Neuvokas Corporation Design and Installation Manual for GatorBar®

Revision 01 – Released 2021-03-12

Document # D-IM-GatorBar

Questions or Comments can be addressed to Neuvokas Corporation with contact information listed below

Neuvokas Corporation

PO Box 220

3206 #6 Road

Ahmeek, MI 49901

906-934-2661

info@neuvokascorp.com

Company and Product websites

www.gatorbar.com

www.neuvokascorp.com

Contents

1.0 Introduction

The purpose of this design and installation manual is to provide design guidelines as part of ESR-4526 per AC454. This document contains design equations, reference to other design tools, multiple design examples, and installation instructions/guidelines.

This document has been prepared using the following documents.

- ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (318R- -14)," American Concrete Institute, Farmington Hills, MI, 2011
- ACI Committee 440, "Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars
- "Reinforced Concrete with FRP Bars, Mechanics and Design", Nanni, Antonio, Antonio De Luca, and Hany Jawaheri Zadeh, 2014

2.0 GatorBar® FRP Rebar by Neuvokas

2.1 FRP Composite Description

GatorBar® by Neuvokas is a glass fiber reinforced composite rebar that is composed of fiber embedded in a polymer resin. Across the industry these products are known as glass fiber reinforced polymer (GFRP) rebar. At the date of this design manual release GatorBar can be purchased in #3 (0.375 inch) and #4 (0.5 inch) sizes but the ICC-ES evaluation report only covers the #3 rebar size.

2.2 GatorBar® Experimental Properties

The following values have been tested by a certified third party (University of Miami) and a copy of this report is available upon request. Sampling of test specimens was completed per ICC AC85 and ASTM D7957 requirements. The quantity of specimens for each experimental value were completed following ASTM D7957. Guaranteed properties are equal to the defined ACI 440 nomenclature. It should be noted that the tensile behavior of GFRP bars is characterized by a linear elastic stress-strain relationship until failure.

Property	Test or Calculation Method	Experimental Value	
Fiber Mass Content	ASTM D2584	80	%
Mean glass transition temperature	ASTM E1356	117	DegC
Mean Total Enthalpy of Resin	ASTM E2160	303	J/g
Guaranteed Ultimate Tensile Force	ASTM D7205	17.1	Kip
Tensile Modulus of Elasticity	ASTM D7205	6.81	Msi
Guaranteed Transverse Shear Strength	ASTM D7617	27	Ksi
Guaranteed Bond Strength	ASTM D7913	1.4	Ksi
Mean Moisture Absorption (24 hours)	ASTM D570	0.05	%
Mean Moisture Absorption to Saturation	ASTM D570	0.23	%
Mean Alkaline Resistance	ASTM D7705	80	%
k_b		1.4	

3.0 Installation Instructions

GatorBar® placement in concrete is no different than other composite rebar products. Neuvokas recommends following the American Concrete Institute (ACI) guidelines that are laid out in ACI 440.5-08. Section 3.2 – Bar Placement, which includes the following items

- Tolerances
- FRP reinforcement relocation
- Concrete cover
- FRP reinforcement supports

Other general installation comments are discussed below.

- Field Fabrication. Provide composite reinforcement in accordance with the details shown on the plans. The minimum bending radius is two feet and must utilize the necessary tying and stabilization methods to ensure reinforcement remains in the proper position before and during concrete placement. Field cut reinforcement may be accomplished using high speed grinding cutter, fine blade saw, diamond blade, or masonry blade.
- Handling. Bars can be handled similar to their steel counterparts. Minor scratches and chipping that do not impact performance may be permitted with approval of the Engineer.
- Storage of Reinforcement. Store reinforcement above the surface of the ground on platforms, skids, pallets, or other supports. If stored outside for an extended period of time GatorBar will

yellow and it can be covered if desired. Overall strength is not affected by this yellowing and GatorBar does not need to be covered.

- Placing and Fastening. Place all reinforcement within the tolerances recommended in the CRSI "Manual of Standard Practice" unless otherwise specified in the contract documents. Secure reinforcement firmly with mechanical fasteners during the placing and setting of the concrete. Suspend concrete placement and take corrective action if it is observed that the reinforcement is not adequately supported or tied to resist settlement, floating upward, or movement in any direction during concrete placement.
- Ties and Supports. It is recommended that all accessories for use with the bars such as tie wires, bar chairs, supports or clips are either plastic coated steel, stainless steel, galvanized steel or plastic, but that depending on engineering plans or application plain steel may be used. Place all reinforcement in locations as shown on the plans and securely hold in position while placing and consolidating concrete. Fasten bars together with ties at all intersections.
- Lap Splices. Lap splices are the only approved method to tie bars together to make a continuous bar. Mechanical splices are prohibited. Ensure lap length and spacing is as specified in the contract. Provide the same cover clearances for splices that is shown or specified for the reinforcement.

4.0 General Design Considerations

4.1 FRP Creep Rupture and Fatigue

To account for potential failure of FRP reinforcement due to creep rupture or fatigue, FRP stress at service shall be limited to 30% of the guaranteed and nominal tensile strengths, respectively.

