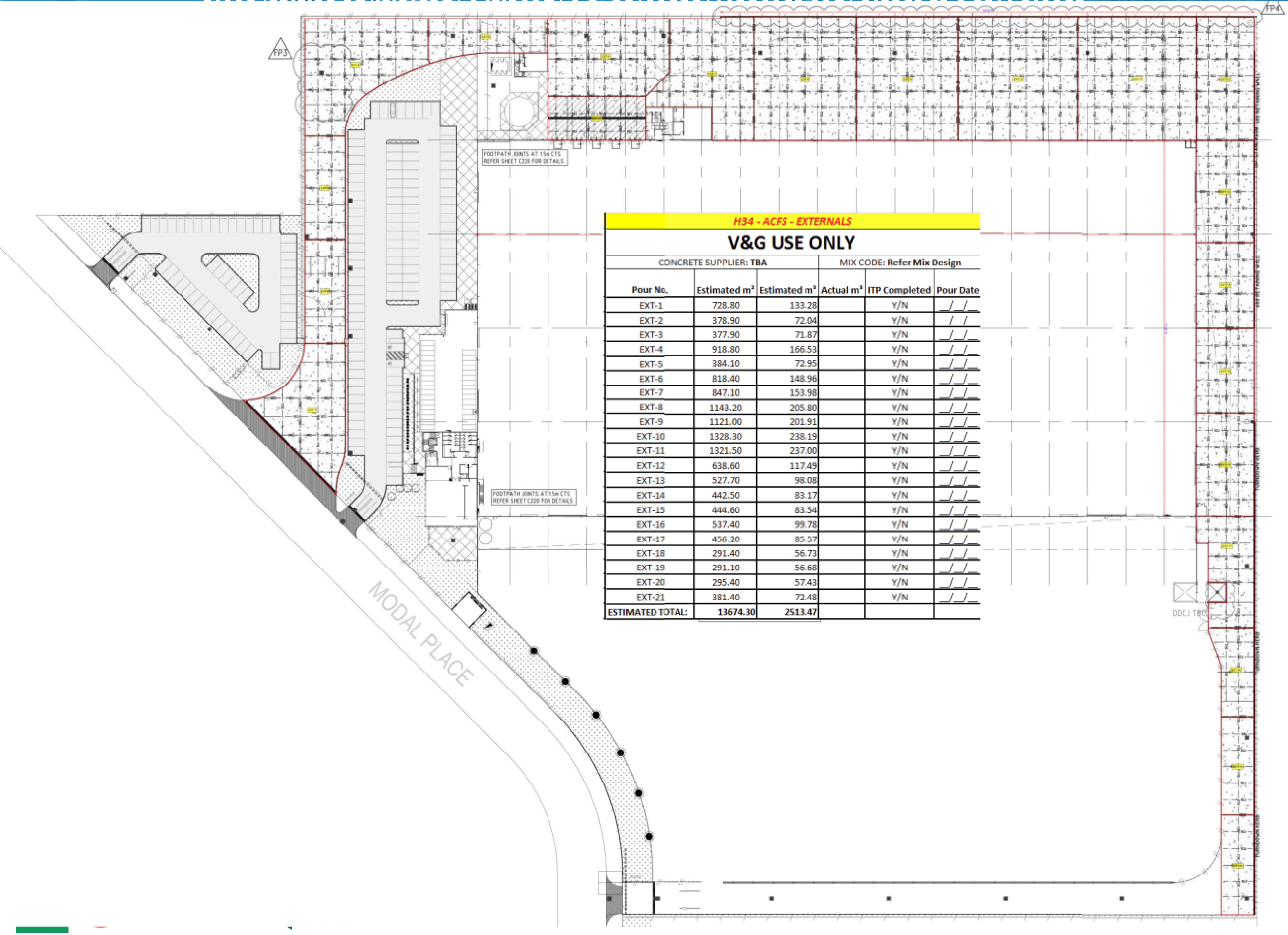

REINFORCEMENT SECTION
5
TOP REINFORCEMENT (REFER TO PLAN 4)
BOTTOM REINFORCEMENT (REFER TO PLAN 3)
C.L.
1500
4800
7000
750
DISTANCE FROM CENTER


