



UNIVERSITÉ DE
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DEVELOPMENT AND SPLICE LENGTHS OF GFRP BARS

Technical Report

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**NSERC RESEARCH CHAIR IN INNOVATIVE FRP REINFORCEMENT
FOR CONCRETE INFRASTRUCTURE**

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1- Introduction

This report presents the development and splices lengths of glass FRP bars calculated using three different North American codes and design guidelines. This includes; (1) the Canadian Highway Bridge Design Code (**CAN/CSA-S6-06; Edition 2010**), (2) Design and Construction of Building Components with Fibre-Reinforced Polymers Code (**S806-02**), and (3) the Guide for the Design and Construction of structural Concrete Reinforced with FRP Bars (**ACI 440.1R-06**).

Note:

The development and splice lengths provided in this report are the maximum based on the full strength capacity of the FRP bars, taking into account the FRP resistance factor equal to one at ULS. The values can be modified based on the actual stress calculation for different project.

2- Development and splice lengths according to CAN/CSA-S6-06; edition 2010

The development length, l_d , of FRP bars in tension shall be taken as;

$$l_d = 0.45 \frac{k_1 k_4}{\left(d_{cs} + K_{tr} \frac{E_{FRP}}{E_s} \right)} \frac{f_{FRP}}{f_{cr}} A \quad \text{(Clause 16.8.4)}$$

where

k_1 is the bar location factor
= 1.3 for horizontal reinforcement placed so that more than 300 mm of fresh concrete is cast in the component below the development length or splice

= **1.0** for other cases

k_4 is the bar surface factor, being the ratio of the bond strength of the FRP bar to that of a steel deformed bar having the same cross-sectional area as the FRP bar, but not greater than 1.0; In absence of experimental data, the factor k_4 shall be taken as **0.8**.

f_{FRP} stress in the tension reinforcement at ULS, MPa,

A is the area of cross-section of bar, mm²

f_{cr} the cracking strength of concrete, MPa

= 0.4√ f'_c for normal density concrete

The term $(d_{cs} + K_{tr} E_{FRP}/E_s)$ in the above equation shall not be taken greater than **2.5d_b**.

Assumptions for the calculations:

$$k_l = 1,$$

$$k_4 = 0.8,$$

$$f_c' = 40 \text{ MPa.} \rightarrow f_{cr} = 2.53$$

$$\text{the term } (d_{cs} + K_{tr} E_{FRP}/E_s) = \underline{2.5d_b}$$

f_{FRP} = stress in the tension reinforcement at ULS, MPa,

$$= \phi_{FRP} f_{FRP}^*$$

Where

ϕ_{FRP} = (FRP resistance factor) (taken equal to one)

f_{FRP}^* : Guaranteed tensile strength of the FRP bars (provided by the manufacturer)

The splice length for FRP bars in tension shall be **1.3l_d** (Clause 16.8.4.2)

3- Development and splice lengths according to S806-02

The development length, l_d , of FRP bars in tension shall be taken as;

Normal requirement

$$l_d = 1.15 \frac{k_1 k_2 k_3 k_4 k_5}{d_{cs}} \frac{f_f}{\sqrt{f_c'}} A_b \quad \text{(Clause 9.3.2, Eq. 9.1)}$$

where

k_l is the bar location factor

= 1.3 for horizontal reinforcement placed so that more than 300 mm of fresh concrete is cast in the component below the development length or splice

= **1.0** for other cases

k_2 is the concrete density factor
= 1.3 for structural low-density concrete
= 1.2 for structural semi-low-density concrete
= **1.0** for normal density concrete

k_3 is the bar size factor
= **0.8** for $A_b \leq 300 \text{ mm}^2$
= **1.0** for $A_b > 300 \text{ mm}^2$

k_4 is the bar fibre factor
= **1.0** for CFRP and GFRP
= 1.25 for AFRP

k_5 is the bar surface profile factor
= **1.0** for sand-coated surfaces

A_b is the area of cross-section of bar, mm^2

d_{cs} is the smaller of
(a) the distance from the closest concrete surface to the centre of the bar being developed; or
(b) two-thirds of the centre-to-centre spacing of the bars being developed

but d_{cs} shall not be taken greater than $2.5d_b$.

