



- ASLAN 100 GFRP BARS -

TEMPERATURE AND SHRINKAGE
REINFORCEMENT, AND
DEVELOPMENT LENGTH DESIGN

- ACCORDING TO ACI 440.1R-03 -

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A.1. Temperature and Shrinkage Reinforcement

a) Temperature and shrinkage reinforcement is intended to limit crack width. The design approach followed in ACI 440.1R-03 is similar to that of ACI 318-02 (Section 7.12) indicating that the amount of reinforcement should be determined as follows (Eq. (10-1) ACI 440.1R-03):

$$\rho_{f,ts} = 0.0018 \frac{f_y E_s}{f_{fu} E_f} \quad (1)$$

where f_y (psi) is the steel yield strength, f_{fu} (psi) is the design tensile strength of FRP bars, and E_s and E_f are the elastic moduli of steel and GFRP, respectively.

The engineer may consider an upper limit for the ratio of temperature and shrinkage reinforcement equal to 0.0036.

The area of GFRP reinforcement deemed necessary for temperature and shrinkage can be expressed as follows:

$$A_{f,ts} = \rho_{f,ts} b \frac{t}{2} \quad (2)$$

and it is subdivided in two layers, each close to one of the concrete surfaces. In the previous equation, b and t represent unit width (12") and thickness of the concrete cross-section, respectively.

b) Spacing of temperature and shrinkage FRP reinforcement should not exceed three times the slab thickness or 12 in., whichever is less.

c) Figure 1 shows spacing of Aslan 100 GFRP bars used as temperature and shrinkage reinforcement as a function of both slab thickness and size of the adopted bar according to Eqs. (1) and (2). The figure is given for concrete thicknesses ranging from 5 to 50 in. Figure 1 is shown adopting the suggested limitation of 0.0036.

Table 1 summarizes the same results of Figure 1 for concrete thicknesses from 5 to 30 in. A linear interpolation for slabs thicknesses not represented in the table is allowed.