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

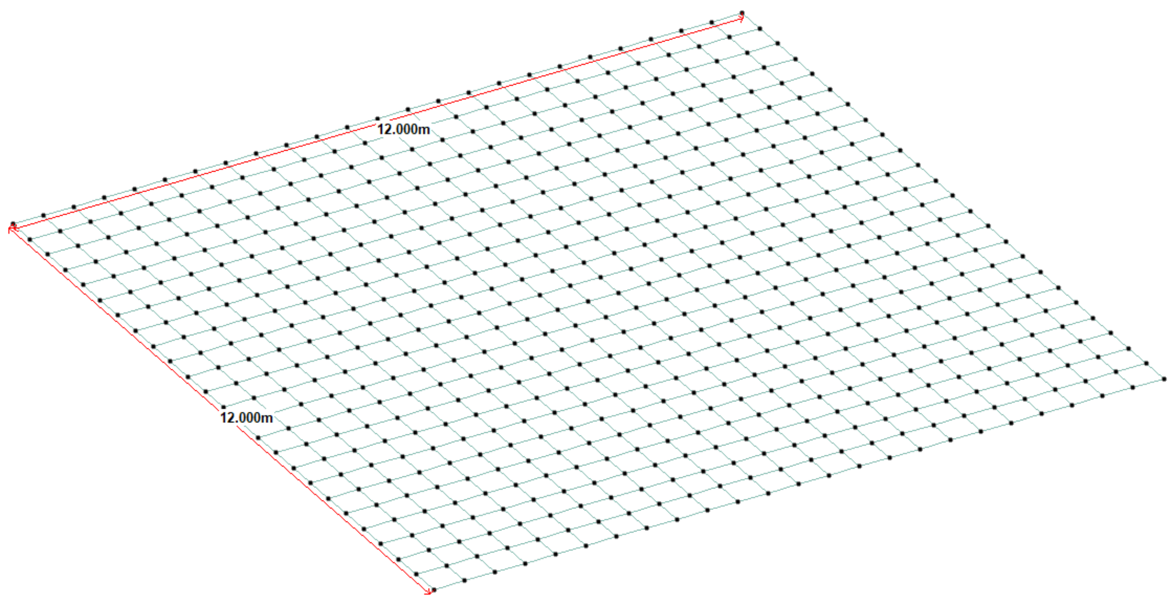
Pour No.	Estimated m²	Estimated m³	Actual m³	ITP Completed	Pour Date
EXT-1	728.80	133.28		Y/N	__/__/__
EXT-2	378.90	72.04		Y/N	__/__/__
EXT-3	377.90	71.87		Y/N	__/__/__
EXT-4	918.80	166.53		Y/N	__/__/__
EXT-5	384.10	72.95		Y/N	__/__/__
EXT-6	818.40	148.96		Y/N	__/__/__
EXT-7	847.10	153.98		Y/N	__/__/__
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			