$f_c' = 30; 40; 50 \text{ MPa}$

f_f is the design stress in FRP tension reinforcement at ultimate limit state (to be calculated for each structure and loading conditions).

$$f_f = \phi_{FRP} f_{FRP}^*$$

Where

ϕ_{FRP} = (FRP resistance factor) (taken equal to one)

f_{FRP}^* : Guaranteed tensile strength of the FRP bars (provided by the manufacturer)

Assumptions for the calculations:

$k_1 = 1$,

$k_2 = 1$,

$k_3 = 0.8$ or 1 (when applicable),

$$k_4 = 1,$$

$$k_5 = 1,$$

$$f_c' = 30; 40; 50 \text{ MPa.}$$

$$d_{cs} = 2.5d_b$$

f_f = the characteristic tensile strength of FRP bar

Splice lengths shall be provided by the bar manufacturer and shown in the contract document (Clause 9.6).

4- Development and splice lengths according to ACI 440.1R-06

The development length, l_d , of FRP bars in tension shall be taken as;

$$l_d = \frac{\alpha \frac{f_{fr}}{0.083\sqrt{f_c'}} - 340}{13.6 + \frac{C}{d_b}} \quad \text{(Clause 11.3, Eq. 11.6)}$$

where

α is the bar location modification factor (Clause 11.1.1)

= 1.5 for horizontal reinforcement placed so that more than 300 mm of fresh concrete is cast in the component below the development length or splice

= **1.0** for other cases

f_{fr} should be the minimum of

(1) f_{fu} (design tensile strength of FRP bar, considering reduction for service environment) where $f_{fu} = C_E f_{fu}^*$

f_{fu}^* (the guaranteed tensile strength) (Clause 7.2).

(2) the stress given by Eq. (8-4d) (need calculations for each structure), and

(3) the stress given by Eq. (11.3) (also need calculations for each structure)

However it cannot exceed the design tensile strength of FRP bar (f_{fu})

C is the concrete cover

d_b is the bar diameter

Assumptions for the calculations:

$$\alpha = 1,$$

$$f_c' = 30; 40; 50 \text{ MPa.}$$

$$f_{fr} = f_{fu}$$

$$C/d_b = 2.5$$

The splice length for FRP bars in tension shall be $1.3l_d$ for all splices (Clause 11.4)

5- REFERENCES

American Concrete Institute (ACI). (2006). Guide for the design and construction of concrete reinforced with FRP bars, ACI 440.1R-01;03; 06, Farmington Hills, Mich.

Canadian Standards Association (CSA). (2002). "Design and construction of building components with fiber reinforced polymers." CAN/CSAS806-02, Rexdale, Toronto.

Canadian Standards Association (CSA). (2006-Edition 2010). "Canadian highway bridge design code—Section 16, updated version for public review." CAN/CSA-S6-06, Rexdale, Toronto.

Table 1 Development and splice lengths of Standards GFRP Rebar & Concrete strength (30 MPa)

Bar No.		#2 GFRP	#3 GFRP	#4 GFRP	#5 GFRP	#6 GFRP	#7 GFRP	#8 GFRP
Bar Type		V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD
Guaranteed tensile strength	MPa	784	765	708	683	656	625	597
Bar Diameter	mm	6.4	9.5	12.7	15.9	19.1	22	25.4
CSA-S6-06 Edition 1010								
(a) Development length (clause 16.8.4)	mm	257	376	464	560	645	717	783
	l_d/d_b	41	40	37	35	34	32	31
(b) Splice length	mm	334	489	604	728	839	932	1018
	$splice /d_b$	53	51	48	46	44	42	40
CSA-S806-02								
(a) Development length (clause 16.8.3, Eq. 9.1)	mm	263	385	475	572	659	733	800
	l_d/d_b	41	40	37	36	35	33	32
(b) Splice length (not given)	mm	----	----	----	----	----	----	----
	$splice /d_b$	----	----	----	----	----	----	----
ACI 440.1R-06								
(a) Development length, (clause 11.3, Eq. 11-6)	mm	546	794	960	1146	1305	1428	1535
	l_d/d_b	86	83	76	72	69	64	60
(b) Splice length (clause 11.4)	mm	710	1033	1248	1490	1697	1857	1996
	$splice /d_b$	112	108	98	94	89	84	79

All calculations were done based on the previous assumptions.

