Introduction to Glass Fiber Reinforced Polymer

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1-888-99-REBAR

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Steel Rebar

Steel rebar is the standard method of reinforcing concrete structures.

Steel rebar has a long history.

It is appropriate for more than 80% of applications.

But, what about those situations where steel rebar is not appropriate?

What about the other 20%?

2

Corrosion

As long as we reinforce concrete with **steel, it will rust.**

Traditionally, concrete structures crack and expose the steel reinforcement to chloride intrusion. This triggers premature corrosion ultimately resulting in the spalling (or blow out) of concrete pieces to the point where **the structure is deemed fully failed.**

Natural Laws: Concrete cracks and steel corrodes.
This is a ticking time bomb!

Conclusion: Service life of a structure is dramatically reduced by corrosion.

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Problem is Rusting Steel Rebar

Reinforced Concrete with **Steel Rebar** is the cause of the failing infrastructure.

Corrosion occurs when moisture or salt come in contact with the steel reinforcement bar.

Steel rebar **expands 10x** in diameter, it rusts and causes concrete to **crack** and **fail.**

Corrosion weakens metal, putting additional pressure on the concrete and compromising the structure.

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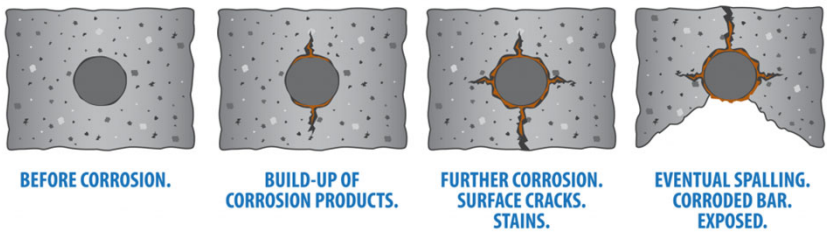
How Corrosion Occurs?



Corrosion is an electrochemical reaction between a metal and its environment. Corrosion occurs when steel reacts with chloride ions (Cl-), CO2 in presence of toxic environment. This is the most expensive chemical reaction in the world.

$$4Fe + 3O_2 + 6H_2O \rightarrow 4Fe(OH)_3 - \$$$

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The Cost of Corrosion

All steel reinforced concrete worldwide is at risk due to corrosion PLUS **corrosion is the single largest cause of concrete repair.**

The global cost of corrosion is estimated to be US$2.5 trillion.

FACT: According to FHWA, 1 in 3 bridges in the United States are structurally deficient.

National Association of Corrosion Engineers (NACE) estimates the cost of corrosion of concrete structures in the USA to be approximately **$100 billion per year.**

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The Traditional Solutions to Corrosion

Regular Maintenance and Repairs

Admixtures

Increase Concrete Cover

Alter Concrete Mix

Membranes & Overlays

Epoxy-Coated or Galvanized Steel

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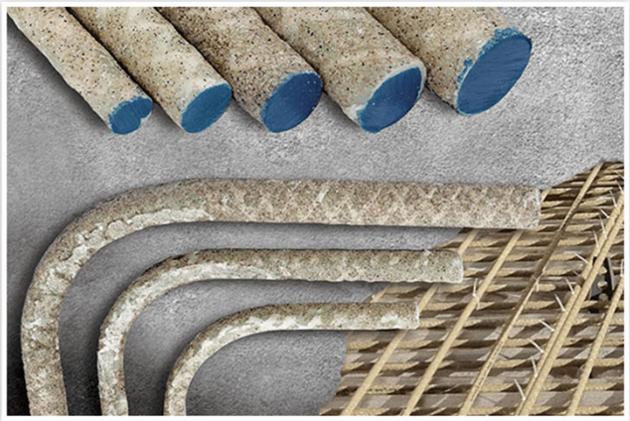
The Solution: GFRP

TUF-BAR Fiberglass Rebar is THE solution



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Fiberglass Products

Fiberglass is used in a wide variety of products.





