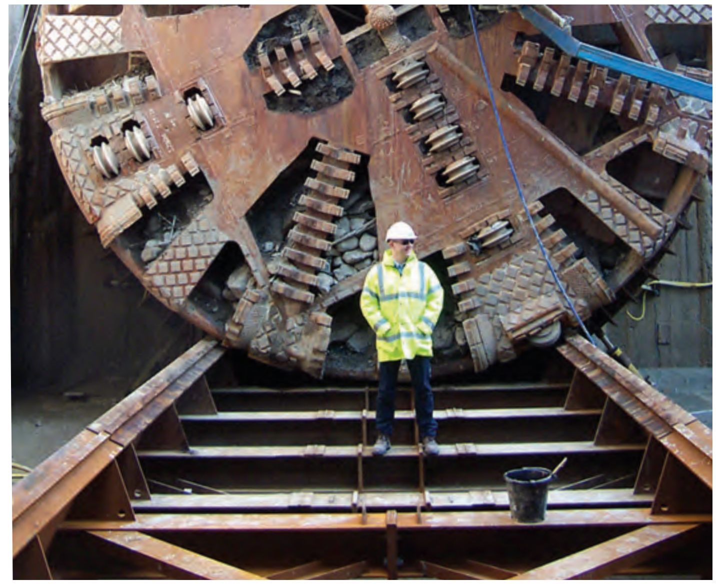
ASLAN™ 100 FIBERGLASS REBAR

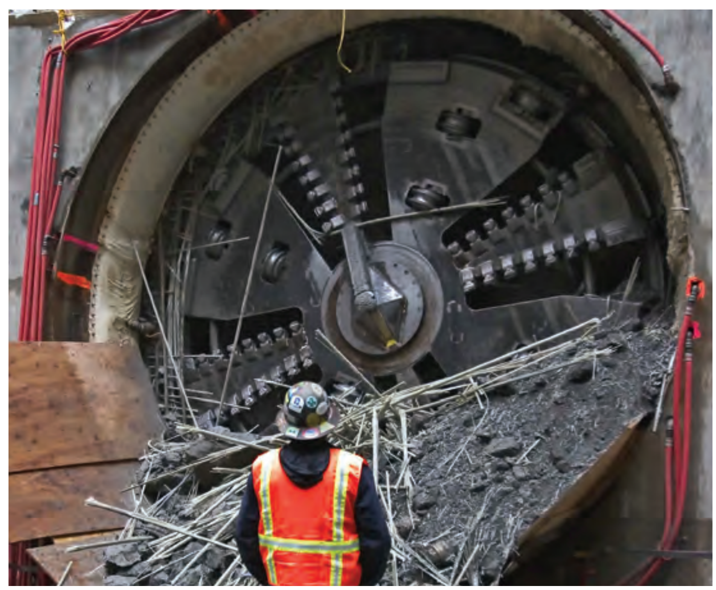
SETTING THE BAR IN SOFT-EYE OPENINGS

FOR TUNNEL BORING MACHINES

Easily Consumable | 4x Lighter than Steel

ASLAN™ 100 PROJECT EXAMPLES





ASLAN™ 100 FRP REBAR

A TRUE SOLUTION FOR SOFT EYE-OPENINGS

A unique use of Aslan™ FRP bars takes advantage of their “anisotropic” property, meaning they are strong along the main axis, but can be machined, abraded away or “consumed” by excavation equipment such as Tunnel Boring Machines. Beginning in 1998, Aslan™ FRP pioneered the use of FRP rebar in a soft-eye opening for the Bangkok Metro. General Contractors in projects world-wide began to realize the benefits of using Aslan™ FRP rebar in deep foundation diaphragm walls in allowing TBM’s to drive directly through the “soft-eyeopening” to launch and retrieve TBM’s.

Since 1993, we have been at the forefront of worldwide academic and industry efforts to define consensus standards and methods. The use of FRP bars in soft-eye openings for soft earth TBMs is now a standard practice. Well over 300 soft-eye openings have been successfully completed using Aslan™ FRP bars.

