Bridge Deck Reinforced with Glass Fiber Reinforced Polymer Bars (GFRP)

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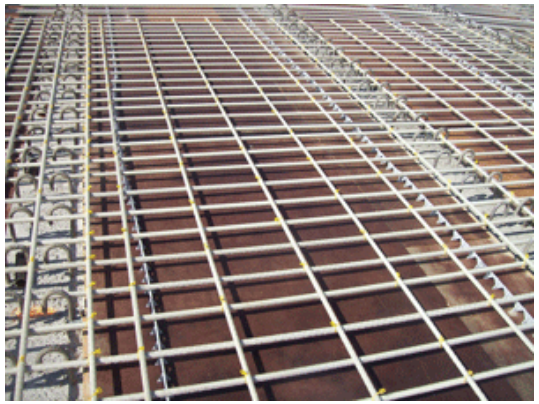
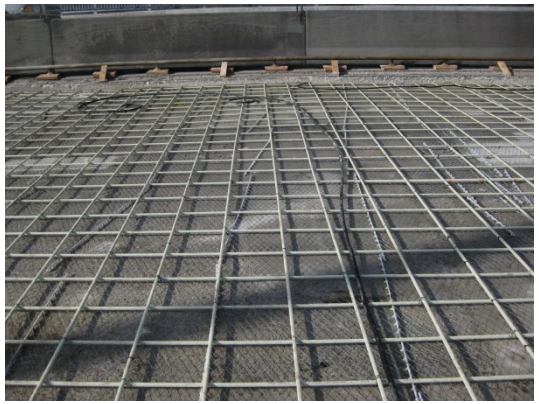
Composites
AN INFINITE WORLD OF POSSIBILITIES

Outline

- GFRP Bars in Ontario: History & Use
- Why GFRP in Bridge deck?
- Durability of GFRP: MTO perspective
- What has changed lately? Product and Market
- GFRP Bars in bridge deck
- Rational design of bridge deck
- What's Next?
- Q&A

» GFRP in Ontario

- ☑ Use of GFRP started in mid 90's
- ☑ Trial projects implemented in 2005
- ☑ CHBDC first adopted GFRP as a primary Rebar in 2006
- ☑ MTO first adopted GFRP as part of corrosion protection policy in 2008


GFRP in Ontario

- MTO has constructed over 400 Bridges with GFRP Including:
  - Precast Deck Panels between girders
  - Cast in place on girders(simply supported or semi-continuous)
  - Pl2/TL4 and PL3/TL5 Barrier walls
  - Topping slab over side by side box girders
  - Stirrups in Precast box girders
  - Overlays and side walks
- Progressed beyond trial stage

Examples of Full GFRP Bridge Decks

- HWY 11/7 CPR Overhead Ouimet
- Third Street Bridge Over the Thames River
- Whiteman's Creek Precast Deck, Hwy 24
- Humber River Bridge Cast-in-place deck, Hwy 401
- Nestor Falls Hwy 71 Precast Deck
- Rainy Lake/Noden Causeway PC Deck
- Chukuni River Bridge Precast Deck Hwy 105
- Ottawa Queensway bridges cast-in-place deck
- Warden Avenue Hwy 401 overlay
- Bonnechere River Bridge cast-in-place exposed, Hwy 60
- Nipigon River Bridge

» Why GFRP in Bridge Deck?

- **Lighter**
  - More rebar on a truck (4x)
  - Less back injury and workers don't tire out by the end of the week
  - Faster schedule
  - Less than half manpower
  - **Greener World!**

**Greener Word: Less Carbon footprint, Less gas/fuel usage, Easier demolition and end up better end of life than steel!

» Why GFRP in Bridge Deck?

- ☑ **Lighter Precast Deck**
  - ☑ Longer precast panel due to weight
  - ☑ Lower cost of transportation
  - ☑ **Greener world!**

» Why GFRP in Bridge Deck?

- **Rust Free**
  - More Saving in long term
  - In One year Canadian Government spent $46B on costs associated to corrosion of rebar(US MARKET 10x)
  - Safer infrastructure for generations
  - Less demolition and rehabilitation which result in less greenhouse gas pumped into atmosphere
  - Tremendous initial cost saving by removing CNI
  - **Greener World!**

» Durability of GFRP(MTO Perspective)

- **Alkaline attack in concrete**
  - For high durability GFRP products, more recent tests show possibly 10 to 12% loss of strength in 75 years for typical application in Ontario (worse in warm and humid climate)

    CHBDC 2014 requires Φ = 0.55 at ULS

    CHBDC 2019 requires Φ = 0.65 at ULS

- **Creep rupture**
  - for sustained load > 45% f_{pu} **[New generation of GFRPs]**

    CHBDC requires Φ = 0.25 at SLS

AASHTO has different resistance and durability factors, but the end result is similar:

Environmental reduction factor C_E= 0.7 (apply to guaranteed Fu)
Creep rupture reduction factor C_C= 0.3
Fatigue rupture reduction factor C_f = 0.25
Strength resistance factor Φ = 0.55 to 0.75

» Durability of GFRP(MTO Perspective)

☑ **Accelerated aging and natural aging condition**

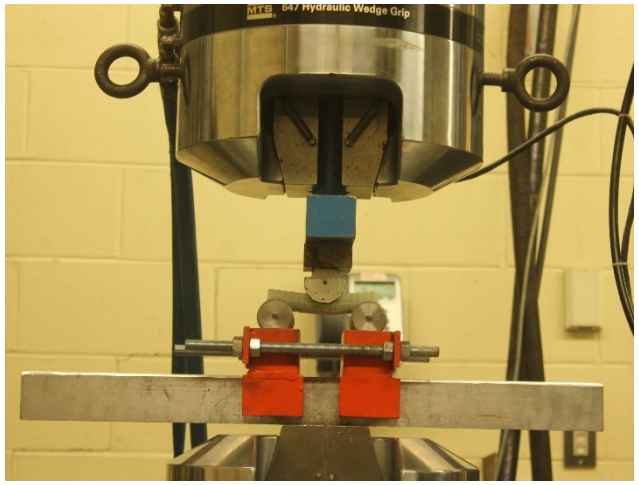
$$\frac{N}{C} = 0.098\, e^{0.0558T}$$

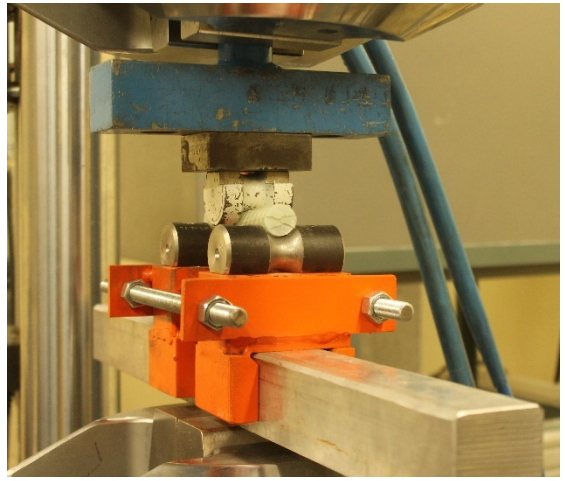
Temperature (°C)	Solution (pH 12.6-12.8)	Accelerated ages (days)	Natural ages (years)
40	Alkaline	150	13
40	Alkaline	300	27
60	Alkaline	150	100
60	Alkaline	300	199

» Durability of GFRP?