4.2 Concrete Member Cross-Section

There is no restriction for the shape of the concrete member cross-section for flexure or shear.

4.3 FRP Bar Arrangement

- For flexural reinforcement, the use of multiple bar layers and bar bundling is permitted.

- For multiple bar layers, the relevant provisions for steel reinforcing bar in ACI 318 also apply to FRP bars. Because FRP materials have no plastic region, the stress in each reinforcement layer varies depending on its distance from the neutral axis. Thus, the analysis of the flexural capacity shall be based on a strain-compatibility approach.

- For bundled bars, all relevant provisions of ACI 318 apply.

5.0 Design Manual

This Design Manual is applicable to non-prestressed FRP bars that are solid and have circular cross sections. FRP bars under this Design Manual are used as:

- Flexural or shear reinforcement in structural concrete members such as beams, shallow foundations and one-way or two-way slabs, compressive strength of the reinforcement is ignored
- Vertical reinforcement in columns or walls.

5.1 Flexural Reinforcement:

5.1.1 Flexural and shear reinforcement in structural concrete members such as beams, shallow foundations and one-way or two-way slabs must follow the design provisions as given in Chapter 7 and 8 of ACI 440.1R-15.

5.1.2 Design examples given in ACI 440.1R can be used for guidance.

5.2 Notation

The following notation will be used in the design examples following within this report

Acp = area enclosed by outside perimeter of concrete cross section, in2.
Af = area of nonprestressed GFRP longitudinal tension reinforcement in2.
Af,min= minimum area of GFRP flexural reinforcement, in2.
Afv = area of GFRP shear reinforcement within spacing *s*, in2.
Afv,min = minimum area of GFRP shear reinforcement within spacing *s*, in2.
Ag = gross area of concrete section, in2. For a hollow section, *Ag* is the area of the concrete only and does not include the area of the void(s)
Ao = gross area enclosed by torsional shear flow path, in2.
Aoh = area enclosed by centerline of the outermost closed transverse GFRP torsional reinforcement, in2.
bw = web width or diameter of circular section, in.
CE = environmental reduction factor
db = nominal diameter of GFRP bar, wire, or prestressing strand, in.
fc′ = specified compressive strength of concrete, psi
ffb = design tensile strength of bent portion of GFRP reinforcement, psi
*ffb** = guaranteed tensile strength of bent portion of GFRP reinforcement, psi
ffd = tensile stress in the GFRP reinforcement corresponding to a strain of 0.01, psi
ffr = tensile stress in the GFRP reinforcement required to develop the full nominal sectional capacity, psi
ffs = tensile stress in GFRP reinforcement at service loads, excluding prestressing reinforcement, psi
ffs,sus = tensile stress in GFRP longitudinal reinforcement due to sustained service loads, psi
fft = specified yield design tensile strength of GFRP transverse reinforcement, psi
ffu = design tensile strength of GFRP longitudinal reinforcement, psi
*ffu** = specified yield guaranteed tensile strength of GFRP longitudinal for nonprestressed reinforcement, psi
fr = modulus of rupture of concrete, psi
h = overall thickness, height, or depth of member, in.
k = effective length factor for compression members
ℓc = length of compression member, measured center-to-center of the joints, in.
ℓd = development length in tension of deformed GFRP bar, deformed wire, plain and deformed welded wire reinforcement, or pretensioned strand, in.
ℓst = tension lap splice length, in.
ℓw = length of entire wall, or length of wall segment or wall pier considered in direction of shear force, in.
Mn = nominal flexural strength at section, in.-lb
Mu = factored moment at section, in.-lb
pcp = outside perimeter of concrete cross section, in.
Pn = nominal axial compressive strength of member, lb
Pn,max = maximum nominal axial compressive strength of a member, lb
Pnt = nominal axial tensile strength of member, lb
Pnt,max = maximum nominal axial tensile strength of member, lb
Po = nominal axial strength at zero eccentricity, lb
Pu = factored axial force; to be taken as positive for compression and negative for tension, lb
s = center-to-center spacing of items, such as longitudinal reinforcement, or transverse reinforcement, tendons, or anchors, in.
Tcr = cracking torsional moment, in.-lb

Tn = nominal torsional moment strength, in.-lb
Tth = threshold torsional moment, in.-lb
Tu = factored torsional moment at section, in.-lb
Vc = nominal shear strength provided by concrete, lb
Vf = nominal shear strength provided by GFRP shear reinforcement, lb
Vn = nominal shear strength, lb
Vu = factored shear force at section, lb
ε*ft* = net tensile strain in extreme layer of GFRP longitudinal tension reinforcement at nominal strength, excluding strains due to effective prestress, creep, shrinkage, and temperature
ε*fu* = design rupture strain of GFRP reinforcement, defined as the guaranteed tensile strain 549 multiplied by the environmental reduction factor (ε*fu*=*CE*ε*fu**)
ρ*f* = ratio of *As Af* to *bd*
ρ*f,st* = reinforcement ratio for temperature and shrinkage GFRP reinforcement
ρ*fb* = GFRP reinforcement ratio producing balanced strain conditions
ρfℓ = ratio of area of distributed GFRP longitudinal reinforcement to gross concrete area perpendicular to that reinforcement
ρ*ft* = ratio of area of distributed GFRP transverse reinforcement to gross concrete area perpendicular to that reinforcement
ρ*s* = ratio of volume of spiral reinforcement to total volume of core confined by the spiral, measured out-to-out of spirals
ϕ= strength reduction factor

5.3 Reinforcement in Columns

5.3.1 Scope

This chapter shall apply to the design of nonprestressed columns reinforced with GFRP bars, including reinforced concrete pedestals.