Table 2 Development and splice lengths of Standards GFRP Rebar & Concrete strength (40 MPa)

Bar No.		#2 GFRP	#3 GFRP	#4 GFRP	#5 GFRP	#6 GFRP	#7 GFRP	#8 GFRP
Bar Type		V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD
Guaranteed tensile strength	MPa	784	765	708	683	656	625	597
Bar Diameter	mm	6.4	9.5	12.7	15.9	19.1	22	25.4
CSA-S6-06 Edition 1010								
(a) Development length (clause 16.8.4)	mm	250	326	402	485	559	621	678
	l_d/d_b	39	34	32	31	29	28	27
(b) Splice length	mm	400	522	643	775	894	994	1085
	$splice /d_b$	63	55	51	49	47	45	43
CSA-S806-02								
(a) Development length (clause 16.8.3, Eq. 9.1)	mm	228	333	411	495	571	635	693
	l_d/d_b	36	35	32	31	30	29	27
(b) Splice length (not given)	mm	----	----	----	----	----	----	----
	$splice /d_b$	----	----	----	----	----	----	----
ACI 440.1R-06								
(a) Development length, (clause 11.3, Eq. 11-6)	mm	455	661	796	948	1076	1174	1258
	l_d/d_b	72	69	63	60	57	53	50
(b) Splice length (clause 11.4)	mm	591	859	1034	1232	1399	1526	1635
	$splice /d_b$	93	90	81	78	73	69	64

All calculations were done based on the previous assumptions.

Table 3 Development and splice lengths of Standards GFRP Rebar & Concrete strength (50 MPa)

Bar No.		#2 GFRP	#3 GFRP	#4 GFRP	#5 GFRP	#6 GFRP	#7 GFRP	#8 GFRP
Bar Type		V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD
Guaranteed tensile strength	MPa	784	765	708	683	656	625	597
Bar Diameter	mm	6.4	9.5	12.7	15.9	19.1	22	25.4
CSA-S6-06 Edition 1010								
(a) Development length (clause 16.8.4)	mm	250	292	360	433	500	556	606
	l_d/d_b	39	31	28	27	26	25	24
(b) Splice length	mm	400	466	575	694	799	889	970
	$splice /d_b$	63	49	45	44	42	40	38
CSA-S806-02								
(a) Development length (clause 16.8.3, Eq. 9.1)	mm	204	298	368	443	511	568	620
	l_d/d_b	32	31	29	28	27	26	24
(b) Splice length (not given)	mm	----	----	----	----	----	----	----
	$splice /d_b$	----	----	----	----	----	----	----
ACI 440.1R-06								
(a) Development length, (clause 11.3, Eq. 11-6)	mm	393	570	683	812	920	1001	1068
	l_d/d_b	62	60	54	51	48	45	42
(b) Splice length (clause 11.4)	mm	511	741	888	1056	1196	1301	1389
	$splice /d_b$	80	78	70	67	63	59	55

All calculations were done based on the previous assumptions.

