Glass Fiber Reinforced Polymer (GFRP) Rebar - Aslan™ 100 series

FIBERGLASS REBAR

Aslan 100 Fiberglass Rebar

November 10, 2011

Aslan FRP

Hughes Brothers, Inc. 210 N. 13th Street Seward NE 68434 www.aslanfrp.com Ph:800-869-0359 doug@hughesbros.com

Corrosion of internal reinforcing steel is one of the chief causes of failure of concrete structures. Inevitably concrete will crack, creating a direct avenue for chlorides to begin oxidizing the steel rebar. Fiber Reinforced Polymers (FRP's) are a proven and successful alternative reinforcing that will give structures a longer service life. A complete spectrum of authoritative consensus design guides, test methods, material and construction standards, product procurement specifications and qualification procedures are available to the designer and owner to safely and commercially implement FRP's in many different types of structures.

Since 1993, Hughes Brothers has been at the forefront of worldwide academic and industry efforts to define consensus standards and methods. Many thousands of structures remain in-service and are performing well, that incorporate Aslan™ 100 Glass Fiber Reinforced Polymer (GFRP) also referred to as "fiberglass rebar".

Concrete Exposed to De-Icing Chlorides

- Bridge Decks & Railings
- Median Barriers
- Approach Slabs
- Salt Storage Facilities
- Continuously Reinforced Concrete Paving
- Precast Elements -
  Manhole Covers, Culverts, Rail Grade Crossings, Full Depth Deck Panels, etc.

Concrete Exposed to Marine Chlorides

- Sea Walls, Wharfs, Quays & Dry Docks
- Coastal Construction exposed to Salt Fog
- Desalinization intakes
- Port Aprons

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Benefits of Aslan 100 Fiberglass Rebar

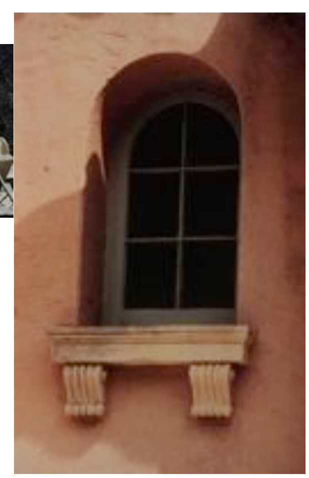
- Impervious to Chloride Ion and low pH chemical attack
- Tensile strengths greater than steel
- 1/4th the weight of steel rebar
- Transparent to magnetic fields and radio frequencies
- Electrically non-conductive
- Thermally non-conductive

Concrete Exposed to High Voltages & Electromagnetic Fields

- Light & Heavy Rail 3rd Rail Isolation
- Hospital MRI Areas
- High Voltage Substations
- Cable Ducts & Banks
- Aluminum Smelters & Steel Mills
- Radio Frequency Sensitive Areas
- High Speed Highway Tolling Zones

Concrete Susceptible to Corrosion

- Waste Water Treatment
- Inadequate Concrete Cover
- Architectural Concrete Elements
- Historic Preservation



Aslan FRP

Tunneling & Mining

- Deep Foundation Tunnel Boring Machine “Soft-eye” Openings For Launch & Reception
- Sequential Excavation or NATM Tunneling
- Soil Nails & Earth Retention
- Rock Bolts & Cable Bolts

Masonry Strengthening & Historic Preservation

- Strengthening for “Event Loading” of Clay & Concrete Masonry
- Historic Preservation – Restoration and Pinning of Stone Elements

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Aslan 100 Mechanical Properties – Tensile, Modulus & Strain