5.3.2 General

5.3.2.1 Materials

Modulus of rupture f_r shall be calculated by the equation shown in ACI 440.1R-15 7.3.2.3 due to the modification of the λ factor from that shown in ACI 318-14.

Exposure class of structure should be checked to determine maximum allowable crack width. Materials, design, and detailing requirements for embedment in concrete shall be in accordance with 20.7 of ACI 318-14 with the exception of reinforcement perpendicular to pipe embedment's and in this case shall be 0.004.

5.3.2.2 Connection to other members

The area of all legs of transverse reinforcement in each principal direction of beam-column and slab-column joints shall be at least the greater of (a) and (b).

(a) $0.75\sqrt{f'_c}\frac{b_w s}{f_{fv}}$

(b) $50\frac{b_w s}{f_{fv}}$

. It should be noted that the contribution of GFRP reinforcement to the nominal shear strength at the contact surface between supported member and foundation shall be verified by testing and the shear-friction provisions in Chapter 22 of the ACI 318-14 have not been verified for the GFRP reinforced concrete.

5.3.3 Design Limits

5.3.3.2 Strain Limits

If factored axial compression $P_u > 0.10f'_cA_g$, the tensile design strain of the longitudinal GFRP bars shall be limited to 0.01. The corresponding design strength, f_{fd}, shall then be calculated as:

f_{fd} = Min (f_{fu}, 0.01E_f)

5.3.4 Required Strength

5.3.4.1 General

Redistribution of moments calculated in accordance with plastic hinge regions is not permitted.

5.3.4.2 Factored axial force and moment

P_u and M_u occurring simultaneously for each applicable factored load combination shall be considered.

5.3.5 Design strength

5.3.5.1 General

For each applicable factored load combination, design strength at all sections shall satisfy $\phi S_n \geq U$, including (a) through (d). Interaction between load effects shall be considered:

(a) $\phi P_n \geq P_u$
(b) $\phi M_n \geq M_u$
(c) $\phi V_n \geq V_u$
(d) $\phi T_n \geq T_u$

5.3.5.2 Axial force and moment

P_n and M_n shall be calculated in accordance with Section 22.4 of ACI 318R-14 with maximum axial strength calculated per the table below.

Transverse Reinforcement	$P_{n,max}$	
Ties conforming to 22.4.2.4	$0.80P_o$	(a)
Spirals conforming to 22.4.2.5	$0.85P_o$	(b)

P_o should be calculated per the equation below for members reinforced with GFRP.

$$P_o = 0.85f'_cA_g$$

Nominal axial tensile strength of concrete members reinforced with GFRP should be calculated with the equation below

$$P_{nt,max} = f_{fu}A_f$$

5.3.5.3 Shear

- For solid, circular sections b_w shall be permitted to be taken as the diameter and d shall be permitted to be taken as 0.8 times the diameter.

$$V_u \leq \phi(0.2f'_cb_wd)$$

- The value of f_{fv} used to calculate V_f shall be smaller of $0.005E_f$ or f_{fb} where f_{fb} is defined in Chapter 20 of ACI 318R-14

- Section 22.5.4.1 of ACI 318R-14 provided that the composite action does not rely on GFRP dowel action.

- For members without axial force V_c shall be calculated as the greater of the equations below, where k is the ratio of the elastic cracked transformed section neutral axis depth to the effective depth and λ_s is the size effect factor in the table below.

  (a) $V_c = 5k\lambda_s\sqrt{f'_c}b_w d$

  (b) $V_c = 0.8\lambda_s\sqrt{f'_c}b_w d$

Size effect factor λ_s

Criteria	λ_s
$A_v < A_{v,min}$	$\sqrt{\frac{2}{1+(\frac{d}{10})}} \leq 1.0$
$A_v \geq A_{v,min}$	*1.0*

$A_{v,min}$ for beams and one-way slabs is defined in chapter 9 of ACI 318R-14

- For members with axial compression, V_c shall be the greater of Equation (a) or (b), where axial compression may be taken into consideration in the calculation of the ratio of the elastic cracked transformed section neutral axis depth to the effective depth, k

- The value used for the ratio of elastic cracked transformed neutral axis depth to the effective depth of the section k shall not exceed 1.0 in Equation (a).

- In the presence of the sustained axial load results in compressive stress over the entire cross section (i.e. $k = h/d \geq 1$) and upper limit of $k=1$ is imposed in Equation (a).

- For solid, circular sections, $b_w kd$ shall be replaced by the compression area of the elastic cracked transformed section in Equation (a) and b_w shall be permitted to be taken as the diameter and d shall be permitted to be taken as 0.8 times the diameter in Equation (b).