Table 4 Development and splice lengths of LM GFRP Rebar & Concrete strength (30 MPa)

Bar No.		#3 GFRP	#4 GFRP	#5 GFRP	#6 GFRP	#8 GFRP
Bar Type		V•ROD	V•ROD	V•ROD	V•ROD	V•ROD
Guaranteed tensile strength	MPa	799	780	903	796	672
Bar Diameter	mm	9.5	12.7	15.9	19.1	25.4
CSA-S6-06 Edition 1010						
(a) Development length (clause 16.8.4)	mm	393	511	740	783	881
	l_d/d_b	41	40	47	41	35
(b) Splice length	mm	511	665	962	1018	1145
	$splice/d_b$	54	52	61	53	45
CSA-S806-02						
(a) Development length (clause 16.8.3, Eq. 9.1)	mm	402	523	756	800	901
	l_d/d_b	42	41	48	42	35
(b) Splice length (not given)	mm	----	----	----	----	----
	$splice/d_b$	----	----	----	----	----
ACI 440.1R-06						
(a) Development length, (clause 11.3, Eq. 11-6)	mm	527	679	1036	1048	1096
	l_d/d_b	55	53	65	55	43
(b) Splice length (clause 11.4)	mm	685	883	1346	1362	1425
	$splice/d_b$	72	70	85	72	56

All calculations were done based on the previous assumptions.

Table 5 Development and splice lengths of LM GFRP Rebar & Concrete strength (40 MPa)

Bar No.		#3 GFRP	#4 GFRP	#5 GFRP	#6 GFRP	#8 GFRP
Bar Type		V•ROD	V•ROD	V•ROD	V•ROD	V•ROD
Guaranteed tensile strength	MPa	799	780	903	796	672
Bar Diameter	mm	9.5	12.7	15.9	19.1	25.4
CSA-S6-06 Edition 1010						
(a) Development length (clause 16.8.4)	mm	340	443	641	678	763
	l_d/d_b	36	35	40	36	30
(b) Splice length	mm	443	576	833	881	992
	$splice /d_b$	46	45	52	46	39
CSA-S806-02						
(a) Development length (clause 16.8.3, Eq. 9.1)	mm	348	453	655	693	780
	l_d/d_b	37	36	41	36	31
(b) Splice length (not given)	mm	----	----	----	----	----
	$splice /d_b$	----	----	----	----	----
ACI 440.1R-06						
(a) Development length, (clause 11.3, Eq. 11-6)	mm	429	552	852	854	877
	l_d/d_b	45	43	54	45	35
(b) Splice length (clause 11.4)	mm	558	718	1108	1110	1141
	$splice /d_b$	59	57	70	58	45

All calculations were done based on the previous assumptions.

Table 6 Development and splice lengths of LM GFRP Rebar & Concrete strength (50 MPa)

Bar No.		#3 GFRP	#4 GFRP	#5 GFRP	#6 GFRP	#8 GFRP
Bar Type		V•ROD	V•ROD	V•ROD	V•ROD	V•ROD
Guaranteed tensile strength	MPa	799	780	903	796	672
Bar Diameter	mm	9.5	12.7	15.9	19.1	25.4
CSA-S6-06 Edition 1010						
(a) Development length (clause 16.8.4)	mm	305	396	573	606	683
	l_d/d_b	32	31	36	32	27
(b) Splice length	mm	396	515	745	788	887
	$splice /d_b$	42	41	47	41	35
CSA-S806-02						
(a) Development length (clause 16.8.3, Eq. 9.1)	mm	311	405	586	620	698
	l_d/d_b	33	32	37	33	27
(b) Splice length (not given)	mm	----	----	----	----	----
	$splice /d_b$	----	----	----	----	----
ACI 440.1R-06						
(a) Development length, (clause 11.3, Eq. 11-6)	mm	363	466	727	721	728
	l_d/d_b	38	37	46	38	29
(b) Splice length (clause 11.4)	mm	471	605	945	937	947
	$splice /d_b$	49	48	60	49	37

All calculations were done based on the previous assumptions.