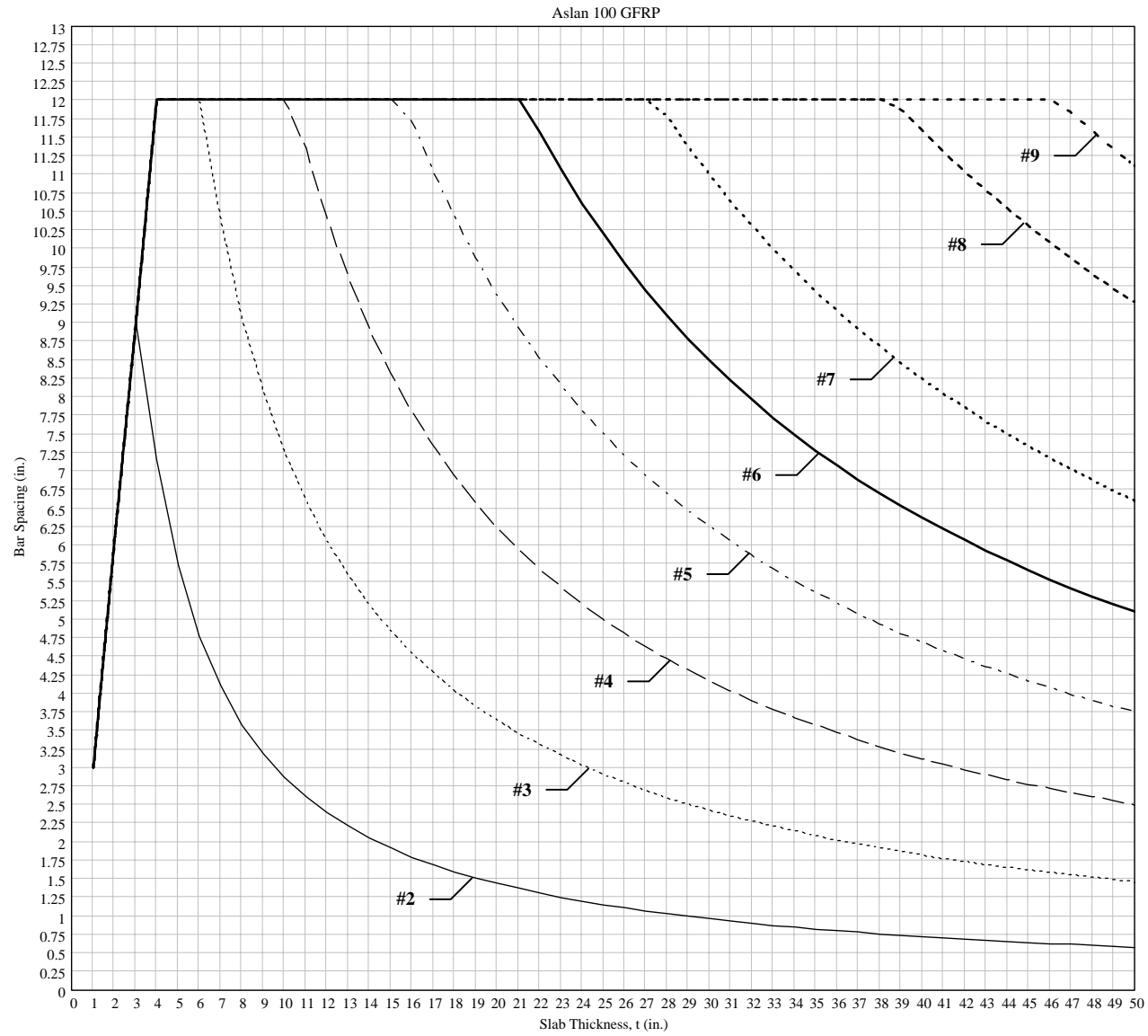


Figure 1 – Temperature and Shrinkage Reinforcement for Aslan 100 GFRP Bars
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Table 1 – Temperature & Shrinkage Reinforcement for different Slab Thicknesses

Slab Thickness (in.)	Spacing of Aslan 100 GFRP Bar (in.)								
	#2	#3	#4	#5	#6	#7	#8	#9	#10
5	5.7	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
6	4.8	12.1	12.0	12.0	12.0	12.0	12.0	12.0	12.0
7	4.1	10.4	17.8	12.0	12.0	12.0	12.0	12.0	12.0
8	3.6	9.1	15.6	12.0	12.0	12.0	12.0	12.0	12.0
9	3.2	8.1	13.9	12.0	12.0	12.0	12.0	12.0	12.0
10	2.9	7.3	12.5	12.0	12.0	12.0	12.0	12.0	12.0
11	2.6	6.6	11.3	12.0	12.0	12.0	12.0	12.0	12.0
12	2.4	6.1	10.4	12.0	12.0	12.0	12.0	12.0	12.0
13	2.2	5.6	9.6	12.0	12.0	12.0	12.0	12.0	12.0
14	2.0	5.2	8.9	12.0	12.0	12.0	12.0	12.0	12.0
15	1.9	4.8	8.3	12.0	12.0	12.0	12.0	12.0	12.0
16	1.8	4.5	7.8	11.7	12.0	12.0	12.0	12.0	12.0
17	1.7	4.3	7.3	11.0	12.0	12.0	12.0	12.0	12.0
18	1.6	4.0	6.9	10.4	12.0	12.0	12.0	12.0	12.0
19	1.5	3.8	6.6	9.9	12.0	12.0	12.0	12.0	12.0
20	1.4	3.6	6.2	9.4	12.0	12.0	12.0	12.0	12.0
21	1.4	3.5	5.9	8.9	12.0	12.0	12.0	12.0	12.0
22	1.3	3.3	5.7	8.5	11.6	12.0	12.0	12.0	12.0
23	1.2	3.2	5.4	8.1	11.1	12.0	12.0	12.0	12.0
24	1.2	3.0	5.2	7.8	10.6	12.0	12.0	12.0	12.0
25	1.1	1.9	5.0	7.5	10.2	12.0	12.0	12.0	12.0
26	1.1	2.8	4.8	7.2	9.8	12.0	12.0	12.0	12.0
27	1.1	2.7	4.6	6.9	9.4	12.0	12.0	12.0	12.0
28	1.0	2.6	4.5	6.7	9.1	11.8	12.0	12.0	12.0
29	1.0	2.5	4.3	6.5	8.8	11.4	12.0	12.0	12.0
30	1.0	2.4	4.2	6.2	8.5	11.0	12.0	12.0	12.0