- V_c for members with significant axial tension, V_c shall be calculated by Equation (a) where the axial tension shall be taken into consideration in the calculation of the ratio of cracked transformed section neutral axis depth to the effective depth, k. Should the presence of axial load result in tensile stress over the entire cross section, shear reinforcement shall be designed to resist total shear.
- V_f for shear reinforcement shall be calculated by

$$V_f = A_{fv} f_{fv} \frac{d}{s}$$

Where s is the spiral pitch or the longitudinal spacing of the shear reinforcement and A_{fv} is given in Chapter 22 of ACI 318R-14. For solid, circular sections d shall be permitted to be taken as 0.8 times the diameter

- V_c shall be calculated in accordance with equations below

$V_c = 10\lambda_s k\sqrt{f'_c}$ (a)

But V_c need not be less than

$$V_c = 1.6\lambda_s\sqrt{f'_c}$$

Where k is the ratio of the elastic cracked transformed section neutral axis depth to the effective depth and λ_s is the size effect factor

5.3.5.4 Torsion

If $T_u \geq \phi T_{th}$, where T_{th} is given in Section 22.7 of ACI 318-14 with the following revisions, torsion shall be considered in accordance with Chapter 9 of the ACI 318R-14 with the following revisions.

- Hollow members in torsion cannot be considered

- The value of f_{ft} for transverse torsional reinforcement shall not exceed the smaller of $0.005E_f$ or f_{fb} where f_{fb} is defined

- Threshold torsion for solid cross sections

Type of member	T_{th}	
Member not subjected to axial force	$\sqrt{f'_c\left(\frac{A_{cp}^2}{p_{cp}}\right)}$	(a)
Member	$\sqrt{f'_c}\left(\frac{A_{cp}^2}{p_{cp}}\right)\sqrt{1+\frac{N_u}{4A_g\sqrt{f'_c}}}$	(b)

- Cracking Torsion

Type of member	T_{cr}	
Member not subjected to axial force	$4\sqrt{f'_c\left(\frac{A_{cp}^2}{p_{cp}}\right)}$	(a)
Member	$4\sqrt{f'_c}\left(\frac{A_{cp}^2}{p_{cp}}\right)\sqrt{1+\frac{N_u}{4A_g\sqrt{f'_c}}}$	(b)

- Torsional Strength T_n shall be less of (a) or (b) below.

(a) $T_n = \frac{2A_0A_{ft}f_{ft}}{s}$

(b) $T_n = \frac{2A_0A_{ft}f_{fu}}{p_h}$

- Cross-sectional dimension shall be selected such that for solid sections

$$\sqrt{\left(\frac{V_u}{b_w d}\right)^2 + \left(\frac{T_u p_h}{1.7 A_{oh}^2}\right)^2} \leq \phi\,(0.2 f_c')$$

5.3.6 Reinforcement limits

5.3.6.1 Minimum and maximum longitudinal reinforcement

Area of longitudinal reinforcement shall be at least $0.01A_g$ but shall not exceed $0.08A_g$.

5.3.6.2 Minimum Shear Reinforcement

Minimum area of shear reinforcement, $A_{fv,min}$ shall be provided in all regions where $V_u > 0.5\phi V_c$

*If s*hear reinforcement is required, $A_{fv,min}$-shall be the greater of (a) and (b):

(a) $0.75 * \sqrt{f_c{}'}\frac{b_w s}{f_{fv}}$

(b) $50 * \frac{b_w s}{f_{fv}}$

5.3.7 Reinforcement detailing

5.3.7.1 General

Concrete cover for reinforcement shall be in accordance with Chapter 20.6 of ACI 318R-14 and utilizing the table below.

Concrete Exposure	**Member**	**Reinforcement**	**Specified Cover, in**
Cast against and permanently in contact with ground	All	All	3
Exposed to weather	All	No. 5 bar and smaller	1.5
Not exposed to weather or cast against the ground	Slabs, joists, and walls	All	¾
	Beams, columns, pedestals, and tension ties	All	1-1/2

5.3.7.3 Longitudinal reinforcement

The minimum number of longitudinal bars shall be (a), (b), or (c):

(a) Three within triangular ties
(b) Four within rectangular or circular ties

(c) Six enclosed by spirals

5.3.8.4 Splices of Longitudinal Reinforcement

5.3.8.4.2 Lap Splices

If the bar force due to factored loads is compressive, compression lap splices shall be permitted. Compression splices shall be designed in accordance with 25.5 of ACI 318R-14 assuming $f_f = 0.25\,f_{fu}$. It shall be permitted to decrease the compression lap splice length in accordance with (a) or (b), but the lap splice length shall be at least 12 in.

(a) For tied columns, where ties throughout the lap splice length have an effective area not less than 0.0065*hs* in both directions, lap splice length shall be permitted to be multiplied by 0.83. Tie legs perpendicular to dimension *h* shall be considered in calculating effective area.

(b) For spiral columns, where spirals throughout the lap splice length satisfy 25.7.3, lap splice length shall be permitted to be multiplied by 0.75.