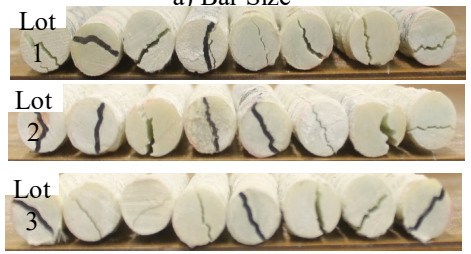
- **Most Recent Alkali Resistance Interlaminar Shear Strength(ILSS)**
- Apparent Horizontal Shear Strength by Short-Beam Method of Glass Fibre-Reinforced Polymer (GFRP) Bars in High pH Alkaline Solution at 60 °C – Reference and Conditioned Bars #3, #4, #5, and #8

Durability of GFRP Bars

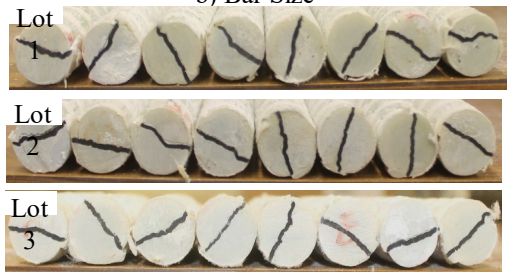




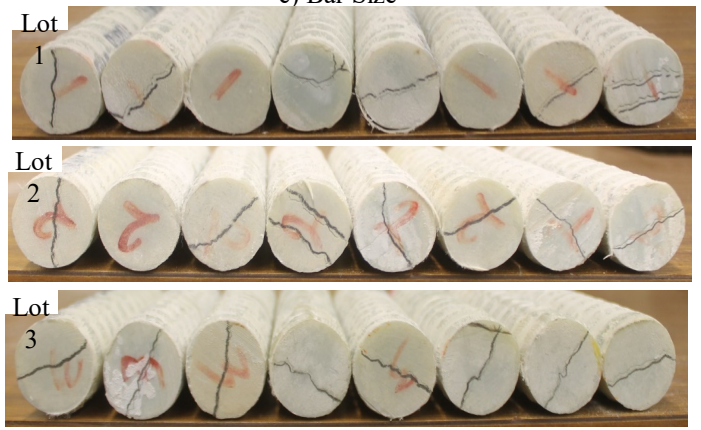
a) Bar Size



b) Bar Size



c) Bar Size



d) Bar Size #8

Durability of GFRP Bars

Bar Size	Lot #	Specimens	Apparent Horizontal Shear Strength (MPa)	Strength Retention R_{et}
#3	1	Reference	48	96%
		Conditioned	46	
	2	Reference	49	96%
		Conditioned	47	
	3	Reference	47	96%
		Conditioned	45	
#4	1	Reference	53	92%
		Conditioned	49	
	2	Reference	52	96%
		Conditioned	50	
	3	Reference	51	96%
		Conditioned	49	
#5	1	Reference	70	99%
		Conditioned	69	
	2	Reference	71	96%
		Conditioned	68	
	3	Reference	70	99%
		Conditioned	69	
#8	1	Reference	60	97%
		Conditioned	58	
	2	Reference	59	97%
		Conditioned	57	
	3	Reference	60	97%
		Conditioned	58	

» What has changed lately? Material Standpoint

E-Glass

Degrade in Alkaline environment

Boron Free Glass

Never degrade

What has changed lately? Material Standpoint

Polyester

Degrade in Alkaline environment

Vinyl-Ester

Never degrade

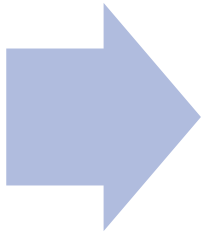
Better elongation

Higher strength

What has changed lately? Material Standpoint

E=40GPa

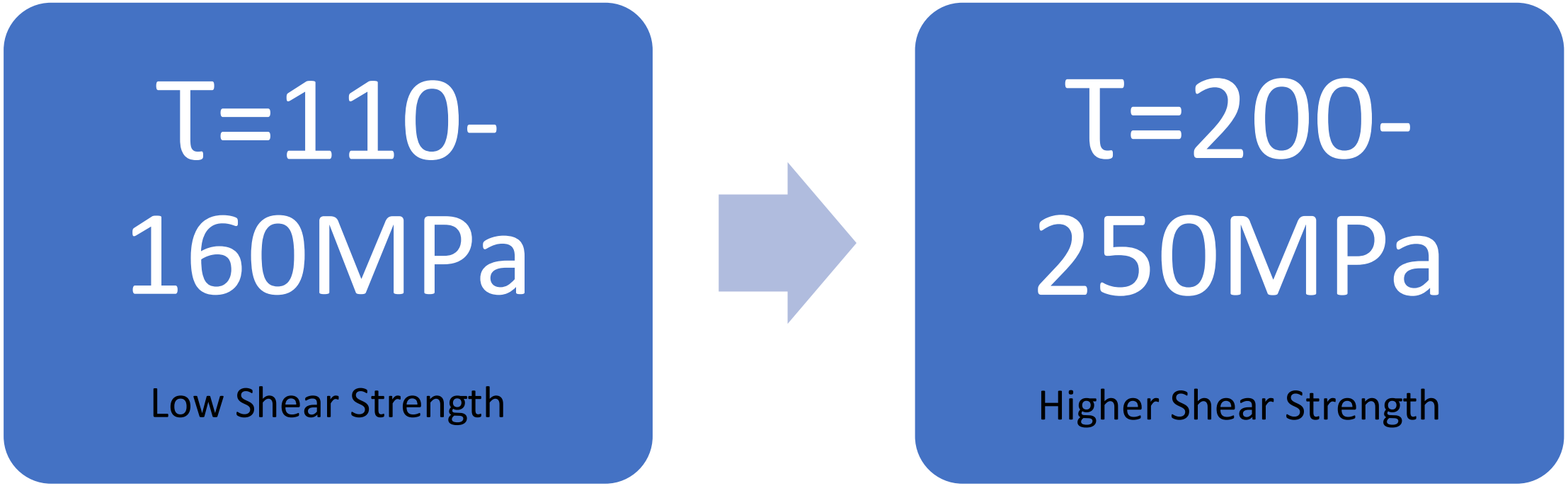
Low stiffness required more rebar



E=60GPa

Higher stiffness required less rebar

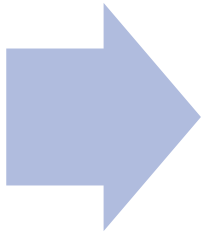
What has changed lately? Material Standpoint