Nominal Diameter			Nominal Area		f^*_{fu} - Guaranteed Tensile Strength		Ultimate Tensile Load		E_f - Tensile Modulus of Elasticity		Ultimate Strain
Size	mm	in	mm^2	in^2	MPa	ksi	kN	kips	GPa	psi 10^6	%
2	6	¼	31.67	0.049	896	130	28.34	6.37	46	6.7	1.94%
3	10	⅜	71.26	0.110	827	120	58.72	13.20	46	6.7	1.79%
4	13	½	126.7	0.196	758	110	95.90	21.56	46	6.7	1.64%
5	16	⅝	197.9	0.307	724	105	143.41	32.24	46	6.7	1.57%
6	19	¾	285.0	0.442	690	100	196.60	44.20	46	6.7	1.49%
7	22	⅞	387.9	0.601	655	95	254.00	57.10	46	6.7	1.42%
8	25	1	506.7	0.785	620	90	314.27	70.65	46	6.7	1.34%
9	29	1-⅛	641.3	0.994	586	85	375.83	84.49	46	6.7	1.27%
10	32	1-¼	791.7	1.227	551	80	436.60	98.16	46	6.7	1.19%
11*	35	1-⅜	958.1	1.485	*482*	*70*	*462.40*	*104**	46	6.7	1.04%
12*	38	1-½	1160	1.800	*448*	*65*	*520.40*	*117**	46	6.7	0.97%
13*	41	1-⅝	1338	2.074	*413*	*60*	*553.50*	*124**	46	6.7	0.90%

* Tensile properties of #11, #12 & #13 bar are NOT guaranteed due to the inability to achieve a valid bar break per ASTM D7205.

Hughes Brothers reserves the right to make improvements in the product and/or process which may result in benefits or changes to some physical-mechanical characteristics. The data contained herein is considered representative of current production and is believed to be reliable and to represent the best available characterization of the product as of July 2011. Tensile tests per ASTM D7205.

Design Tensile & Modulus Properties

Tensile and Modulus Properties are measured per ASTM D7205-06, Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars. The ultimate tensile load is measured and the tensile modulus is measured at approximately 10% to 50% of the ultimate load. The slope of the stress-strain curve is determined as the tensile modulus. Ultimate Strain is extrapolated from the ultimate load divided by the nominal area and modulus. The area used in calculating the tensile strength is the nominal cross sectional area.

The “Guaranteed Tensile Strength”, f^*_{fu} is as defined by ACI 440.1R as the mean tensile strength of a given production lot, minus three times the standard deviation or $f^*_{fu} = f_{u,ave} – 3\sigma$.

The “Design or Guaranteed Modulus of Elasticity is as defined by ACI 440.1R as the mean modulus of a production lot or $E_f = E_{f,ave}$.

Material Certs & Traceability

Material test certs are available for any production lot of Aslan 100 bar. 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 bar diameter, stock order and production date. In addition to ASTM D7205 Tensile, Modulus and Strain values, the test cert includes a full accounting of various additional properties and lab tests performed on the production lot.

Aslan FRP

Cross Sectional Area

The design properties are determined using "Nominal" diameters and equivalent calculated cross sectional areas. Surface undulations and sand coatings that facilitate bond are accommodated in ASTM D7205, section 11.2.5, with a tolerance of minus zero, plus 20% as determined by the Archimedes method of volume displacement in a fluid.

Characteristic Properties

Characteristic Properties are those that are inherent to the FRP bar and not necessarily measured or quantified from production lot to production lot.

Bond

Bond to concrete is achieved in the Aslan 100 series by means of a slight surface undulation created by an external helical wrap along with a sand coating. There are many different methods for measuring the bond characteristics of a bar with each test method providing a different value depending on the influences of the testing apparatus and method.

Lap Splice bond beam tests – Purdue University

As a means of determining "characteristic" bond strength, block pullout tests are often used as a relative gage of bond performance. However, to accurately define the bond strength it is necessary to perform full -scale beam or beam lap splice tests on a bar.

In consensus design guidelines such as ACI, CSA and AASHTO, perfect bond is assumed for flexural design. With any of the test methods for bond, caution is urged as a very wide scatter of statistical results is found depending on the strain in the bar in the test and inaccuracies involved in the measuring of crack widths.