A.2. Development Length

a) The basic development length, ℓ_{bf} , of a straight FRP bar controlled by pullout failure can be expressed by Eq. (11-7a) of ACI 440.1R-03:

$$\ell_{bf} = \frac{d_b f_{fu}}{2700} \quad (3)$$

where d_b (in.) is the FRP bar diameter.

b) The development length, ℓ_{df} , can be expressed as a function of the basic development length (Eq. (11-7b) ACI 440.1R-03):

$$\ell_{df} = k_m \ell_{bf} \quad (4)$$

where the bar location modification factor, k_m , is equal to 1.3 for top bars (the term top bars usually refers to horizontal reinforcement with more than 12 in. of concrete below it at the time of embedment). For bottom bars, k_m can be set equal to (Eq. (11-7c) ACI 440.1R-03):

$$k_m = \begin{cases} 1.0 & \text{if } c > 2d_b \\ \frac{4d_b - c}{2d_b} & \text{if } d_b \leq c \leq 2d_b \end{cases} \quad (5)$$

where the clear concrete cover, c , is shown in Figure 2. The clear concrete cover should not be less than d_b .

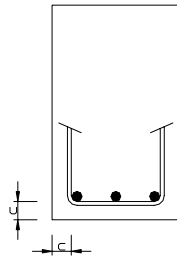


Figure 2 – Clear Concrete Cover Definition

c) Tension lap splice follows the requirement of ACI 440.1R-03 (Table 11.1). For instance, a value of $L_{df} = 1.6 \ell_{df}$ is recommended for tension lap splice when 100% of the tension area requires lap length.

d) Figure 3 to Figure 5 show the development length, ℓ_{df} , obtained from Eq. (4) as a function of Aslan 100 GFRP bar size and clear concrete cover, c . Figure 6 shows the suggested development length for top bar reinforcement.