What has changed lately? Material Standpoint

δ=750MPa

Average Tensile Strength



τ=1000 MPa

High Tensile Strength

What has changed lately? Material Standpoint

δBond<10MPa

Low Bond Strength

τ>25 MPa

High Bond Strength

What has changed lately? Material Standpoint

δ=450MPa

Low Bend Strength

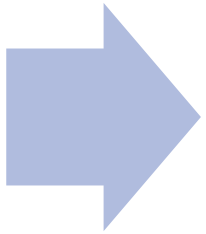
τ=700-800 MPa

High Bend Strength

What has changed lately? Market Standpoint

Corrosion Niche Market

Corrosive applications

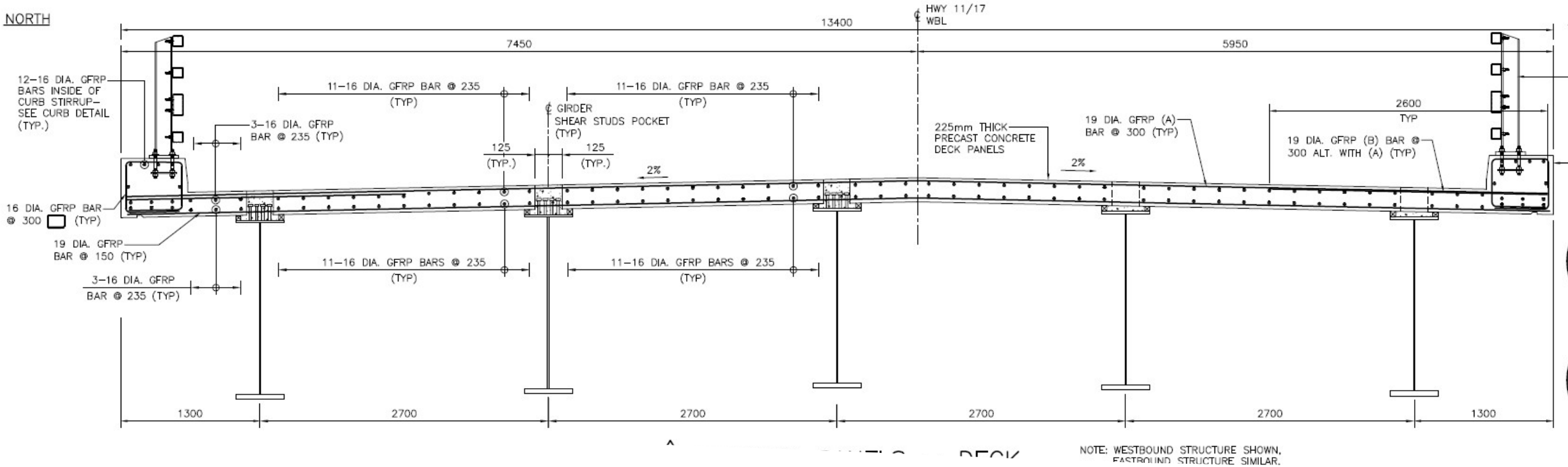


Any Concrete Market

Due to Weight, Price & Strength

GFRP in Bridge Deck

- Pre-Cast panels with UHPC joints
- Cast in Place over Girders



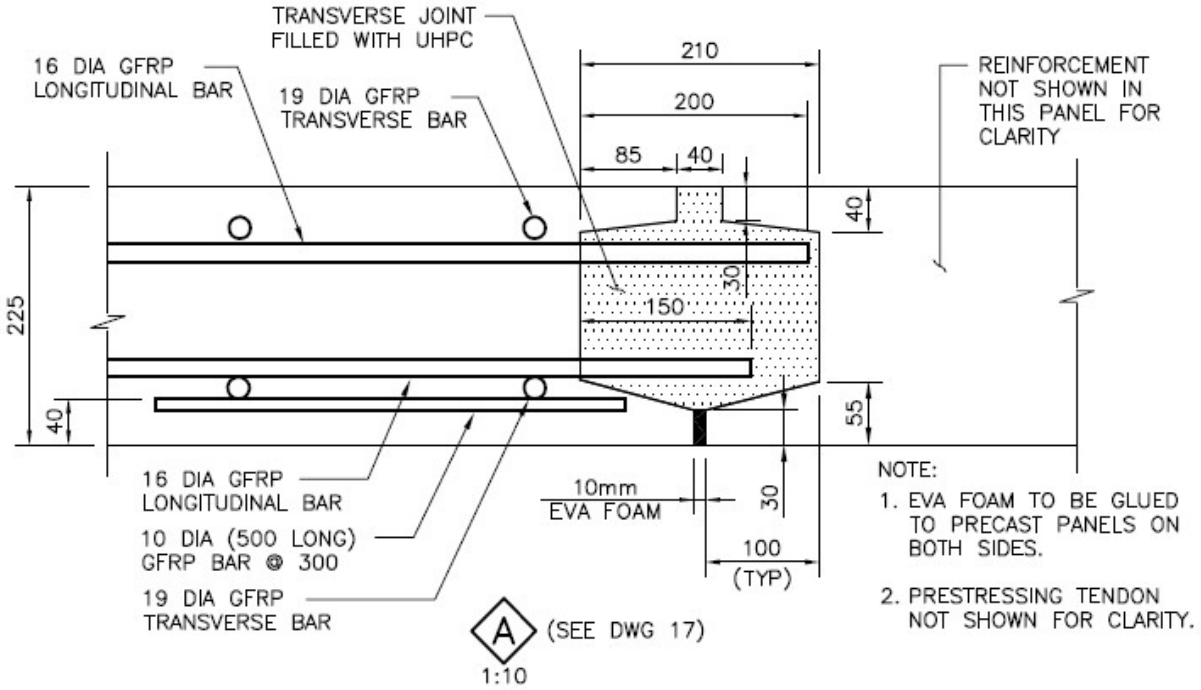
Pre-Cast panels with UHPC joints

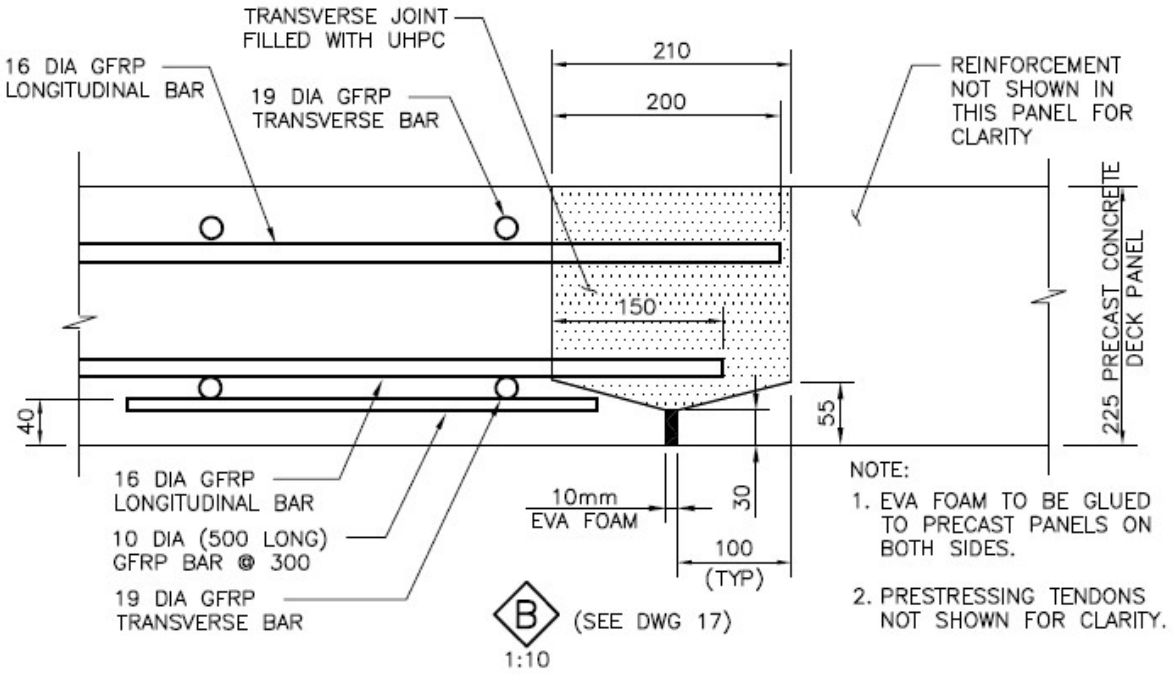
Advantages

- ☑ Save Construction Time
- ☑ QA/QC
- ☑ Durability
- ☑ Less Change in Contract Price

Disadvantages

- ☑ Higher initial cost
- ☑ Transportation and handling
- ☑ Modification





UHPC= Stronger Connection & Less Overlap

» Rational Design-Deck Slab with GFRP

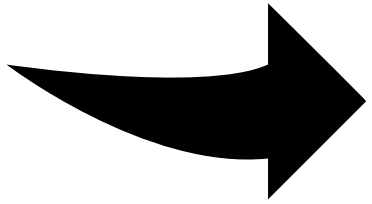