The bond depended coefficient K_b is empirically derived from beam specimens where the dimensions of the beam, concrete strengths, bar properties and strain in the bars are carefully measured. After initial cracking has occurred, the crack widths are measured using LVDT's and the bond dependent coefficient for Aslan 100 GFRP bars is derived.

The K_b bond dependent coefficient for Aslan 100 GFRP bars is … **K_b = 0.90**
per ASTM draft test method. As used in ACI equation 8-9.

K_b testing – Kiewit Institute

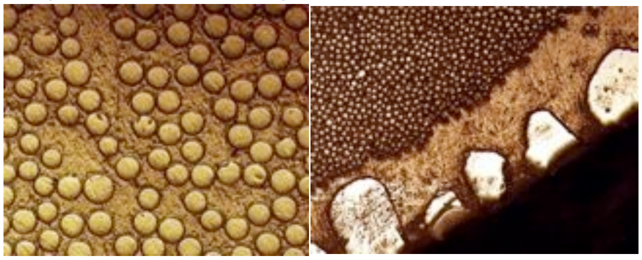
LVDT measuring Crack Width

Aslan 100 bars have been used in all the basic fundamental research studies that appear in peer review papers establishing the consensus design equations for serviceability, flexural capacity, crack widths and development lengths for FRP bars. The designer is urged to follow consensus equations in authoritative publications.

Aslan FRP

Durability - Alkali Resistance – without load

One of the main concerns about the use of Glass FRP's is the potential to be degraded in the long term by the high pH environment of the concrete itself. This phenomenon is analogous to an alkali silica reaction with certain types of aggregate. A great deal of research has been performed on this subject with the conclusion being that a properly designed and manufactured composite system of resin and glass can adequately protect the glass fibers from degradation.



Aslan 100 bar is made only from a vinyl ester resin matrix using ECR glass fibers. Selection of high caliber raw materials, which have appropriate "sizing chemistry" resulting in a good bond between the ECR fiber itself and the protective resin are a key to successful long term performance of the GFRP bar. For this reason the designer needs to be aware of short term and long-term properties of the GFRP bar.

To characterize the long term properties of the Aslan 100 bar, Hughes Brothers frequently subjects production lot samples to a 12.8pH alkaline solution, at 60 °C (140 °F) for 90 days and measures the residual tensile, modulus and strain properties of the sample.

Aslan 100 bars achieve residual tensile strength retention in excess of 80% making them a "D1" durability according to CSA Standard S-807.

Tensile modulus properties are typically not affected by the alkaline bath at elevated temperatures.

Subjecting the GFRP bars to an aqueous, high pH solution at elevated temperatures is not intended to be a perfectly accurate measure of the long term residual properties of the GFRP bar, rather its purpose is to differentiate high caliber GFRP bars from lesser quality ones. The unlimited supply of free ions in the purely aqueous elevated pH solution are much more harmful than actual field conditions. This conclusion is drawn from a series of tests performed on GFRP bars extracted from service in several structures across Canada by the ISIS research network that reveals NO DEGREDATION of GFRP bars after being in service for eight to ten years. At this time, there is no consensus as to what would be an accurate service life prediction model for the use of GFRP bars. Links to the complete ISIS findings are available at the Aslan FRP web site.

Transverse Shear Strength

The transverse shear strength of the Aslan 100 GFRP bars are frequently measured from random production runs. The testing is performed per ACI 440.3R test method B.4 and ASTM D7617. The property is consistent across bar diameters. *Transverse Shear Strength = 22,000 psi (150MPa)*

Coefficient of Thermal Expansion

The Coefficient of Thermal Expansion or CTE of the GFRP bars is an inherent characteristic property and if sufficient concrete cover of two bar diameters is used, it is not an important design consideration. This is because there is not enough radial force to cause reflective concrete cracking if adequate concrete confinement is present. These findings are elaborated in the work of Aiello, Focacci & Nanni in ACI Materials Journal, Vol. 98 No. 4, July-Aug 2001, pp. 332-339 "Effects of Thermal Loads on Concrete Cover of FRP Reinforced Elements: Theoretical and Experiential Analysis." Further, the transverse CTE is a non-linear property and affected by the helical wrap on the Aslan 100 bar. Differing labs achieve a wide scatter in measured CTE results depending on the test method and set-up.