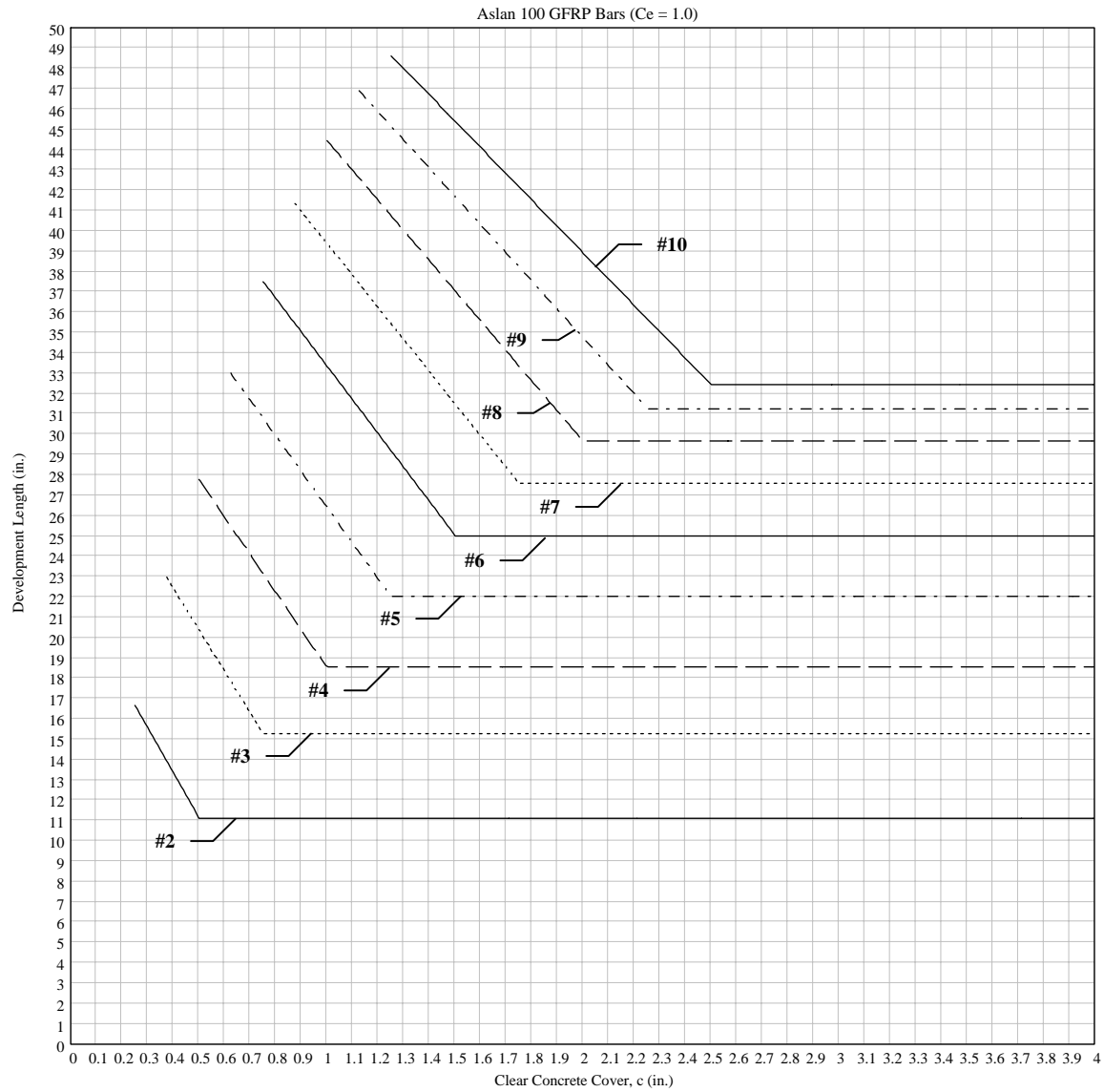


Figure 3 – Development Length for Aslan 100 GFRP Bars ($C_E = 1.0$)