- Started in Ontario from 1979
- Design by either empirical method or flexural methods is allowed (Clause 16.8.8). For simplicity, **empirical method** can always be used when the conditions for its use are satisfied.
- Crack widths need not be checked for the empirical method.(importance of Kb factor)
- Only use GFRP grades 3 in the deck slab: No Grade 1.
- No need for Corrosion Inhibitors or other corrosion protection.
- No need for strengths higher than 30 MPa for a typical slab on girder bridge.
- For economy:
  - For a deck slab t = 200 mm, use empirical methods for girder spacing over 2.4 m, otherwise flexural methods.
  - For a deck slab t = 225 mm, use flexural methods.

Advantages of Using Empirical Design in Bridge Deck Slab

- **Empirical method** Can be considered since it would result in a more economical design than traditional method.
- **Empirical method** could result in material saving by using less reinforcing bar.
- Initial cost of 10% less when using Empirical design method Vs. Traditional method.

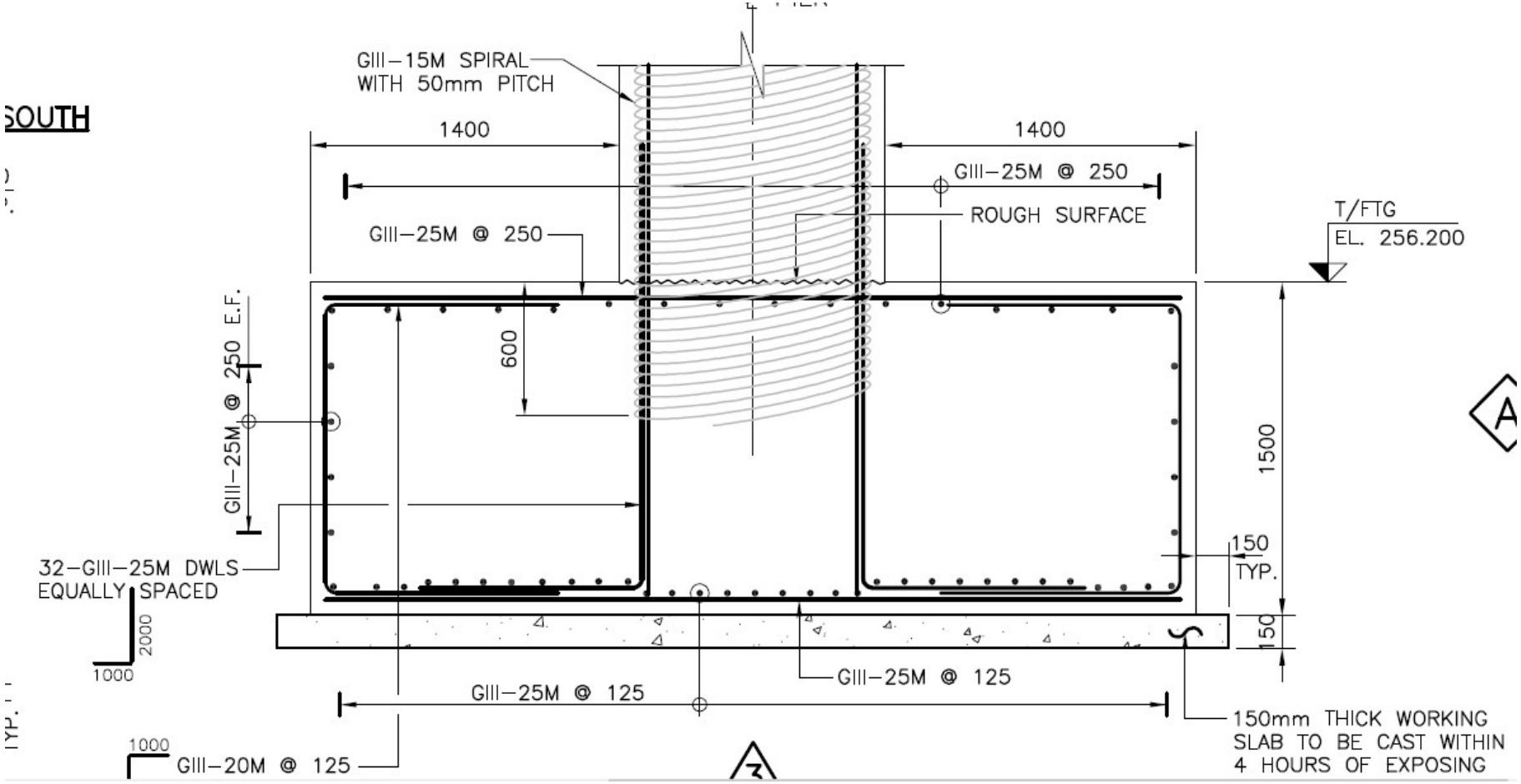
» What's Next?