Made from a mixture of silica, limestone and other materials. This mixture is heated and extruded into fine strands which are collected into bundles called rovings.

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What is GFRP?

GFRP – Glass Fiber Reinforced Polymer composite material.

A composite material system made of Fibers + Resin.

Pultrusion method is used to manufacture bars, with thousands of **E-CR Glass Fiber rovings** being pulled through a **Vinyl-Ester resin bath.**

Bars are coated in sand to improve the bonding surface between the bar and concrete.

Impervious to chloride ion and chemical attack. Manufactured in sizes #2 - #12 (45 GPa to 60 GPa).

Bends are manufactured at TUF-BAR.

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Benefits

100% Corrosion Resistant: no need for 3" cover, corrosion inhibitor or sealants

Non-Magnetic: transparent to magnetic fields and radio frequencies

Non-Conductive: Electrically and Thermally

Lightweight: ¼ the weight of steel – saving in transportation, labor and carbon footprint

Superior Tensile Strength: high strength-to-weight ratio

Cost Effective: saving in construction, maintenance and repair costs over the service life of the structure

Longer Service Life: because GFRP will never rust, the concrete will last longer.

100% Recyclable

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Non Metallic – No Rust!

Corrosion-Free Fiberglass Rebar
No need for 3" cover, corrosion inhibitors or sealants.

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Lightweight

1/4 the weight of steel: 1.0” bar at 20’ length weighs less than 15lbs

Significant savings in transportation and carbon footprint

Substantial labor savings on construction site

Easier and safer to install

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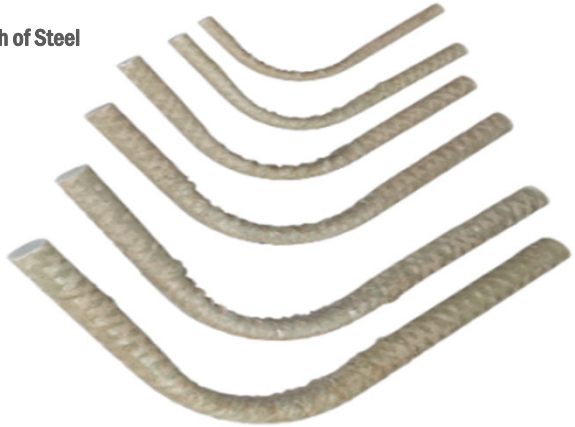
Tensile Strength

2x the Tensile Strength of Steel



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Non-Conductive

Contains zero metal or ferrous material making TUF-BAR non-magnetic and non-conductive

- Safety in High Voltage Areas
- No Electro-magnetic induction
- No Electrical Interference

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GFRP as a Thermal Insulator

Does not conduct heat or transfer cold:

- Insulated Concrete Sandwich Panels
- Refrigerated Warehouses
- Concrete Balconies

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Boring / Tunneling

Perfect Solution for Soft Eye Application

TUF-BAR takes advantage of its "anisotropic" property, meaning they are strong along the main axis, but can be "consumed" by excavation equipment such as Tunnel Boring Machines.

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100% Recyclable

Ease of Demolishing

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Sustainable & Environmentally Friendly

- Canada Green Building Council Member
- 100% Recyclable
- TUF-BAR® contributes:
  - 6 LEED® Credits in Canada
  - 7 LEED® Credits in USA

TUF-BAR® in Pre-fab Bridge Deck Slabs

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Applications

1. Concrete structures susceptible to corrosion.
2. Concrete structures requiring non-ferrous reinforcement due to electro-magnetic considerations or thermal non-conductivity.
3. Where machinery will "consume" the reinforced concrete member (mining/tunneling).