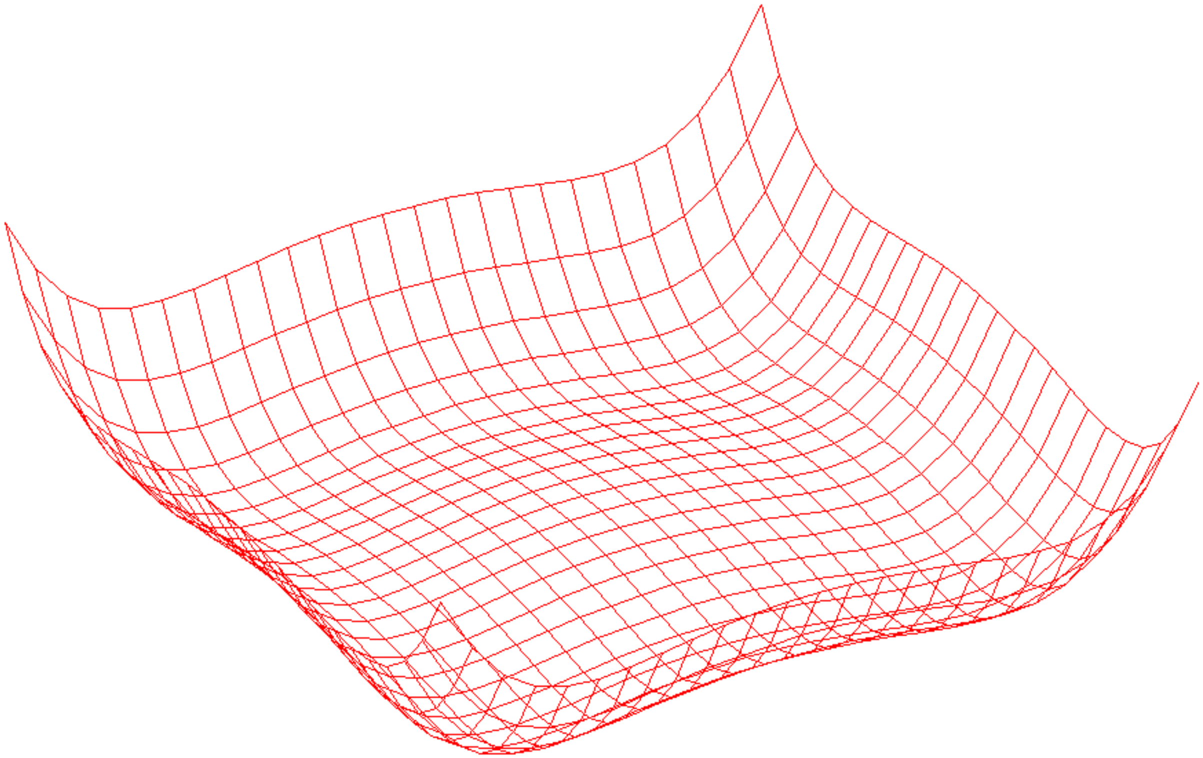
Major design considerations

- 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

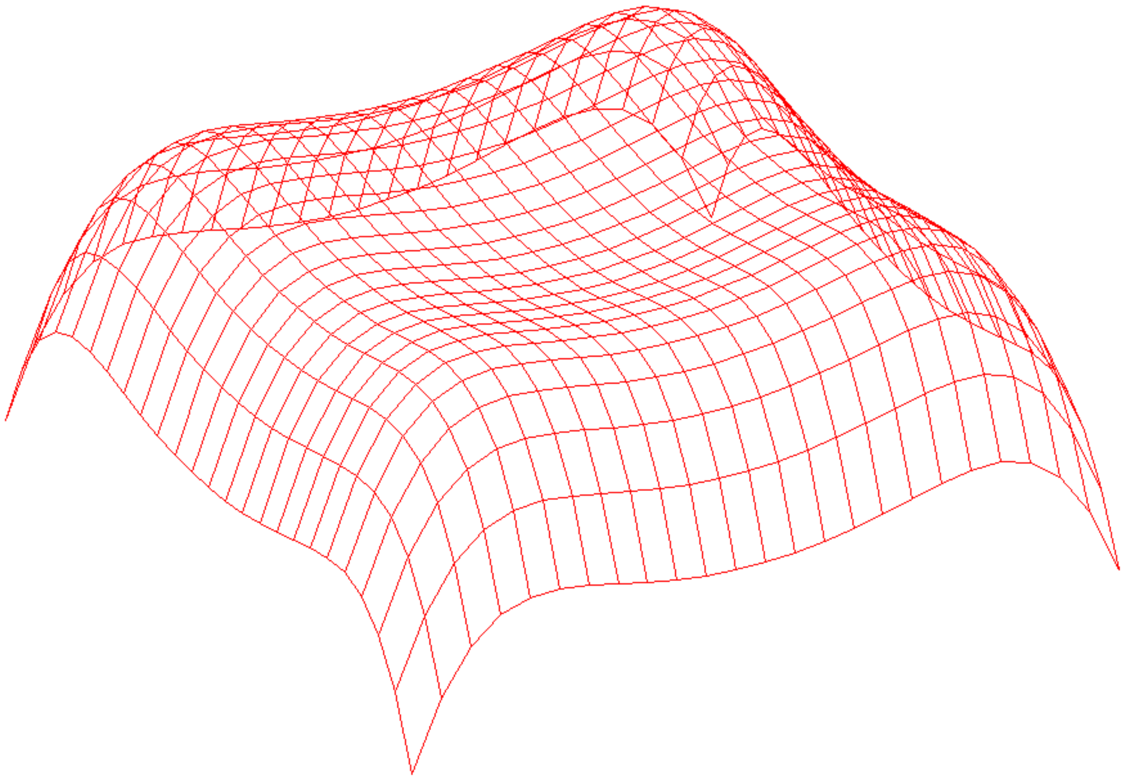
Finite Element Analysis

- 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