If the bar force due to factored loads is tensile, tension lap splices shall be in accordance with table below.

Tensile bar stress	Splice details	Splice type
$\leq 0.5f_{fu}$	$\leq$ 50% bars spliced at any section and lap splices on adjacent bars staggered by at least ℓ_d	Class A
	Other	Class B
$> 0.5f_{fu}$	All cases	Class B

Tension Lap Splice Class Table

5.3.8.5 Transverse reinforcement

5.3.8.5.1 General

- Transverse reinforcement shall satisfy the most restrictive requirements for reinforcement spacing and it shall be anchored at each end.
- Details of transverse reinforcement shall be in accordance with 25.7.2 for ties or 25.7.3 for spirals.
- Longitudinal reinforcement shall be laterally supported using ties in accordance with 5.2.8.5.2 or spirals in accordance with, unless tests and structural analyses demonstrate adequate strength and feasibility of construction.
- Diameter of GFRP tie bar shall be at least #3
- Rectilinear GFRP ties shall be arranged to satisfy (a), (b), and (c)

(a) Every corner and alternate longitudinal bar shall have lateral support provided by the corner of a tie with an included angle of not more than 135 degrees
(b) Each bar shall have less than 6 in. clear on each side along the tie from laterally supported bar
(c) Overlaps at end of adjacent rectilinear ties shall be staggered around the perimeter

- Anchorage of each GFRP stirrup leg shall be in accordance with (a) or (b)

(a) Standard hook around longitudinal reinforcement at both ends
(b) Lap of at least $20d_b$ on one end and standard hook around longitudinal reinforcement on the other end

5.3.8.5.2 Lateral Support of Longitudinal bars using ties

In any story, the bottom tie shall be located not more than one-half the tie or hoop spacing above the top of footing or slab.

In any story, the top tie shall be located not more than one-half the tie or hoop spacing below the lowest horizontal reinforcement in the slab, drop panel, or shear cap. If beams or brackets frame into all sides of the column, the top tie or hoop shall be located not more than 3 in. below the lowest horizontal reinforcement in the shallowest beam or bracket.

5.3.8.5.3 Lateral Support of Longitudinal bars using spirals

In any story, the bottom of the spiral shall be located at the top of footing or slab.
In any story, the top of the spiral shall be located in accordance with Table below

Table - Spiral extension requirements at top of column

Framing at column end	**Extension requirements**
Beams or brackets frame into all sides of the column	Extend to the level of the lowest horizontal reinforcement in members supported above.
Beams or brackets do not frame into all sides of the column	Extend to the level of the lowest horizontal reinforcement in members supported above. Additional column ties shall extend above termination of spiral to bottom of slab, drop panel, or shear cap.
Columns with capitals	Extend to the level at which the diameter or width of capital is twice that of the column.

5.3.8.5.4 Shear

If required, shear reinforcement shall be provided using ties or spirals.

Maximum spacing of shear reinforcement shall be the lesser of $d/4$ or 12 in.

5.4 Walls

5.4.1 – Scope

This chapter shall apply to the design of nonprestressed walls including the following

(a) Cast-in-place
(b) Precast in-plant

(c) Precast on-site including tilt-up

GFRP reinforcement in compression is permitted. When present, the area of GFRP reinforcement in compression shall be treated as having the same strength and stiffness as the concrete in the surrounding compression zone.

For straight bars, the design strength f_{fu} shall be determine according to the equation below.

$$f_{fu} = C_E f_{fu}$$

Where

f_{fu} = guaranteed ultimate tensile strength

C_E = environmental reduction factor, which shall b permitted to be taken as 0l.85 for concrete both exposed and not exposed to earth or weather

5.4.2 – General Information

5.4.2.1 – Materials

Design properties for GFRP reinforcement shall be selected based on the material properties discussed earlier in this design manual.

5.4.2.2 – Connection to other members

- Contribution of GFRP reinforcement to the nominal shear strength V_n at the contact surface between supported member and foundation shall be verified,
- For connections between a cast-in-place column or pedestal and foundation, A_f crossing the interface shall be at least $0.01A_g$, where A_g is the gross area of the supported member
- Where moments are transferred to the foundation, reinforcement, or dowels shall satisfy ACI 318R-14. Lap splice lengths shall not be less than 60 d_b

5.4.2.3 – Load distribution

Unless otherwise demonstrated by an analysis, the horizontal length of wall considered as effective for resisting each concentrated load shall not exceed the lesser of the center-to-center distance between loads, and the bearing width plus four times the wall thickness. Effective horizontal length for bearing shall not extend beyond vertical wall joints unless design provides for transfer of forces across the joints.

5.4.2.4 – Intersecting elements

Walls shall be anchored to intersecting elements, such as floors and roofs; columns, pilasters, buttresses, or intersecting walls; and to footings.

5.4.3 – Design Limits

5.4.3.1 Minimum wall thickness

Minimum wall thicknesses shall be in accordance with the Table below. Thinner walls are permitted if adequate strength and stability can be demonstrated by structural analysis.