- Bridge Decks/Approach Slabs
- Marine & Waterfront: Seawalls, Docks, Boat Ramps
- Light Rail Transit
- Water Treatment Facilities
- Parking Garages
- Concrete Balconies
- Box Girders
- Barriers, parapets, sidewalks
- Box Culverts
- Tunneling / Soft Eye
- MRI Rooms

Pre-Cast Applications:
- Columns
- Stairs
- Blocks (lifting anchors)
- Bridge Girders
- Barriers
- Shear Walls
- Parking Curbs
- Underground Utility Boxes

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GFRP Shapes

Straight Bars

Bends

Spirals

Hoops

Hooked Bar

Headed Bar

Coiled Bar

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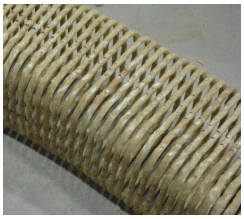
FIBERGLASS REBAR BEND GUIDE

CERTIFIED ISO COMPANY

WWW.TUF-BAR.COM



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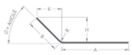
TUF-BAR Shapes

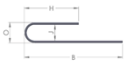
G1 90 DEGREE BENT
Steel Type 2, 17

G2 >90 DEGREE BENT
Steel Type 3



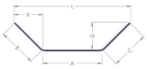
G3 <90 DEGREE BENT
Steel Type 13, 21, 30

G4 HOOKED BAR
Steel Type SP1

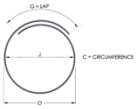


G7 U/C SHAPE BAR
Steel Type 2, 17

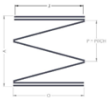
G8 OPEN U
Steel Type 3D, 4C, 14AB, 22B



G13 HOOP
Steel Type T3



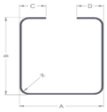
G14 SPIRAL
Steel Type SP1



G20 DUAL HOOKED
Steel Type 1

G21 PAPERCLIP
Steel Type - None

G22 CLOSED U/C SHAPE BAR
Steel Type S6



G24 RECTANGULAR SPIRAL
Steel Type - None

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Long-Term Durability

According to field performance of existing GFRP reinforced concrete structures over the last 20 years and numerous research studies, the corrosion resistant nature of this alternative has demonstrated its ability to **extend the service life** of concrete structures to more than 100 years

Cores from a 17-year old bridge show **no sign of damage.**

Cores from five concrete structures in Canada 12 to 15 years old showed similar performance

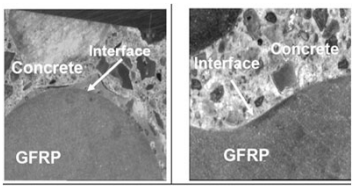

Figure 39: High Magnification Images of GFRP-Concrete Interfaces: (Left) Sample from Hall's Harbor Wharf and (Right) Sample from Joffre Bridge (31-32)

More than 750 projects in US and Canada have used GFRP rebars

GFRP is a more durable, proven and successful reinforcing alternative to heavy, corrosive steel.

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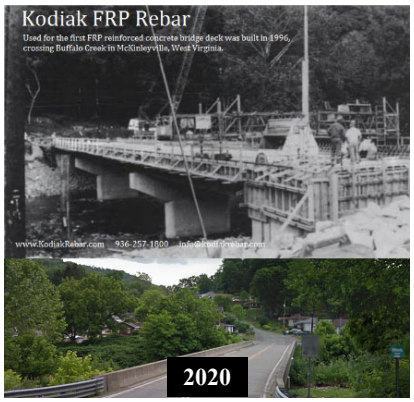
1st Bridge with GFRP

McKinleyville, WV (1996)

The McKinleyville Bridge was the first vehicular bridge in the U.S. to be constructed with a concrete deck reinforced with GFRP rebar. The bridge is 177 feet long by 30 feet wide and accommodates two lanes of traffic.

Original surface, no repairs required in 20+ years.