Creep Rupture / Sustained Loads

FRP bars subjected to a constant load over time can suddenly fail after a time period called the endurance time. The endurance time is greatly affected by the environmental conditions such as high temperature, alkalinity, wet and dry cycles, freezing and thawing cycles. As the percentage of sustained tensile stress to short-term strength of the bar increases, the endurance time decreases. For this reason, the design limits on GFRP bars in consensus standards limit sustained loads on GFRP bars to very low levels of utilization. The design professional should use the appropriate consensus guideline for creep rupture stress limits.

Density

GFRP bars are approximately one fourth the weight of steel rebar.

Diameter			Unit Weight / length	
Size	mm	in	kg / m	lbs / ft
2	6	¼	0.0774	0.052
3	10	⅜	0.159	0.107
4	13	½	0.2813	0.189
5	16	⅝	0.4271	0.287
6	19	¾	0.6072	0.408
7	22	⅞	0.8096	0.544
8	25	1	1.0462	0.730
9	29	1-⅛	1.4137	0.950
10	32	1-¼	1.7114	1.15
11	35	1-⅜	1.9346	1.30
12	38	1-½	2.4554	1.65
13	41	1-⅝	2.8721	1.93

Bent Bars & Stirrups

Most industry standard bent shapes are available in Aslan 100 GFRP bar with some exceptions as noted herewith. Standard shape codes are used.

All bends must be made at the factory. Field bending of FRP bars is not possible. This is because the bent bars must be formed in the factory while the thermo-set resin is uncured. Once the resin is cured, the process cannot be reversed.

We advise that you work closely with the factory to implement the most economical detailing of bent bars and stirrups.

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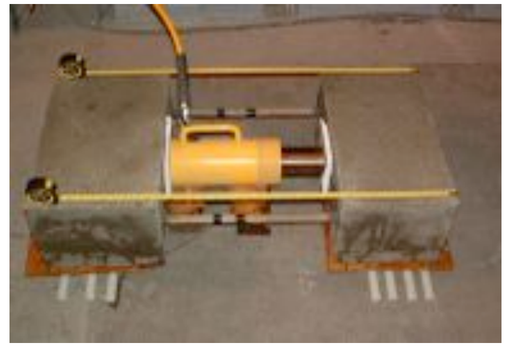
Strength of the Bent Portion of the Bar

All FRP bars exhibit a strength reduction through the bent portion of the bar, which is recognized by all the consensus design guidelines.

Testing per ACI440.3R test method B.5, "Test method for strength of FRP bent bars and stirrups at bend locations" show that Aslan 100 bar are nearly twice the strength of the design levels in the guidelines.



Detailing Limitations

While most standard steel rebar shapes are available, there are a handful of limitations that influence the economics of the detailing.

Closed square shapes are not available. They must be furnished as either pairs of U-bars or a continuous spiral. Generally, pairs of U-shaped bars are more economical.

Z-shapes or gull-wing type configurations are not very economical.

A 90-degree bend with $12d_b$, bar diameter, pigtail used to shorten development length is just as effective as a J-shape as per ACI 440.1R.

The maximum leg length on any bend is 5 ft (1.5 m).

The radius on all bends is fixed as per the following table. Accordingly, some U-shaped stirrups that fall in between the range of these two bend radiuses are not possible.