Aslan™ FRP Bars in Deep Foundation Diaphragm Walls

- Slurry Walls
- Cast in Drilled Hole Pile Walls
- Secant Pile Walls

Aslan™ 100 FRP Bars

- Resist large forces associated with Deep Foundations
- Are used in many permanent structures
- Use is based on authoritative consensus design guidelines
- Easily consumed by TBM's
- Available in straight lengths, bent stirrups and continuous spiral hoops

Tunneling & Mining

- Sequential Excavation or NATM Tunneling
- Soil Nails & Earth Retention
- Rock Bolts & Cable Bolts

Experience From Many Other Applications

+ Bridge Decks
+ Median Barriers
+ Continuously Reinforced Concrete Paving
+ Precast Concrete
+ Sea Walls, Wharfs, Quays & Dry Docks
+ Light & Heavy Rail 3rd Rail Isolation
+ High Voltage Substations
+ Hospital MRI Rooms
+ Waste Water Treatment Plants

BENEFITS & MECHANICAL PROPERTIES

Benefits

- Eliminate the need for a pressure grout block: Substantial time & construction cost savings
- TBM passes directly through the diaphragm wall: Speeds up construction schedule
- TBM can pass through station box prior to excavation
- Improved safety with no workers needing to enter shaft to manually cut through reinforcing
- Lightweight material results in easy cage construction

Mechanical Properties

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	1/4	31.67	0.049	896	130	28.34	6.37	46	6.7	1.94%
3	10	3/8	71.26	0.110	827	120	58.72	13.20	46	6.7	1.79%
4	13	1/2	126.7	0.196	758	110	95.90	21.56	46	6.7	1.64%
5	16	5/8	197.9	0.307	724	105	143.41	32.24	46	6.7	1.57%
6	19	3/4	285.0	0.442	690	100	196.60	44.20	46	6.7	1.49%
7	22	7/8	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	1-1/8	641.3	0.994	586	85	375.83	84.49	46	6.7	1.27%
10	32	1-1/4	791.7	1.227	551	80	436.60	98.16	46	6.7	1.19%
11*	35	1-3/8	958.1	1.485	482	70	462.40	104*	46	6.7	1.04%
12*	38	1-1/2	1160	1.800	448	65	520.40	117*	46	6.7	0.97%
13*	41	1-5/8	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. We reserve 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 $f^*_{fu} = fu_{,ave} - 3\sigma$. The “Design or Guaranteed Modulus of Elasticity is as defined by ACI 440.1R as the mean modulus of a production lot or $E_f = Ef_{,ave}$.

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.

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.

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.

Aslan™ 100 bars have been used in all the basic fundamental research studies that appear in peer review papersestablishing 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.

Transverse Shear Strength

The transverse shear strength of the Aslan™ 100 FRP 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 FRP 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 FRP bars in consensus standards limit sustained loads on FRP bars to very low levels of utilization. The design professional should use the appropriate consensus guideline for creep rupture stress limits. Often, reduction factors are set to one for soft-eye openings.

Density

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

NOMINAL DIAMETER			UNIT WEIGHT/LENGTH	
Size	mm	in	kg/m	lbs/ft
2	6	1/4	0.0774	0.052
3	10	3/8	0.1590	0.107
4	13	1/2	0.2813	0.189
5	16	5/8	0.4271	0.287
6	19	3/4	0.6072	0.408
7	22	7/8	0.8096	0.544
8	25	1	1.0462	0.730
9	29	1-1/8	1.4137	0.950
10	32	1-1/4	1.7114	1.15
11*	35	1-3/8	1.9346	1.30
12*	38	1-1/2	2.4554	1.65
13*	41	1-5/8	2.8721	1.93

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% minimum by weight per ASTM D2584

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. T_g = 230°F (110°C)4

BENT BARS AND STIRRUPS

Most industry standard bent shapes are available in Aslan™ 100 FRP 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.

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.