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Specifications & Design Guides

ASTM D7957-17 Material Specifications

ACI 440.1R-15 Design with FRP rebars

ACI 440.5-08 Construction with FRP rebars

AASHTO LRFD Bridge Design Guide Specifications

CSA 807-19 Specification for Fibre Reinforced Polymers

CSA 806-12 Design and Construction of Building Components

CSA S6-19 Highway Bridge Design Code

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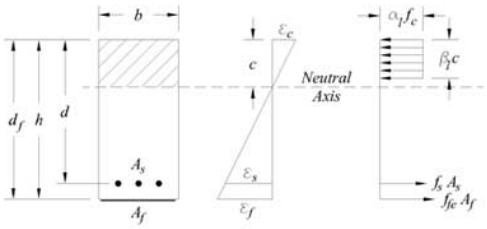
GFRP Software & Tools

FRPpro™ Engineering Calculator is an advanced software package for structural and civil engineers used to calculate the strength and adequacy of concrete structural members reinforced with fiber reinforced polymers (FRPs).



The goal of the FRPpro Engineering Calculator is to give specifiers, concrete design engineers and precasters a reliable tool for converting conventional steel reinforcement into non-corrosive composite reinforcement.

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Material Certification & Traceability

High Embedment Strength Material test certs are available for any production lot of TUF-BAR.

Table 1: Quality Control Tests Conducted

Test	Test Method	Limits – metric
Tensile Strength	ASTM D7205	ASTM D7957 Table 2
Ultimate Elongation	ASTM D7205	ASTM D7957 Table 2
Tensile Modulus	ASTM D7205	ASTM D7957 Table 2
Interlaminar Shear	ASTM D4475	≥ 35 MPa for Grade I ≥ 40 MPa for Grade II ≥ 45 MPa for Grade III
Fiber Content	ASTM D2584	≥ 70% by weight
Cure Ratio	ASTM E2160	≥ 95%
Glass Transition Temperature	ASTM E1356	≥ 100 Degrees Celsius
Measured Cross-Sectional Area	ASTM D7205	ASTM D7957 Table 3
24-hour Moisture Absorption	ASTM D570	≤ 0.25% mass increase

Each individual sample taken must meet the property limits. Test Certificates are available for any production lot upon request. Bars are given a designation that is unique to each production lot for traceability.

The certs are traceable to the bar by means of a series of bar marks imprinted along the length of the bar in intervals showing the manufacturer's name, bar size & diameter, grade designation and applicable codes.

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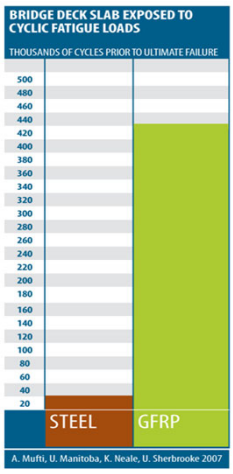
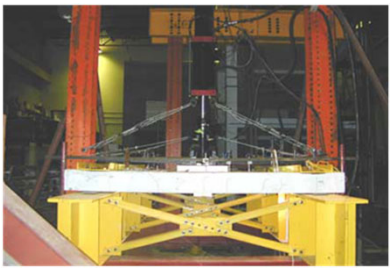
Fatigue Resistance



Steel: 20,000 cycles
GFRP: 420,000 cycles

Lasts **20x Longer** under cyclic Loads

- Truck Traffic, Wave Action, Seismic



60 Ton Loading Fixture
A. El-Ragaby , E. F. El-Salakawy and B. Benmokrane

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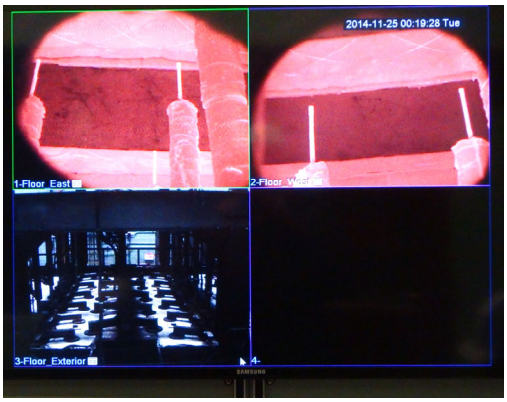
Fire Rating: Bridge Slabs