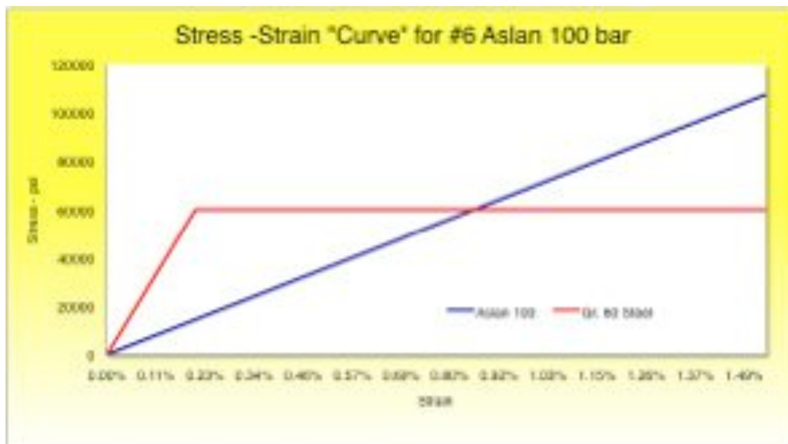
Diameter			Inside Bend Radius	
Size	mm	in	mm	in
2	6	¼	38	1.5
3	10	⅜	54	2.125
4	13	½	54	2.125
5	16	⅝	57	2.25
6	19	¾	57	2.25
7	22	⅞	76	3.0
8	25	1	76	3.0

Field Forming of Large Radius Curves

Due to the low modulus of the Aslan 100 GFRP bar, it is possible to field form the bar into large radius curves. This induces a bending stress in the bar. A radius smaller than those in the following table would exceed the long term sustained stresses allowable. The table gives the minimum allowable radius for induced bending stresses without any consideration for additional sustained structural loads.

Diameter			Interior Use $C_e = 0.8$ Min Radius		Exterior Use $C_e = 0.7$ Min Radius	
Size	mm	in	cm	in	cm	in
2	6	¼	107	42	122	48
3	10	⅜	170	67	196	77
4	13	½	246	97	282	111
5	16	⅝	323	127	368	145
6	19	¾	404	159	462	182
7	22	⅞	495	195	566	223
8	25	1	597	235	678	267
9	29	1-⅛	711	280	813	320
10	32	1-¼	871	343	996	392
11	35	1-⅜	1052	414	1204	474
12	38	1-½	1237	487	1412	556
13	41	1-⅝	1448	570	1656	652

Design Considerations



There are a number of authoritative consensus design guidelines for the designer to follow. Generally the design methodology for FRP reinforced concrete members follows that of steel reinforcing but taking into account the linear elastic or non-ductile nature of the material with different safety factors. Care is taken to avoid the possibility of a balance failure mode where concrete crushing and rupture of the bar could occur simultaneously.
The designer must choose between compression failure of concrete, which is the preferred mode, and rupture of the FRP bar with a higher factor of safety.

Due to the low modulus of elasticity of FRP bars, serviceability issues such as deflections and crack widths generally control design.

The compressive strength of FRP bars is disregarded in design calculations.

Although the FRP bars themselves are not ductile, an FRP reinforced concrete section is characterized by large deformability i.e. significant deflections and crack widths are a warning of pending failure of the section.

The designer should follow the recommendations in the appropriate consensus design guideline. To aid the designer who might not be familiar with these guides and standards, Hughes Brothers maintains a staff of registered professional engineers to assist the engineer of record in safely implementing our products.

Design Guides

ACI 440.1R "Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars"

The American Concrete Institute 440 guide is a mature and living document that has undergone a number of revisions since its first publication in 2001.

Companion documents to the 440.1R design guide include the ACI 440.3R "Guide Test Methods for FRP's for Reinforcing or Strengthening Concrete Structures" which is intended as an interim document superseded by new ASTM test methods as they become available. The ACI 440.5 "Specification for Construction with Fiber Reinforced Polymer Reinforcing Bars" and ACI 440.6 "Specification for FRP Bar Materials for Concrete Reinforcement" give guidance in mandatory language for the use and specification of FRP bars.