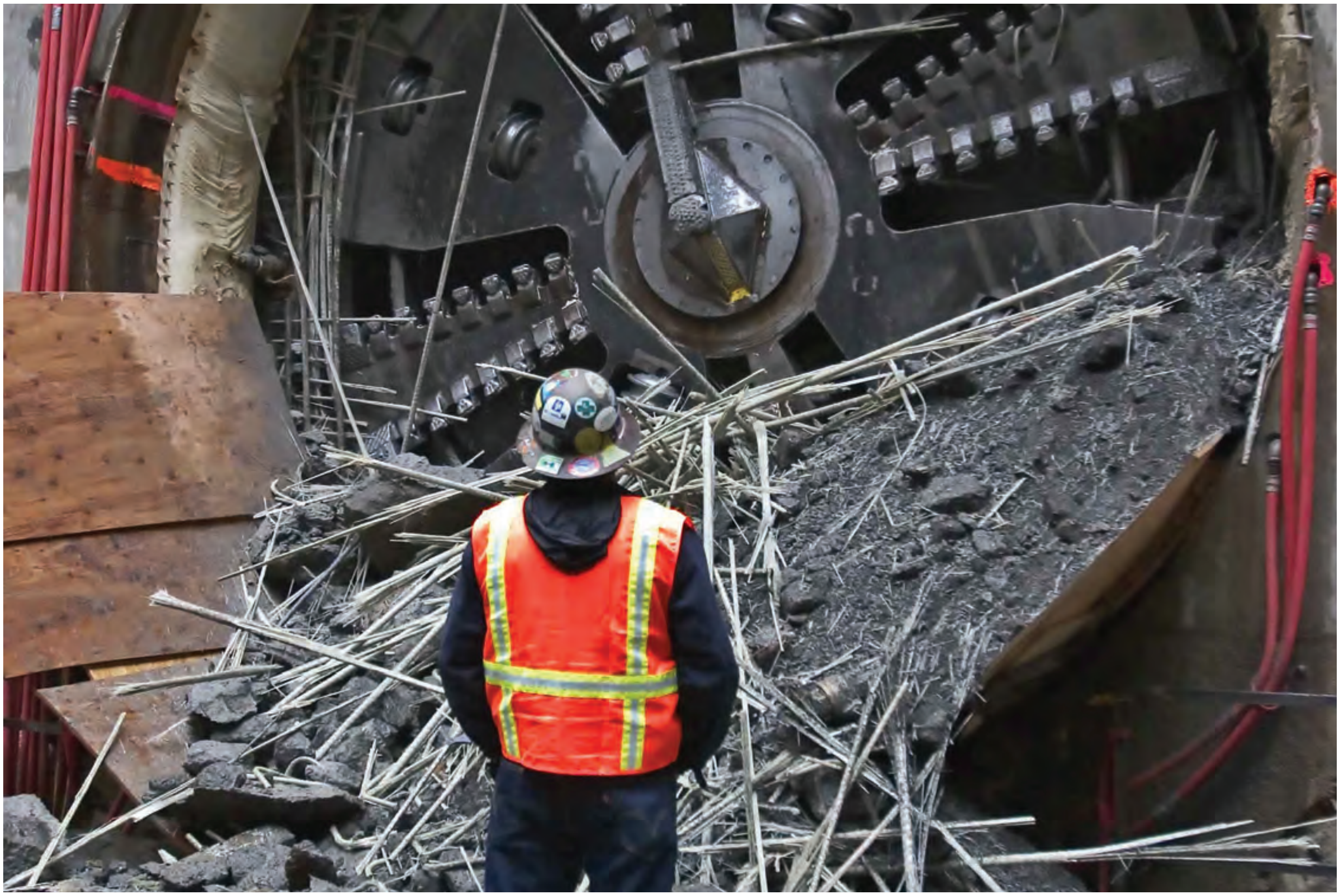
Testing per ACI440.3R test method B.5, "Test method for strength of FRP bent bars and stirrups at bend locations" show that Aslan™ 100 bar are nearly twice the strength of the design levels in the guidelines.

NOMINAL DIAMETER			**INSIDE BEND RADIUS**	
Size	mm	in	mm	in
2	6	1/4	38	1.5
3	10	3/8	54	2.125
4	13	1/2	54	2.125
5	16	5/8	57	2.25
6	19	3/4	57	2.25
7	22	7/8	76	3.0
8	25	1	76	3.0

Field Forming of Large Radius Curves

Due to the low modulus of the Aslan™ 100 FRP 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.