Over 3 Hours Fire Rating Test

NRC Laboratories - Ottawa Canada

40 mm concrete cover
&
60 mm concrete cover



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GFRP Mechanical Properties

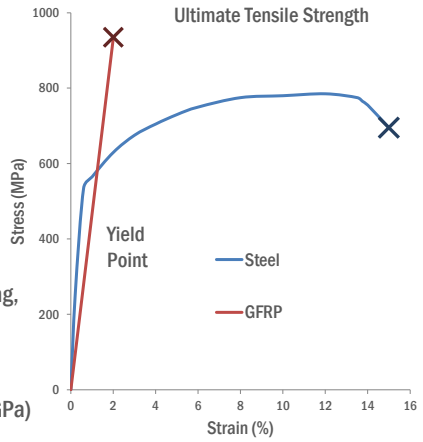
Higher Tensile strength, but less stiff than steel

Anisotropic behavior
- High strength in the fiber direction
- Low shear strength and dowel action

GFRP is linear elastic up to failure
- no ductility
- 2% elastic deformation

Glass Creep - not recommended for Pre-Tensioning, Post-Tensioning
Dead Loads (max 25% UTS)

Modulus of Elasticity - ¼ that of Steel (45 to 60 GPa)



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Things to Know

High Embedment Strength
- Rough Surface
- Sand Coating

K_b Factor
- Crack Width < 0.023 in
- Sand Coating K_b = 0.8
- 20% Less Bar Required

TUF-BAR® Sand Coating

$$w_{cr} = 2\frac{f_{FRP}}{E_{FRP}}\frac{h_2}{h_1}k_b\sqrt{{d_c}^2 + (s/2)^2}$$

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Design and Construction Considerations

Concrete Crushing as preferred failure mode

Lower modulus

Lap splices longer

Support chairs at 2/3 conventional spacings

Bid by foot rather than by pound

Recommend using PVC coated Tie-Wire

60 GPa Bends – reduces congestion in the stirrups by 30%

TUF-BAR® Grid

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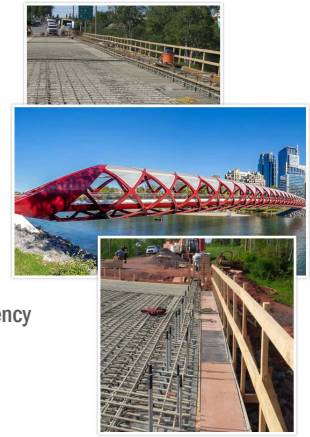
Project Cost Savings

Less Concrete Cover: GFRP placed closer to the surface
Fewer Concrete Additives
No Concrete Treatments and no Protective Membranes
Lightweight
- Lower Transport Costs
- Less Handling
- Less Injuries (WCB/OSHA)

Fast Installation – Easier and Safer
- Easy to work with and improves installation efficiency
- Cuts with Chop Saw or Grinding Disc in Seconds



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Maintenance Costs

TUF-BAR rebar dramatically reduces the maintenance, inspection and repair costs over the life cycle of the structure.

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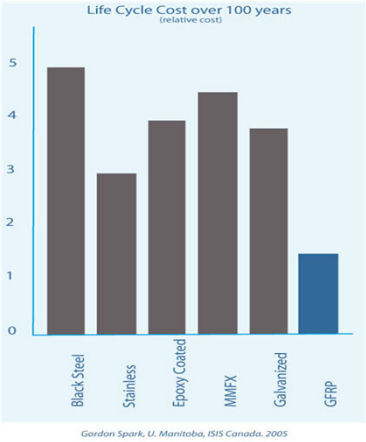
Life Cycle Cost Analysis



Save money in the long run: GFRP is indeed initially more expensive than traditional black steel rebar.