Wall Type	**Minimum Wall Thickness h**		
Bearing (1)	Greater of	5.5 in	(a)

		1/24 the lesser of unsupported length and unsupported height	(b)
Nonbearing	Greater of	4 in	(c)
		1/30 the lesser of unsupported length and unsupported height	(d)
Exterior basement and foundation	7.5 in		(e)

(1) Only applies to walls designed in accordance with the simplified design method

5.4.4 – Required Strength

5.4.4.1 General

Required strength shall be calculated in accordance with the factored load combinations

Required strength shall be calculated in accordance with the analysis procedures

Slenderness effects shall be calculated

Walls shall be designed for eccentric axial loads and any lateral or other loads to which they are subjected.

5.4.4.2 Factored axial force and moment

Walls shall be designed for the maximum factored moment *Mu* that can accompany the factored axial force for each applicable load combination. The factored axial force *Pu* at given eccentricity shall not exceed $\phi P_{n,max}$, where $P_{n,max}$ shall be as given in maximum axial strength table below and strength reduction factor ϕ shall be that for compression-controlled sections in the strength reduction factor table below. The maximum factored moment *Mu* shall be magnified for slenderness effects in accordance with 6.6.4 of ACI 318R-14 with the exception of columns or 6.7 of ACI 318R-14.

Maximum axial strength

Transverse Reinforcement	$\mathbf{P_{n,max}}$	
Ties	$0.80\ P_o$	(a)
Spirals	$0.85\ P_o$	(b)

Strength reduction factor φ for moment, axial force, or combined moment and axial force

Net tensile strain at failure in the outermost layer of reinforcement, ε_{ft}	**Classification**	**ϕ**
$\varepsilon_{ft} = \varepsilon_{fu}$	Tension-controlled	0.55
$\varepsilon_{fu} > \varepsilon_{ft} > 0.8\varepsilon_{fu}$	Transition	$1.05 - 0.5\ \varepsilon_{ft}/\varepsilon_{fu}$
$\varepsilon_{ft} \leq 0.8\varepsilon_{fu}$	Compression-controlled	0.65

5.4.4.3 Factored shear

Walls shall be designed for the maximum in-plan V_u and out-of-plane V_u

5.4.5 – Design Strength

5.4.5.1 General

For each applicable factored load combination, design strength at all sections shall satisfy $\phi S_n \geq U$, including (a) through (c). Interaction between axial load and moment shall be considered.

(a) $\phi P_n \geq P_u$
(b) $\phi M_n \geq M_u$
(c) $\phi V_n \geq V_u$

ϕ shall be determined in accordance with 21.2.

5.4.5.2 Axial load and in-plane or out-of-plane flexure

For bearing walls, P_n and M_n (in-plane or out-of-plane) shall be calculated in accordance with 22.4 of ACI 318R-14 with the additions below. Alternatively, axial load and out-of-plane flexure shall be permitted to be considered in accordance with 11.5.3.

- For members reinforced with GFRP, P_o shall be calculated with equation below

$$P_o = 0.85 f_c' A_g$$

- Nominal axial tensile strength of concrete members reinforced with GFRP, P_{nt} shall not be taken greater than $P_{nt,max}$ calculated by equation below

$$P_{nt,max} = f_{fu} A_f$$

For nonbearing walls, M_n shall be calculated in accordance with 22.3 of ACI 318R-14.

5.4.5.3 Axial load and out-of-plane flexure – simplified design method

If the resultant of all factored loads is located within the middle third of the thickness of a solid wall with a rectangular cross section, P_n shall be permitted to be calculated by:

$$P_n = 0.45 f'_c A_g \left[1 - \left(\frac{k l_c}{32h}\right)\left(\frac{k l_c}{32h}\right)\right]$$

Effective length factor k for use with the equation above shall be in accordance with Table below.

Boundary Conditions	K
Walls braced top and bottom against lateral translation and	
(a) Restrained against rotation at one or both ends (top bottom, or both)	0.8
(b) Unrestrained against rotation at both ends	1.0
Walls not braced against lateral translation	2.0

P_n from equation above shall be reduced by ϕ for compression-controlled sections in the Strength reduction factor ϕ for moment, axial force, or combined moment and axial force table in section 5.3.4.2 of this design manual

Wall reinforcement shall be at least that required by 11.6 of ACI 318R-14

5.4.5.4 In-plane shear

V_n shall be calculated in accordance with equations below. Reinforcement shall satisfy the limits of reinforcement limits, spacings of longitudinal reinforcement, and spacings of transverse reinforcement.

For in-plane shear design, *h* is thickness of wall and *d* shall be taken equal to $0.8\ell w$. A larger value of *d*, equal to the distance from extreme compression fiber to center of force of all reinforcement in tension, shall be permitted if the center of tension is calculated by a strain compatibility analysis.

V_n at any horizontal section shall not exceed $0.2fc'hd$

V_n shall be calculated by:

$$V_n = V_c + V_f$$

It shall be permitted to calculate V_c in accordance with 22.5.5, 22.5.6, or 22.5.7 with the term *bw* replaced by *h* and with the comments below.