NOMINAL 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	1/4	107	42	122	48
3	10	3/8	170	67	196	77
4	13	1/2	246	97	282	111
5	16	5/8	323	127	368	145
6	19	3/4	404	159	462	182
7	22	7/8	495	195	566	223
8	25	1	597	235	678	267
9	29	1 1/8	711	280	813	320
10	32	1 1/4	871	343	996	392
11*	35	1 3/8	1052	414	1204	474
12*	38	1 1/2	1237	487	1412	556
13*	41	1 5/8	1448	570	1656	652



DESIGN GUIDES & QUALITY ASSURANCE TESTS

Design Considerations

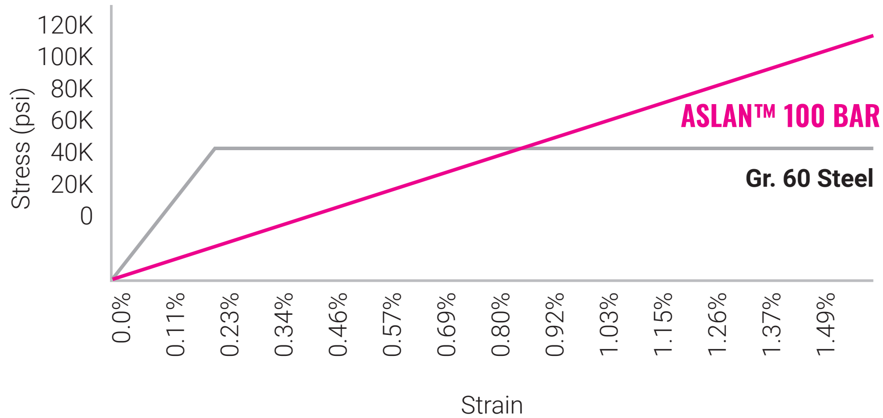
There are a number of authoritative consensus design guidelines for the designer to follow. Generally the design methodology for FRP reinforced concrete members follows that of steel reinforcing but taking into account the linear elastic or non-ductile nature of the material with different safety factors. 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, we maintain a staff of registered professional engineers to assist the engineer of record in safely implementing our products.

Stress-Strain "Curve" for #6 Aslan™ 100 Bar



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 a new material standard – ASTM D7957 Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars 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.

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.

Full Scale Testing - Soft-Eye Unit Strip

In 2006, in conjunction with the University of Missouri Rolla, we under took full scale testing of a unit strip of a typical soft-eye diaphragm wall in order to validate the design provisions of ACI 440.1R when applied to these very deep beams.

Results validate the design provisions of the 440.1R document when Aslan™ 100 FRP bars are used. The complete report is available upon request.

FRP CAGE INSTALLATION

Handling & 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. Plastic coated tie wire is the preferred option for most projects. It is possible, especially in precast applications, for FRP bars to “float” during vibrating. Care should be exercised to adequately secure FRP in the formwork.

Fabrication of GFRP Diaphragm Wall Cage

In general, placing FRP bars is similar to placing steel bars. Lathers will greatly benefit from the fact that FRP bars are 1/4th the weight of steel bars. The FRP cage is constructed in the same manner as the fabrication of ordinary steel diaphragm wall cages. Recommended practices and tolerances for construction and materials should apply with some exceptions for the specifications prepared by the engineer as noted:

1. Cage should be fabricated on steel or wooden support blocks to prevent the cage from being laid directly on the ground. This prevents the FRP rebars from being contaminated by substances on ground, which in turn affects the bond. Note that due to the relative lower stiffness of FRP rebars, the supports for fabrication should be placed at closer spacing at the FRP rebar portion of the cage.
2. On site bending of FRP bars on site is not permitted, because they are made with thermoset resin.
3. Lap splices between vertical steel and FRP rebars are needed in the outside periphery of the soft eye opening (bored area). Steel U-bolts or steel straps are recommended for fixing the lap splices between steel and FRP bars. The number of U-bolts or straps should be enough to develop sufficient strength of the connection to hold its self-weight during the lifting operation and this should be determined by the site engineer.
4. For tying bar intersections other than lapping of vertical rebars, ordinary steel wires, coated tie wires or plastic snap ties can be used. Also, Aslan™ FRP bars can be connected to steel bars via a proprietary swaged coupler that develops the full capacity of the FRP bar.
5. Due to the lower stiffness of FRP rebars compared to steel, the hybrid rebar cage should be stiffened before lifting. A temporary bracing frame, commonly made of steel rebars diameter 32 or 40 mm, or temporary “strong-back” frame is typically used. A frame should be attached to the cage by using U-bolts or other temporary means such that the support frame can be easily removed then the cage is lowered into position.