- ☑ More confident
- ☑ Better QC/QA
- ☑ Better Bent bars
- ☑ More research
- ☑ Lower cost

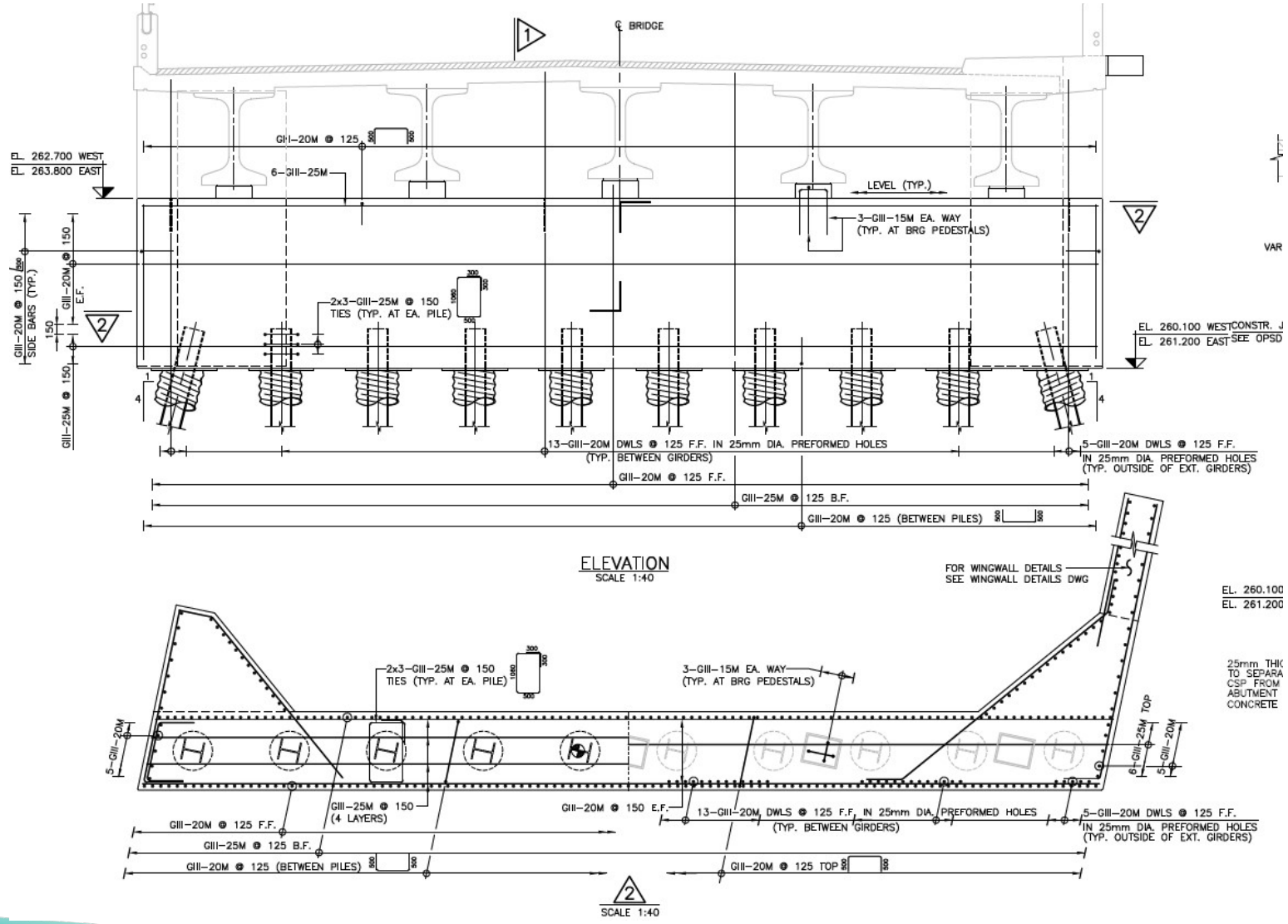


FULL GFRP BRIDGE in 2021

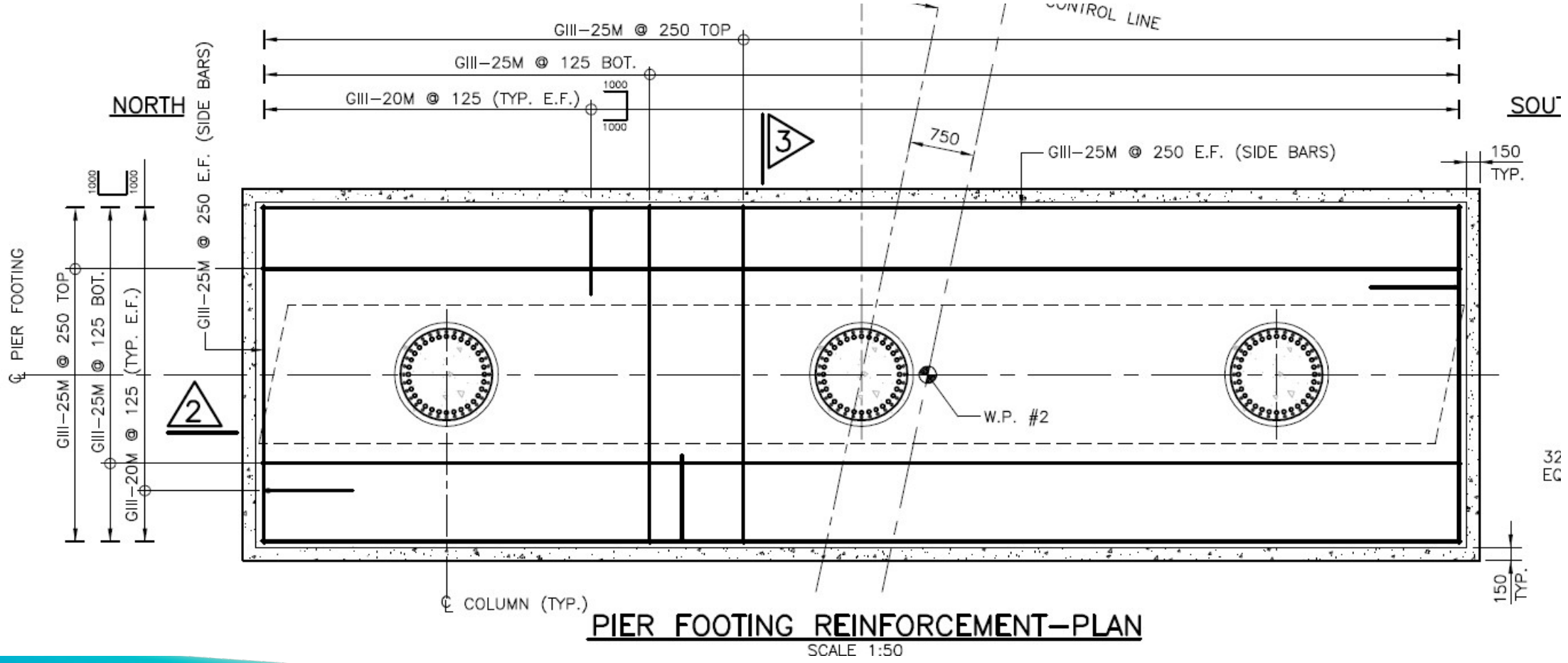
What's Next?