However, it offers **HUGE advantages** over these materials and has a **much LOWER overall cost of ownership.**

Research Study - Composites Innovation Centre University of Manitoba.

- GFRP 70% cost savings over 100 years
- Repairs start in 10-15 years
- More expensive as time goes on

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Cost Comparisons

Cost Estimate - Reinforcing Steel				
Description	Qty	Unit	Unit Cost	Cost
Concrete Class IV, Bulkhead	336.8	CY	$659.78	$222,214
Concrete Additives	336.8	CY	$40.00	$13,472
Reinforcing Steel, Bulkhead	45,468	LB	$1.03	$46,832
			Initial Cost =	$282,518
			Maintenance (25% Total Cost)	$70,629
			TOTAL =	$353,147

Overall Project Savings of 14.35%

Cost Estimate – Glass Fiber Reinforced Polymer Bars				
Description	Qty	Unit	Unit Cost	Cost
Concrete Class IV, Bulkhead	336.8	CY	$659.78	$222,214
Reinforcing Steel, Bulkhead	43,303	LF	$2.00	$86,606
			TOTAL =	$308,820

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Steel vs TUF-BAR®

	Black Steel	Stainless Steel	TUF-BAR®
Price		10x Black Steel	**1.6x Black Steel ≃ Galvanized Steel ≃ Epoxy Coated Steel**
Corrosion	Susceptible	Susceptible	**Non-Susceptible**
Weight			**1/4 of Steel**
Tensile Strength			**2x Steel/Stainless**
Modulus	200 GPa	200 GPa	**45, 60 GPa**
Bond Strength	8-11 MPa	8-11 MPa	**14 MPa**
Thermal Conductivity	Yes	Yes	**No**
Electrical Conductivity	Yes	Yes	**No**
Magnetic	Yes	No	**No**

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Why TUF-BAR?

- ✓ **100% Corrosion Resistant:**
- ✓ **Non-Magnetic**
- ✓ **Non-Conductive**
- ✓ **Lightweight**
- ✓ **Superior Tensile Strength**
- ✓ **Much LOWER overall cost of ownership.**
- ✓ **100% Recyclable**
- ✓ **NSERC Industrial Research Chair**
- ✓ **We help set the standards**

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Teed Bridge
Pre-Cast Deck Slab

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Perry's Creek Bridge

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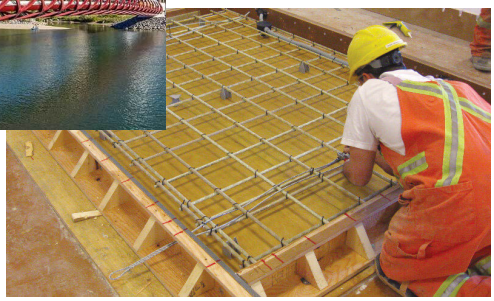
Peace Bridge



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Huntley Bridge

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Neils Brook Bridge

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Water Treatment Plant

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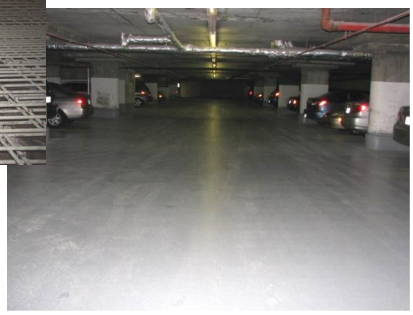
La Chancelière Parking Garage



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Conclusions

Save Money with GFRP and live without Corrosion.

- Eliminate expensive repair and maintenance costs created by black steel reinforcement.
- Reduce concrete cover and corrosion protection measures taken to protect black steel.

Compared to traditional materials, GFRP is corrosion resistant, high strength, light weight, and provides increased longevity, durability and reliability.

100+ Years Sustainability

Structures last up to 4 times longer eliminating expensive capital expenditures over time.

Codes are published and design tools are ready to use.

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Questions?

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