ACI also offers a number of professional educational materials and special publications and proceedings specifically addressing internal FRP reinforcing bars.

AASHTO LRFD Bridge Design Guide Specifications for GFRP Reinforced Concrete Bridge Decks and Traffic Railings

Published in November 2009, this document offers authoritative design guidance to the bridge design community in safely adopting FRP bars in bridge decks and railings.

CSA S-806

The Canadian designer has the luxury of utilizing the S806 document "Design and Construction of Building Components with Fibre-Reinforced Polymers".

CSA S-6 Canadian Highway Bridge Design Code

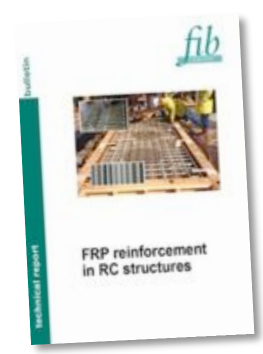
Widespread adoption of GFRP bars in Canadian bridge structures is being made possible by this important document.

CSA S-807 Specification for Fibre-Reinforced Polymers.

This specification offers guidance in terms of limits of constituent materials for FRP bars, criteria for qualification of FRP bar systems, manufacturers quality control reporting and owners acceptance criteria. The specification provides a framework for owners to use to pre-qualify FRP bar suppliers for bidding on major public works projects and for the manufacturers reporting of specific, traceable production lot properties and acceptance limits.

FIB Task Group 9.3 – bulletin 40 "FRP Reinforcement in RC Structures"

In Europe, the Federation Internationale du Beton FIB Task Group 9.3 has published a technical report "Bulletin 40", which is a "state of the art" of FRP reinforcement in RC structures. Work is under way on provisions for FRP bars in EuroCode 2 format. Norway and Italy have published internal design codes for the use of FRP bars.



Aslan FRP

Quality Assurance Tests

Quality Assurance Tests are performed on each production lot and are indicative measures to short and long term performance of the FRP bar.

Void Content

Each production run of Aslan 100 is sampled to screen for longitudinal thermal or mechanical cracks as well as continuous hollow fibers. No continuous voids are permitted after 15 minutes of capillary action. Testing performed per ASTM D5117.

Fiber Content

Fiber content or fiber volume fraction is a key variable in the overall mechanical properties of the FRP bar.

Fiber Content by weight > 70% by weight per ASTM D2584

Moisture Absorption

Susceptibility to moisture absorption is a key indicator of successful long-term durability. Testing per ASTM D570.

24 hour absorption at 122°F (50°C) ≤ 0.25%

At saturation ≤ 0.75%

Transition Temperature of Resin - T_g

Known as the “glass transition temperature” or the temperature at which the resin changes from a “glassy state” and begins to soften. *Tg = 230°F (110°C)*

Tensile Strength at Cold Temperature

As compared to properties at ambient conditions, temperatures at low as *-40°F (-40°C)* have less than 5% effect on the tensile strength of the bar.

Valid Bar Break

When tensile tests are performed, a “valid bar break” occurs in the middle of the specimen and there are no influences from the anchorage or slippage.

Aslan FRP

Handling and Placement

Authoritative guidance for the specifier, in mandatory language, is given in ACI 440.5-08 “Specification for Construction with FRP Bars”, which details submittals, material delivery, storage, handling, permitted damage tolerances, bar supports, placement tolerances, concrete cover, tie-wire, field cutting and more. In general, the field handling and placement of FRP bars is similar to coated steel rebar (epoxy or galvanized), but with the benefit of weighing one-fourth the weight of steel.

Do Not Shear FRP bars. When field cutting of FRP bars is necessary, use a fine blade saw, grinder, carborundum or diamond blade.

Sealing the ends of FRP bars is not necessary.

Support chairs are required at two-thirds the spacing of steel rebar.