- For members without axial force V_c shall be calculated as the greater of the equations below, where *k* is the ratio of the elastic cracked transformed section neutral axis depth to the effective depth and λ_s is the size effect factor in the table below.

  (c) $V_c = 5k\lambda_s\sqrt{f'_c}b_w d$

  (d) $V_c = 0.8\lambda_s\sqrt{f'_c}b_w d$

Size effect factor λ_s

Criteria	λ_s
$A_v < A_{v,min}$	$\sqrt{\dfrac{2}{1+(\frac{d}{10})}} \leq 1.0$
$A_v \geq A_{v,min}$	*1.0*

$A_{v,min}$ for beams and one-way slabs is defined in chapter 9 of ACI 318R-14

- The value used for the ratio of elastic cracked transformed neutral axis depth to the effective depth of the section *k* shall not exceed 1.0 in Equation (a).

- In the presence of the sustained axial load results in compressive stress over the entire cross section (i.e. $k = h/d \geq 1$) and upper limit of $k=1$ is imposed in Equation (a).

- For solid, circular sections, $b_w kd$ shall be replaced by the compression area of the elastic cracked transformed section in Equation (a) and b_w shall be permitted to be taken as the diameter and *d* shall be permitted to be taken as 0.8 times the diameter in Equation (b).

- V_c for members with significant axial tension, V_c shall be calculated by Equation (a) where the axial tension shall be taken into consideration in the calculation of the ratio of cracked transformed section neutral axis depth to the effective depth, k. Should the presence of axial load result in tensile stress over the entire cross section, shear reinforcement shall be designed to resist total shear.

$\boldsymbol{V_f}$ shall be provided by transverse shear reinforcement and shall be calculated by:

$$V_f = \frac{A_v f_{fv} d}{s}$$

The value of f_{fv} used to calculate V_f shall be the smaller of $0.005E_f$

5.4.5.5 Out-of-plane shear

V_n shall be calculated in accordance with ACI 318R-14.

5.4.6 Reinforcement Limits

If in-plane $V_u \leq 0.5\phi V_c$, minimum ρ_ℓ and minimum ρ_t shall be 0.0036. These limits need not be satisfied if adequate strength and stability can be demonstrated by structural analysis.

If in-plane $V_u \geq 0.5\phi V_c$, (a) and (b) shall be satisfied:

(a) ρ_ℓ shall be at least 0.0055 but need not exceed ρ_t required for strength by V_f from transverse shear reinforcement.

(b) ρ_t shall be at least 0.0055.

5.4.7 Reinforcement Detailing

5.4.7.1 General

Concrete cover for reinforcement shall be in accordance with Chapter 20.6 of ACI 318R-14 and utilizing the table below.

Concrete Exposure	Member	Reinforcement	Specified Cover, in
Cast against and permanently in contact with ground	All	All	3
Exposed to weather	All	No. 5 bar and smaller	1.5
Not exposed to weather or cast against the ground	Slabs, joists, and walls	All	¾
	Beams, columns, pedestals, and tension ties	All	1-1/2

Development lengths of GFRP reinforcement shall be in accordance with 25.4 with the additions below.

- Development length ℓ_d for GFRP bars in tension shall be the greater of (a), (b), and (c)
  - (a) Length calculated in accordance with 25.4.2.3 of ACI 318R-14 using the applicable modification factors of 25.4.2.4 of ACI 318R-14
  - (b) $20d_b$

(c) 12 in

- For GFRP bars ℓ_d shall be calculated by equation below.

$$l_d = \frac{d_b\left(\frac{f_{fr}}{\sqrt{f_c'}} - 340\right)\psi_t}{13.6 + \frac{c_b}{d_b}}$$

which the term c_b/d_b shall not be taken greater than 3.5, f_{fr} is the stress in the GFRP bar required to develop the full nominal sectional capacity

- Any mechanical attachment or device capable of developing 1.25*f_{fu} of GFRP bars shall be permitted, provided it is approved by the building official in accordance with 1.10. Development of GFRP bars in tension shall be permitted to consist of a combination of mechanical anchorage plus additional embedment length of the GFRP bars between the critical section and the mechanical attachment or device.

Splice lengths of GFRP reinforcement shall be in accordance with 25.5 with the comments below.

- Tension lap splice length ℓ_{st} for GFRPbars in tension shall be in accordance with table below.

<table>
<tr><th>A_s,provided/A_s,required [1] over length of splice</th><th>Maximum percent of A_s spliced within required lap length</th><th>Splice Type</th><th colspan="2">ℓ_{st}</th></tr>
<tr><td>≥ 2.0</td><td>50</td><td>Class A</td><td>Greater of</td><td>1.0ℓ_d, 20d_b, and 12 in</td></tr>
<tr><td></td><td>100</td><td>Class B</td><td rowspan="2">Greater of</td><td rowspan="2">1.3ℓ_d, 20d_b, and 12 in and 12 in.</td></tr>
<tr><td><2.0</td><td>All cases</td><td>Class B</td></tr>
</table>

- A mechanical splice shall develop in tension or compression, as required, at least 1.25f_{fu} of the bar.
- Mechanical splices shall not contain any parts that are susceptible to corrosion.