SOUTH
GIII–15M SPIRAL
WITH 50mm PITCH
1400
1400
GIII–25M @ 250
GIII–25M @ 250
ROUGH SURFACE
T/FTG
EL. 256.200
600
GIII–25M @ 250 E.F.
1500
150
TYP.
150
32–GIII–25M DWLS
EQUALLY SPACED
2000
1000
GIII–25M @ 125
GIII–25M @ 125
1000
GIII–20M @ 125
150mm THICK WORKING
SLAB TO BE CAST WITHIN
4 HOURS OF EXPOSING

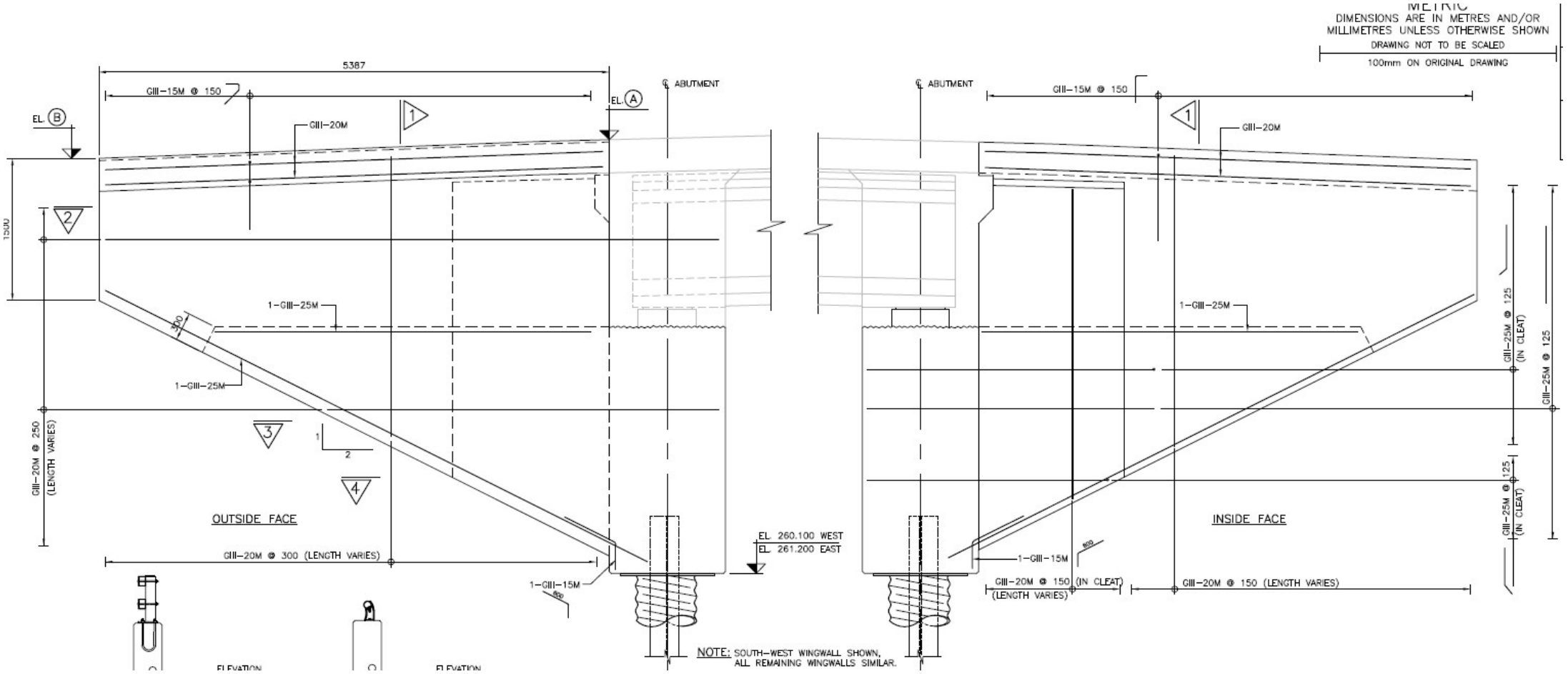
What's Next?


℄ BRIDGE
EL. 262.700 WEST
EL. 263.800 EAST
GII–20M @ 125
6–GIII–25M
LEVEL (TYP.)
3–GIII–15M EA. WAY
(TYP. AT BRG PEDESTALS)
2x3–GIII–25M @ 150
TIES (TYP. AT EA. PILE)
GIII–20M @ 150
SIDE BARS (TYP.)
GIII–20M E.F.
GIII–25M @ 150
EL. 260.100 WEST
EL. 261.200 EAST
CONSTR. J
SEE OPSD
13–GIII–20M DWLS @ 125 F.F. IN 25mm DIA. PREFORMED HOLES
(TYP. BETWEEN GIRDERS)
5–GIII–20M DWLS @ 125 F.F.
IN 25mm DIA. PREFORMED HOLES
(TYP. OUTSIDE OF EXT. GIRDERS)
GII–20M @ 125 F.F.
GIII–25M @ 125 B.F.
GII–20M @ 125 (BETWEEN PILES)
ELEVATION
SCALE 1:40
FOR WINGWALL DETAILS
SEE WINGWALL DETAILS DWG
EL. 260.100
EL. 261.200
25mm THI
TO SEPARA
CSP FROM
ABUTMENT
CONCRETE
5–GIII–20M
6–GIII–25M TOP
5–GIII–20M
GIII–25M @ 150
(4 LAYERS)
GII–20M @ 150 E.F.
GII–20M @ 125 F.F.
GII–25M @ 125 B.F.
GII–20M @ 125 (BETWEEN PILES)
GII–20M @ 125 TOP
SCALE 1:40