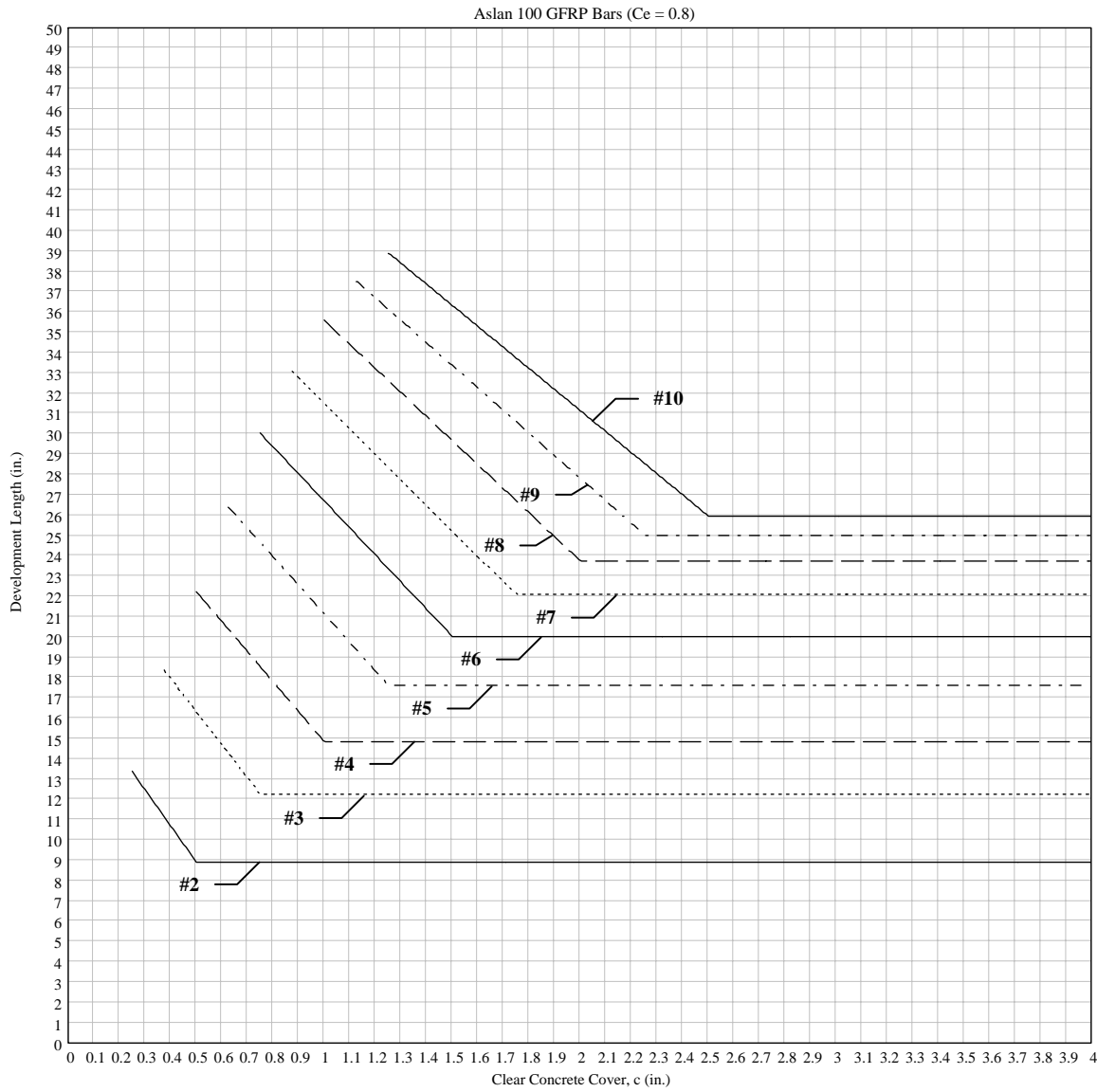


Figure 4 – Development Length for Aslan 100 GFRP Bars ($C_E = 0.8$)