Table 7 Development and splice lengths of HM GFRP Rebar & Concrete strength (30 MPa)

Bar No.		#3 GFRP	#4 GFRP	#5 GFRP	#6 GFRP	#7 GFRP	#8 GFRP	#10 GFRP
Bar Type		V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD
Guaranteed tensile strength	MPa	1472	1412	1284	1205	1089	983	1093
Bar Diameter	mm	9.5	12.7	15.9	19.1	22	25.4	32
CSA-S6-06 Edition 1010								
(a) Development length (clause 16.8.4)	mm	724	926	1052	1185	1250	1289	1778
	l_d/d_b	76	73	66	62	56	51	56
(b) Splice length	mm	941	1204	1368	1540	1624	1676	2311
	$splice /d_b$	99	95	86	81	73	66	72
CSA-S806-02								
(a) Development length (clause 16.8.3, Eq. 9.1)	mm	740	946	1075	1211	1277	1318	740
	l_d/d_b	78	75	68	64	57	52	78
(b) Splice length (not given)	mm	----	----	----	----	----	----	----
	$splice /d_b$	----	----	----	----	----	----	----
ACI 440.1R-06								
(a) Development length, (clause 11.3, Eq. 11-6)	mm	1714	2182	2450	2734	2837	1714	2182
	l_d/d_b	180	172	154	144	128	180	172
(b) Splice length (clause 11.4)	mm	2229	2836	3185	3554	3689	2229	2836
	$splice /d_b$	234	223	201	187	166	234	223

All calculations were done based on the previous assumptions.

Table 8 Development and splice lengths of HM GFRP Rebar & Concrete strength (40 MPa)

Bar No.		#3 GFRP	#4 GFRP	#5 GFRP	#6 GFRP	#7 GFRP	#8 GFRP	#10 GFRP
Bar Type		V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD
Guaranteed tensile strength	MPa	1472	1412	1284	1205	1089	983	1093
Bar Diameter	mm	9.5	12.7	15.9	19.1	22	25.4	32
CSA-S6-06 Edition 1010								
(a) Development length (clause 16.8.4)	mm	627	802	911	1026	1082	1116	1540
	l_d/d_b	66	63	57	54	49	44	48
(b) Splice length	mm	815	1042	1184	1334	1407	1451	2002
	$splice/d_b$	86	82	75	70	63	57	63
CSA-S806-02								
(a) Development length (clause 16.8.3, Eq. 9.1)	mm	641	820	931	1049	1106	1141	1574
	l_d/d_b	67	65	59	55	50	45	49
(b) Splice length (not given)	mm	----	----	----	----	----	----	----
	$splice/d_b$	----	----	----	----	----	----	----
ACI 440.1R-06								
(a) Development length, (clause 11.3, Eq. 11-6)	mm	1458	1854	2077	2314	2394	2418	3463
	l_d/d_b	153	146	131	121	108	95	108
(b) Splice length (clause 11.4)	mm	1895	2410	2700	3008	3113	3143	4501
	$splice/d_b$	199	190	170	158	140	124	141

All calculations were done based on the previous assumptions.

Table 9 Development and splice lengths of HM GFRP Rebar & Concrete strength (50 MPa)

Bar No.		#3 GFRP	#4 GFRP	#5 GFRP	#6 GFRP	#7 GFRP	#8 GFRP	#10 GFRP
Bar Type		V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD	V•ROD
Guaranteed tensile strength	MPa	1472	1412	1284	1205	1089	983	1093
Bar Diameter	mm	9.5	12.7	15.9	19.1	22	25.4	32
CSA-S6-06 Edition 1010								
(a) Development length (clause 16.8.4)	mm	561	717	815	918	968	998	1377
	l_d/d_b	59	56	51	48	44	39	43
(b) Splice length	mm	729	932	1059	1193	1258	1298	1790
	$splice/d_b$	77	73	67	63	57	51	56
CSA-S806-02								
(a) Development length (clause 16.8.3, Eq. 9.1)	mm	573	733	833	938	989	1021	1408
	l_d/d_b	60	58	52	49	45	40	44
(b) Splice length (not given)	mm	----	----	----	----	----	----	----
	$splice/d_b$	----	----	----	----	----	----	----
ACI 440.1R-06								
(a) Development length, (clause 11.3, Eq. 11-6)	mm	1283	1630	1822	2027	2092	2106	1283
	l_d/d_b	135	128	115	106	94	83	135
(b) Splice length (clause 11.4)	mm	1667	2118	2369	2635	2720	2738	1667
	$splice/d_b$	175	167	149	138	122	108	175

All calculations were done based on the previous assumptions.