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Review of design codes for tension splice length for reinforced concrete members

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Abstract

A review of provisions of different design codes for splice lengths of reinforcing bars used in reinforced concrete structures has been presented. The reviewed codes are ACI (2002), BNBC (1993), AASHTO (2007), CEB-FIP Model (1990) and EURO Code 2(2003). Normalized splice length is calculated for particular strength of concrete and reinforcing bars. A parametric study has been conducted for selected parameters. It has been found from the study that for BNBC (1993), the normalized splice length remains the same up to 22 mm diameter bars and for larger diameter bars the normalized splice length increases significantly. In contrast, ACI (2002) recommends the same normalized splice length for 22 mm and larger diameter bars. CEB-FIP Model (1990) advised the larger normalized splice length than ACI (2002) for lower strength of concrete. With increasing of concrete strength CEB-FIP Model exhibits the largest normalized splice length.

Keywords: Splice length, Reinforcing bar and Design codes

1. Introduction

It is very transparent from the context of D.A. Bournas (2008) & T.C. Triantafillou (2008) that the earthquake has a negative effect on the structures, erected in seismic prone region with poorly detailed reinforced concrete columns, which are confined by traditional short and poorly lap spliced longitudinal reinforcement. This splice region is just above the floor levels, where large inelastic demands are expected. In many structures a lap length of 20 to 30 diameters of longitudinal bars is seen frequently used. These buildings are the possessors of inadequate transferring tensile stresses in the longitudinal reinforcement along the lap splice region. During earthquake the above mentioned lap splice length is not adequate for lap splices in tension region, because during earthquake actions in tension splice region a significant bending moment is induced consequences a large tensile stresses. Hence this traditional splice length is no longer adequate in tension regions although, it exceeded the splice length requirements for compression regions.

In this study the authors attempted to investigate the tension splice length requirements for different design codes. Different design code recommends different formulas for determining tension splice length. Different design codes have been reviewed. A parametric study has been conducted to calculate the normalized splice length requirements, using the code ACI (2002), BNBC (1993), AASHTO (2007), CEB-FIP Model (1990) and EURO Code 2(2003). In the parametric study, yield strength of reinforcing bars, compressive strength of concrete and bar diameter have been used as basic parameters. A specific beam-column joint of a building frame has been taken into consideration for the study. In selecting the compressive strength of concrete, a wide range of strength for both concrete and steel has been taken into considerations. The compressive strength of concrete was used 10 MPa, 15 MPa, 20.5 MPa, 23.9 MPa, 26.67 MPa, 30 MPa and 35 Ma, while the yield strength of the reinforcing bars were used 274 MPa, 410 MPa and 500 MPa.

In this study the authors found that each code recommends different splice length for tension region. The ratio of spice length to the diameter of the bars is referred to normalized splice length here. The CEB-FIP Model code recommends the largest development length for 22 mm ϕ and larger diameter bar than other codes. The EURO Code2 recommend the smaller normalized splice length than CEB-FIP Model. It has also been found that the BNBC (1993) and AASHTO (2007) advised the same normalized splice length for 22 mm diameter and larger bars.

Fig.1. Lap splices in column

2. Design provisions

The design codes reviewed in this study for tension development length of members in reinforced concrete structures are ACI (2002), CEB-FIP Model (1990), EURO Code 2 (2003), BNBC (1993) and AASHTO (2007). To allow direct comparison of design equations, the expressions are written using notation similar to that used in ACI 318-02.

2.1 ACI code

According to ACI (2002) the splice length of reinforced bars in tension is classified as a class A & a class B. The class A requires a lap of $1.0\,l_d$, and a class B splice requires a lap of $1.3\,l_d$, where, l_d is the development length of bars in tension. The development length is expressed as follows

$$l_d = \left(\frac{f_y}{25} \frac{\alpha\beta\lambda}{\sqrt{f_c^{'}}} \right) d_b \quad \text{(for case-I and case II, 20 mm } \phi \text{ and smaller bars)} \qquad 1(a)$$

$$l_d = \left(\frac{f_y}{20} \frac{\alpha\beta\lambda}{\sqrt{f_c^{'}}} \right) d_b \quad \text{(for case-I and case-II, 22 mm } \phi \text{ and larger bars)} \qquad 1(b)$$

$$l_d = \left(\frac{3 f_y}{50} \frac{\alpha\beta\lambda}{\sqrt{f_c^{'}}} \right) d_b \quad \text{(for other case, 20 mm } \phi \text{ and smaller bars)} \qquad 1(c)$$

$$l_d = \left(\frac{3 f_y}{40} \frac{\alpha\beta\lambda}{\sqrt{f_c^{'}}} \right) d_b \quad \text{(for other case, 22 mm } \phi \text{ and larger bars)} \qquad 1(d)$$

Each of the above cases is presented in Table 1.