Installation of FRP Soft-Eye Cage

1. The fabricated hybrid rebar cage must be first lifted to vertical. During this lifting operation, care should be taken to ensure the stability and integrity of the cage is maintained. Lifting loops should be provided at the top of the cage during fabrication. The cage should be suspended with the crane hooks in at least 2 points: one close to the top and another one close to the bottom of the cage. For larger cages, one more lifting points and the use of a spreader bar may be necessary at the middle of the cage to prevent the excessive bending.
2. Once the cage is in vertical plane, move the cage to the excavation position. The temporary bracing frame must be removed prior to the cage being lowered into the slurry.

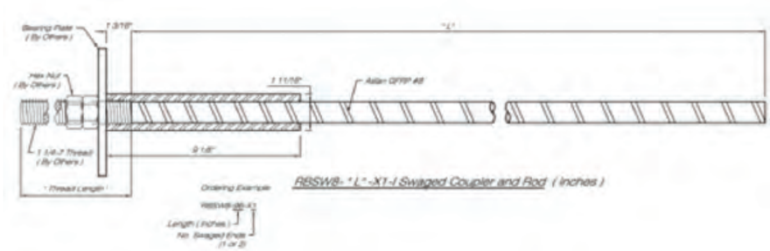
ASLAN™ 150 SERIES

“Passive Removable” Earth Anchor

A proprietary steel anchorage can be affixed to an Aslan™ 100 FRP bar, which develops the full tensile capacity of the bar. This offers the designer several unique benefits. The unique “anisotropic” property of FRP 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 FRP bar is used as passive reinforcing for internally reinforced concrete members. The designer may choose to be less conservative based on their judgment of the circumstances.

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



ASLAN™ 250 SERIES

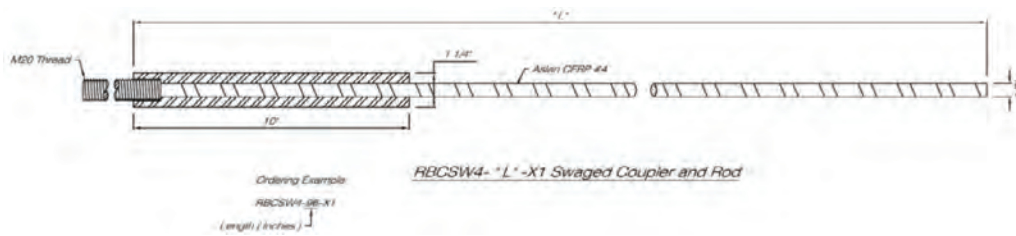
Tendon / “Active Removable” Earth Anchor

A proprietary steel anchorage can be affixed to an Aslan™ 200 Carbon or CFRP bar, which develops the full tensile capacity of the bar. The addition of a factory-affixed anchorage makes the designation “Aslan™ 250 series”. In addition to its inherent non-corrosive nature, the unique “anisotropic” property of CFRP 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. Aslan™ 250 series is considered an “active” pre-stressed system. Sustained load limits in the table shown below are the same as those used in ACI 440 guidelines. The designer may choose to be less conservative based on their judgment of the circumstances.

SIZE		DIAMETER		AREA		ULTIMATE LOAD		JACKING LOAD = 0.65 F_{PU}		PREESTRESS LOAD	
IMP.	SI	IN	MM	IN^2	MM^2	KIPS	KN	KIPS	KN	KIPS	KN
#3	10	0.375	9.5	0.110	71.26	34.65	154.1	24.49	100	17.15	76.29
#4	13	0.500	12.7	0.196	126.7	58.80	261.6	38.22	170	29.10	129.40

Relaxation

Relaxation losses (REL) of the Aslan™ 250 tendon are negligible at Jacking Loads.



Multi-Tendon

Combining multiple Aslan™ 250 tendons with a steel load bearing head allows for much higher load capacities and enables the use of traditional jacking systems in the field. The Aslan™ 250 tendons are corrosion free and due to their “anisotropic characteristics” will not encumber future adjacent land use. Corrosion mitigation is only necessary at the face where it can be monitored.

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