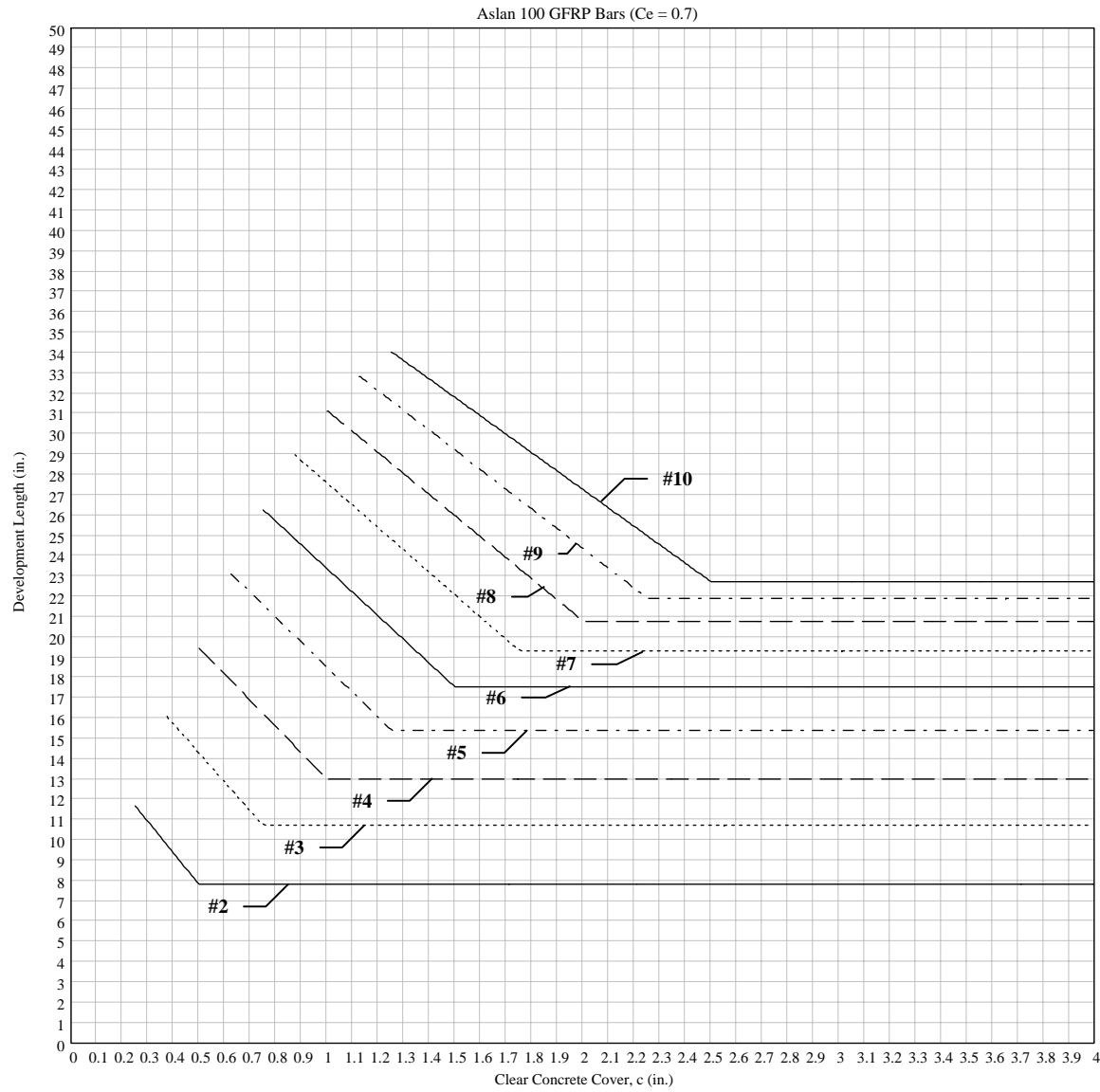


Figure 5 – Development Length for Aslan 100 GFRP Bars ($C_E = 0.7$)