Plastic coated tie wire is the preferred option for most projects. When completely non-ferrous reinforcing, i.e., no steel is required in the concrete, nylon zip ties (available from local building materials centers) or plastic bar clips are recommended. (Don’t forget to use non-metallic form ties in formwork.)

It is possible, especially in precast applications, for GFRP bars to “float” during vibrating. Care should be exercised to adequately secure GFRP in the formwork.







Aslan 100 Fiberglass Rebar

Aslan 150 Series – “Passive Removable” Earth Anchor

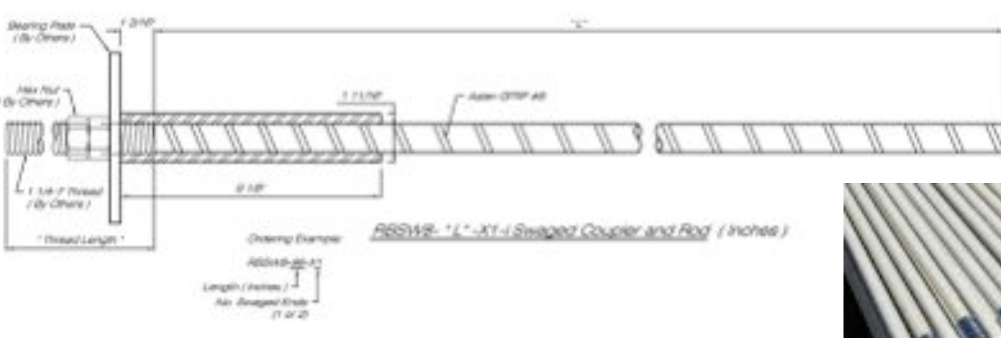
A proprietary steel anchorage can be affixed to an Aslan 100 GFRP bar, which develops the full tensile capacity of the bar. This offers the designer several unique benefits. The unique “anisotropic” property of GFRP bars makes them strong in tension, but easily consumed by excavation machinery of all types. For this reason, they can be considered “Removable Anchors” in the sense that they remain in place and do not disrupt future or adjacent construction activities.

Due to the relatively low levels of creep rupture sustained loads, the Aslan 150 series is considered “passive” rather than an active pre-stressed system. Sustained load limits in the table shown below are the same as those used when the GFRP bar is used as passive reinforcing for internally reinforced concrete members. The designer may choose to be less conservative based on their judgement of the circumstances.

Mechanical Load Ratings

Size		Diameter		Area		Ultimate Load		Sustained Load	
Imp.	SI	(in)	(mm)	in^2	mm^2	kips	kN	kips	kN
#6	19	0.75	19.05	0.44	285	30	138	6	27.6
#7	22	0.88	22.23	0.60	388	40	178	8	35.6
#8	25	1.00	25.40	0.79	507	50	220	10	44.0
#9	29	1.13	28.58	0.99	641	60	263	12	52.6
#10	32	1.25	31.75	1.23	792	70	306	14	61.2

Ultimate Load rating defined as in ACI440.1R-06 f_{fu}* = guaranteed ultimate tensile strength (as measured by ASTM D7205 test methods) X C_e = 0.70 environmental degradation factor. Sustained Load ratings based on ACI440.1R-06 guidance: f_{fu}* X C_e X 0.20 Creep Rupture Strain limits. Material lot test reports available upon request.



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Utah DOT – Emma Park Bridge Precast Deck Panels

Utah DOT – Emma Park Bridge Precast Deck Panels

Texas DOT – High Speed Tolling – Tie Bars

West Virginia – CRCP Paving

Miami MetroRail – Concrete Plinths for electrical isolation

Miami MetroRail – Deck Bars for electrical isolation in Segmental Precast

Aslan FRP

Bulk Lifts Ready for Shipping

20ft Stock Lengths

Hughes Brothers Factory – Seward NE

Missouri DOT – Boone Co Bridge

Floodway Bridge – Winnipeg, Manitoba

Aslan FRP