5.4.7.2 Spacing of Longitudinal Reinforcement

Spacing *s* of longitudinal bars in cast-in-place walls shall not exceed the lesser of 3*h* and 12 in. If shear reinforcement is required for in-plane strength, spacing of longitudinal reinforcement shall not exceed ℓ_w/3.

For walls with *h* greater than 10 in., except basement walls and cantilever retaining walls, distributed reinforcement for each direction shall be placed in two layers parallel with wall faces in accordance with (a) and (b):

(a) One layer consisting of at least one-half and not exceeding two-thirds of total reinforcement required for each direction shall be placed at least 2 in., but not exceeding *h*/3, from the exterior surface.

(b) The other layer consisting of the balance of required reinforcement in that direction, shall be placed at least 3/4 in., but not greater than $h/3$, from the interior surface.

Flexural tension reinforcement shall be well distributed and placed as close as practicable to the tension face.

5.4.7.3 Spacing of Transverse Reinforcement

Spacing s of transverse reinforcement in cast-in-place walls shall not exceed the lesser of $3h$ and 12 in. If shear reinforcement is required for in-plane strength, s shall not exceed $\ell_w/5$.

5.4.7.4 Lateral Support of Longitudinal Reinforcement

If longitudinal reinforcement is required for axial strength or if Af exceeds $0.01Ag$, longitudinal reinforcement shall be laterally supported by transverse ties.

5.4.7.5 Reinforcement around openings

In addition to the minimum reinforcement required by Section 11.6, with the requirements below, at least four No. 5 bars in walls having two layers of reinforcement in both directions and two No. 5 bars in walls having a single layer of reinforcement in both directions shall be provided around window, door, and similarly sized openings. In lieu of more detailed analysis that shows lower bar stresses can be considered under factored loads, such bars shall be anchored to develop ffu in tension at the corners of the openings. An additional two No. 5 bars in walls having two layers of reinforcement in both directions and one No. 5 bar in walls having a single layer of reinforcement in both directions shall be placed diagonally at each corner. Diagonal bars shall have a minimum anchorage length of 24 in. from the corner to either end of the bar.

- If in-plane $V_u \leq 0.5\phi V_c$, minimum ρ_ℓ and minimum ρ_t shall be 0.0036. These limits need not be satisfied if adequate strength and stability can be demonstrated by structural analysis.

5.5 Flatwork (slab-on-grade)

Neuvokas has worked in this market both commerically and residentially for years and has great success replacing #4 steel rebar with #3 GatorBar and #5 steel with #4 GatorBar. It should be noted that there are a plethora of variables that affect concrete crack control performance and the primary purpose of reinforcement is to control the width and spacing of any crack that forms. Reinforcement does not prevent or eliminate cracking. For additional details on design methods for plain concrete slabs-on-ground ACI 360R can be reviewed.

Utilizing equation A-2b of the ACI 440.1R-15 a slab can be designed for shrinkage and temperature reinforcement. This equation has been modified for composite rebar using an allowable amount of strain and the allowable stress.

$$A_{f,sh} = \frac{\mu L w}{2(.0012 * E_f)}$$

μ = coefficient of subgrade friction

L = Distance between joints, ft

w = dead weight of slab, lbs/ft^2

E_f = Elastic modulus of FRP rebar

$A_{f,sh}$ = cross-sectional area of FRP reinforcement

Using this calculation with an elastic modulus of 6,810,000 psi, dead weight of 145 lbs/ft^3, a 1.5 coefficient of friction, and a distance between control joints of 10 feet a rebar spacing for various concrete thickness can be calculated.

- 4” concrete– 29.9” ocew, 53” ocew #4 Shouldn’t this be calculated for #3?
- 6” concrete – 19.9” ocew, 35” ocew #4
- 8” concrete – 15” ocew #3, 26.5” ocew #4

This calculation ensures a sufficient reinforcement to ensure performance of the slab, and to actually calculate the crack width various calculators have been developed to estimate the actual crack width that will form. This calculation is complicated and best determined using these calculators. Once such calculator is the CRCP 10 tool that was developed by the Center for Transportation Research in Austin. Using this tool typically the rebar spacing can be increased by 30% without exceed the recommended crack width recommended by AASHTO for concrete pavements. Based on this in addition to Neuvokas field experience Neuvokas recommends the followings spacing using GatorBar.

- 4” concrete – 24” to 30” #3 GatorBar
- 6” concrete – 18” to 24” #3 GatorBar or 24” to 30” with #4 GatorBar
- 8” concrete – 12” to 18” #3 GatorBar or 18 to 24” with #4 GatorBar

It should be noted that, as is often the case with prescriptive applications, site conditions, load considerations and other items can lead to changing these values for concrete spacing. These values are intended to be starting place for further consideration.

5.6 Footers

In the case of specific design, the engineer of record should be consulted, but in the case of prescriptive footings for light-frame construction (as designated by the IBC) #3 GatorBar can be used replace #4 steel and #4 GatorBar can be used to replace #5 steel.

Little engineering data is available on the current design requirements driving steel requirements and the high strength of GatorBar allows the direct replacement.