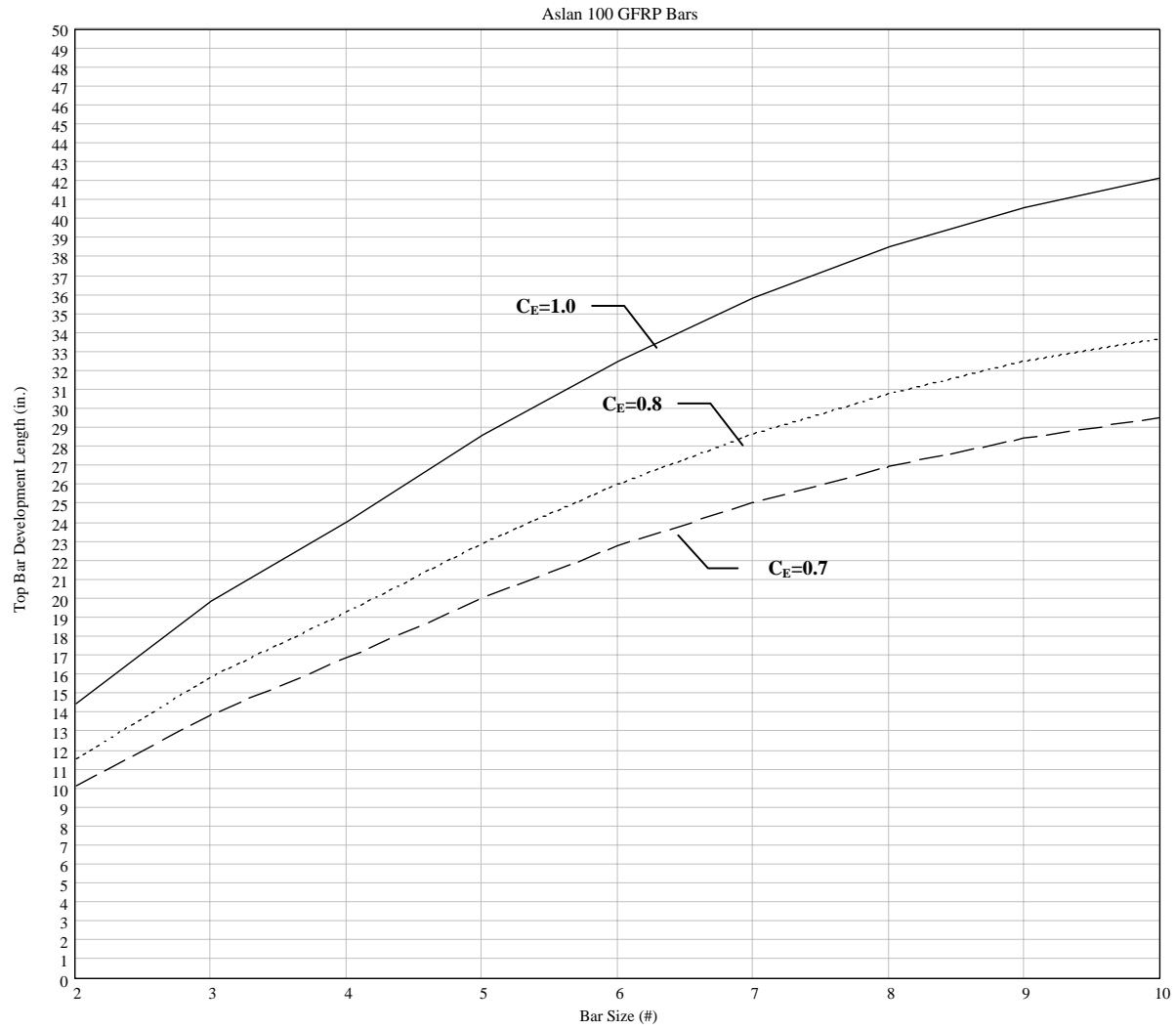


Figure 6 – Top Bar Development Length

B. REFERENCES

ACI 440.1R-03, 2003: "Guide for the Design and Construction of Concrete Reinforced with FRP Bars," Published by the *American Concrete Institute*, Farmington Hills, MI.

ACI 318-02, 1995: "Building Code Requirements for Structural Concrete and Commentary (318R-95)," Published by the American Concrete Institute, Farmington Hills, MI.

C. APPENDIX I

- $A_{f,ts}$ = Area of FRP reinforcement for temperature and shrinkage, in^2
 b = Width of the cross-section, in .
 c = Clear concrete cover, in .
 d_b = Diameter of FRP bars, in .
 E_f = FRP modulus of elasticity, psi
 E_s = Steel modulus of elasticity, psi
 f_{fu} = FRP design tensile strength, psi
 f_y = Yield steel strength, psi
 k_m = Bar location modification factor
 l_{bf} = Basic development length for FRP bars, in .
 l_{df} = Development length for FRP bars, in .
 L_{df} = Lap splice length for FRP bars. In .
 t = Thickness of the concrete slab, in .
 $\rho_{f,ts}$ = FRP reinforcement ratio for temperature and shrinkage