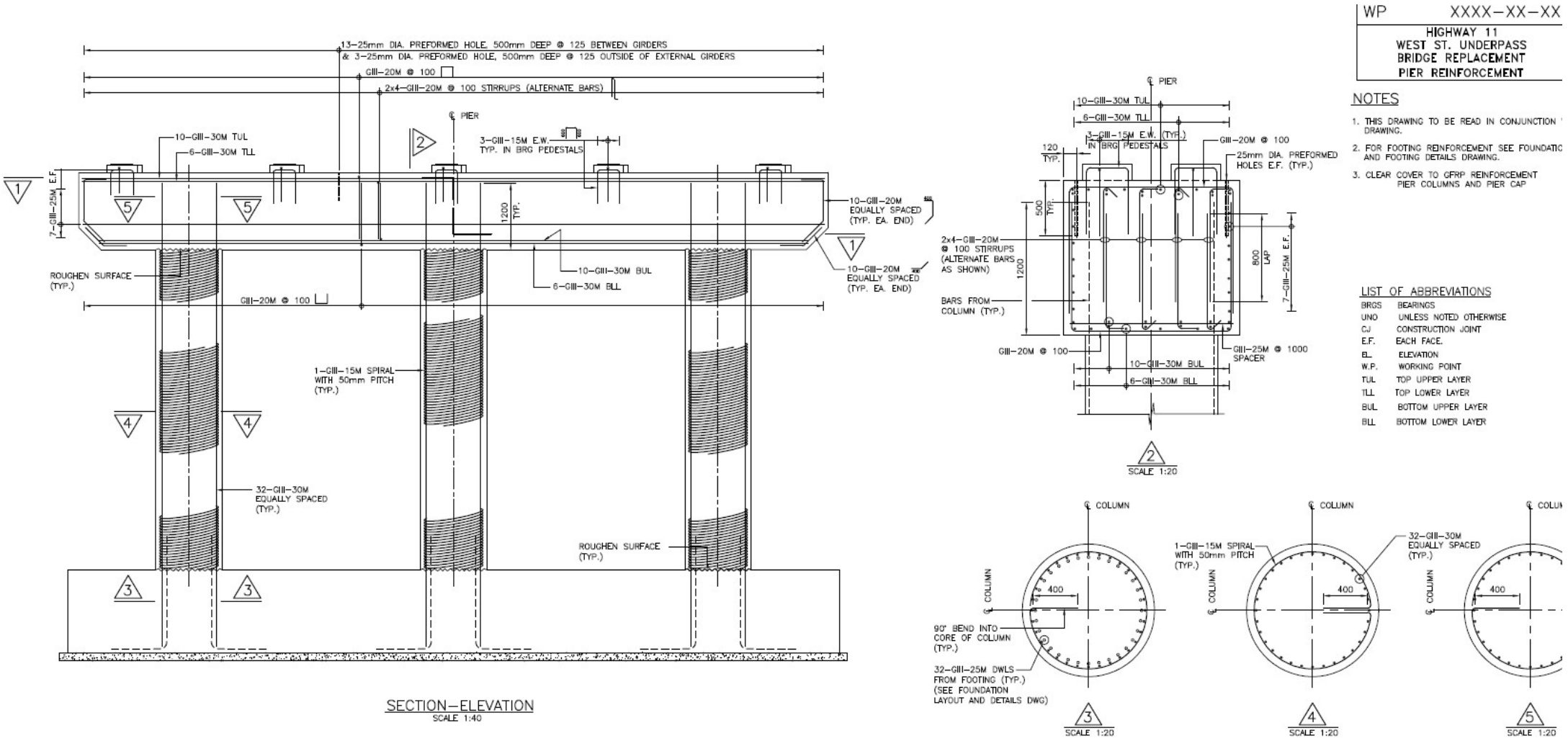
What's Next?


GIII–25M @ 250 TOP
GIII–25M @ 125 BOT.
GIII–20M @ 125 (TYP. E.F.)
1000
1000
NORTH
SOU
3
750
GIII–25M @ 250 E.F. (SIDE BARS)
150
TYP.
1000
1000
℄ PIER FOOTING
GIII–25M @ 250 TOP
GIII–25M @ 125 BOT.
GIII–20M @ 125 (TYP. E.F.)
GIII–25M @ 250 E.F. (SIDE BARS)
2
W.P. #2
℄ COLUMN (TYP.)
150
TYP.
PIER FOOTING REINFORCEMENT–PLAN
SCALE 1:50

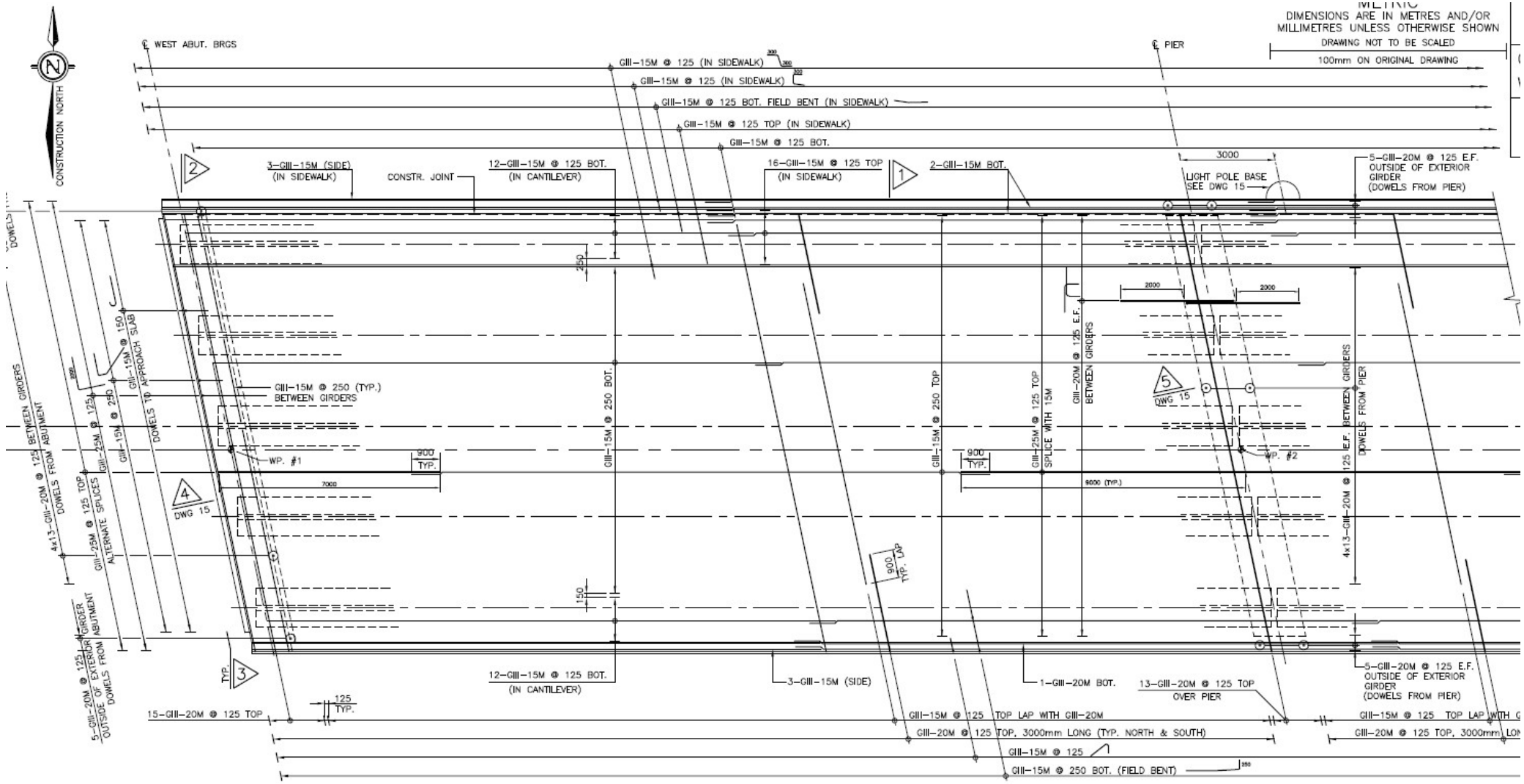
What's Next?


METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN
DRAWING NOT TO BE SCALED
100mm ON ORIGINAL DRAWING
5387
GIII–15M @ 150
GIII–20M
EL. B
EL. A
℄ ABUTMENT
1500
1–GIII–25M
300
1–GIII–15M
GIII–20M @ 250 (LENGTH VARIES)
OUTSIDE FACE
GIII–20M @ 300 (LENGTH VARIES)
EL. 260.100 WEST
EL. 261.200 EAST
INSIDE FACE
GIII–25M @ 125 (IN CLEAT)
GIII–20M @ 150 (IN CLEAT) (LENGTH VARIES)
GIII–20M @ 150 (LENGTH VARIES)
NOTE: SOUTH–WEST WINGWALL SHOWN, ALL REMAINING WINGWALLS SIMILAR.
ELEVATION
ELEVATION

What's Next?


WP XXXX–XX–XX
HIGHWAY 11
WEST ST. UNDERPASS
BRIDGE REPLACEMENT
PIER REINFORCEMENT
NOTES
1. THIS DRAWING TO BE READ IN CONJUNCTION
DRAWING.
2. FOR FOOTING REINFORCEMENT SEE FOUNDATIC
AND FOOTING DETAILS DRAWING.
3. CLEAR COVER TO GFRP REINFORCEMENT
PIER COLUMNS AND PIER CAP
LIST OF ABBREVIATIONS
BRGS BEARINGS
UNO UNLESS NOTED OTHERWISE
CJ CONSTRUCTION JOINT
E.F. EACH FACE.
EL. ELEVATION
W.P. WORKING POINT
TUL TOP UPPER LAYER
TLL TOP LOWER LAYER
BUL BOTTOM UPPER LAYER
BLL BOTTOM LOWER LAYER
13–25mm DIA. PREFORMED HOLE, 500mm DEEP @ 125 BETWEEN GIRDERS
& 3–25mm DIA. PREFORMED HOLE, 500mm DEEP @ 125 OUTSIDE OF EXTERNAL GIRDERS
GIII–20M @ 100
2x4–GIII–20M @ 100 STIRRUPS (ALTERNATE BARS)
℄ PIER
10–GIII–30M TUL
6–GIII–30M TLL
3–GIII–15M E.W. TYP. IN BRG PEDESTALS
7–GIII–25M E.F.
10–GIII–20M EQUALLY SPACED (TYP. EA. END)
1200 TYP.
ROUGHEN SURFACE (TYP.)
10–GIII–30M BUL
6–GIII–30M BLL
1–GIII–15M SPIRAL WITH 50mm PITCH (TYP.)
32–GIII–30M EQUALLY SPACED (TYP.)
SECTION–ELEVATION
SCALE 1:40
120 TYP.
500 TYP.
25mm DIA. PREFORMED HOLES E.F. (TYP.)
2x4–GIII–20M @ 100 STIRRUPS (ALTERNATE BARS AS SHOWN)
BARS FROM COLUMN (TYP.)
800 LAP
GIII–25M @ 1000 SPACER
SCALE 1:20
℄ COLUMN
400
90° BEND INTO CORE OF COLUMN (TYP.)
32–GIII–25M DWLS FROM FOOTING (TYP.) (SEE FOUNDATION LAYOUT AND DETAILS DWG)
SCALE 1:20

What's Next?


METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN
DRAWING NOT TO BE SCALED
100mm ON ORIGINAL DRAWING
CONSTRUCTION NORTH
℄ WEST ABUT. BRGS
℄ PIER
GIII–15M @ 125 (IN SIDEWALK)
GIII–15M @ 125 (IN SIDEWALK)
GIII–15M @ 125 BOT. FIELD BENT (IN SIDEWALK)
GIII–15M @ 125 TOP (IN SIDEWALK)
GIII–15M @ 125 BOT.
3–GIII–15M (SIDE) (IN SIDEWALK)
CONSTR. JOINT
12–GIII–15M @ 125 BOT. (IN CANTILEVER)
16–GIII–15M @ 125 TOP (IN SIDEWALK)
2–GIII–15M BOT.
3000
LIGHT POLE BASE SEE DWG 15
5–GIII–20M @ 125 E.F. OUTSIDE OF EXTERIOR GIRDER (DOWELS FROM PIER)
GIII–15M @ 250 (TYP.) BETWEEN GIRDERS
WP. #1
WP. #2
900 TYP.
7000
9000 (TYP.)
DWG 15
GIII–15M @ 250 BOT.
GIII–15M @ 250 TOP
GIII–25M @ 125 TOP SPLICE WITH 15M
GIII–20M @ 125 E.F. BETWEEN GIRDERS
4x13–GIII–20M @ 125 E.F. BETWEEN GIRDERS DOWELS FROM PIER
4x13–GIII–20M @ 125 BETWEEN GIRDERS DOWELS FROM ABUTMENT
GIII–25M @ 125 TOP ALTERNATE SPLICES
GIII–15M @ 250
GIII–15M @ 150 APPROACH SLAB
DOWELS TO
5–GIII–20M @ 125 EXTERIOR GIRDER OUTSIDE OF DOWELS FROM ABUTMENT
TYP.
12–GIII–15M @ 125 BOT. (IN CANTILEVER)
3–GIII–15M (SIDE)
1–GIII–20M BOT.
13–GIII–20M @ 125 TOP OVER PIER
15–GIII–20M @ 125 TOP
125 TYP.
900 TYP. LAP
GIII–15M @ 125 TOP LAP WITH GIII–20M
GIII–20M @ 125 TOP, 3000mm LONG (TYP. NORTH & SOUTH)
GIII–15M @ 125
GIII–15M @ 250 BOT. (FIELD BENT)

Question & Answer