Table 1
Development length in tension according to ACI (2002)

Special cases	20 mm ϕ and smaller bars	22 mm ϕ bar and larger bars
Clear spacing of bars being developed or spliced ≥ d_b , clear cover ≥ d_b , and stirrups or ties throughout the l_d	$l_d = \left(\frac{f_y}{25} \frac{\alpha\beta\lambda}{\sqrt{f_c^{'}}} \right) d_b$	$l_d = \left(\frac{f_y}{20} \frac{\alpha\beta\lambda}{\sqrt{f_c^{'}}} \right) d_b$
Clear spacing of bars being developed or spliced ≥ 2 d_b , and clear cover ≥ d_b	Same as above	Same as above
Other cases	$l_d = \left(\frac{3 f_y}{50} \frac{\alpha\beta\lambda}{\sqrt{f_c^{'}}} \right) d_b$	$l_d = \left(\frac{3 f_y}{40} \frac{\alpha\beta\lambda}{\sqrt{f_c^{'}}} \right) d_b$

where, α is reinforcement location factor, 1.3: for Horizontal reinforcement so placed that more than 12 in. of fresh concrete is cast in the member below the development length or splice and 1.0: for other reinforcement ; β is coating factor ,1.5: for Epoxy –coated bars or wires with cover less than 3 d_b or clear spacing less than 6 d_b , 1.2: for all other epoxy coated bars or wires, 1.0: for Uncoated reinforcement; λ is lightweight aggregate concrete factor 1.3: when lightweight aggregate concrete is used, 1.0: when normal weight concrete is used. In either case, a minimum splice length of 12 in. applies. The classification is illustrated in Table 2.

Table 2
Classes of tension lap splices: ACI code (2002)

Ratio $\frac{((A)_s \, provided)}{((A)_s \, required)}$	Maximum percent of A_s spliced within required lap length	
	50	100
≥ 2	A	B
≤ 2	B	B

2.2 CEB-FIP Model Code (1990)

The CEB-FIP model code (1990) provisions for splice length are calculated by multiplying l_d by the factor α_b given in Table 3.

$$l_d = \frac{1}{1.228}\left(1.15 - 0.15 * \frac{c_{\min}}{d_b}\right)\left(1 - k\frac{\sum A_{str} - \sum A_{str,\min}}{A_b}\right)\eta \frac{f_{yd}}{f_{ck}^{2/3}} d_b \quad (2)$$

where, d_b is diameter of bar; η = 1.0 for $d_b \le 32$ mm, $\eta = \frac{100}{132 - d_b}$ for $d_b > 32$ mm; each term in parentheses of Eq. (2) is limited to the range of 0.7 □ 1.0; f_{yd} is design yield strength of the bar in MPa. $f_{yd} = \frac{f_{yk}}{1.15}$, where f_{yk} is characteristics yield strength of reinforcement, it is the value that is exceeded by 95% of all possible test results, often described as the 5% fractures value. In US practice, $f_{yk} \approx 1.06 f_y$, where f_y is the minimum specified yield Strength; f_{ck} is the Characteristic compressive strength of concrete. $f_{ck} = f_c^{'} - 2.75$ MPa; $c_{\min} = \min(a/2, c_1, c_2)$ from Fig.2; $\sum A_{str}$ is the cross-sectional area of the transverse reinforcement along l_d ; $\sum A_{str,\min}$ is the cross sectional area of the minimum transverse reinforcement = 0.25 A_s for beams and 0 for slabs ; A_b is the area of a single bar being developed or spliced, with maximum bar diameter; k = values are, k =0:10 for a bar confined at a corner bend of a stirrup or tie, k= 0:05 for a bar confined by a single leg of a stirrup or tie, and k = 0 for a bar that is not confined by transverse reinforcement; The value of l_d in Eq. (2) may be multiplied by 0.7 ≤ (1 -0.04p) ≤ 1.0 where p is transverse pressure in MPa at the ultimate limit state along the development length perpendicular to the splitting plane. The effect of bar placement for top-cast reinforcement is included by dividing l_d by 0.7 for bars with an inclination of less than 45^0 with the horizontal that are both (1) more than 250 mm from the bottom and (2) less than 300 mm from the top of a concrete layer during placement. As in ACI (2002), l_d may be multiplied by the ratio of (As required)/ (As provided), but unlike ACI (2002), this ratio may also be applied when calculating the splice length l_s . Splice lengths in tension are limited as shown in Equation 3.

$$l_{s,\min} = \max\left[\frac{0.3\alpha_b \eta f_{yd}}{1.228 f_{ck}^{2/3}} d_b; 15 d_b; 200mm\right] \quad (3)$$

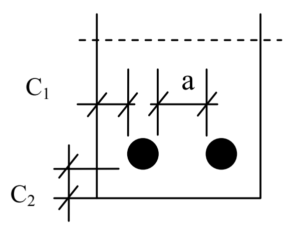


Fig.2. $c_{\min} = \min(a/2, c_1, c_2)$

Table 3
Values of co-efficient α_b : CEB-FIP Model Code

Maximum percent of A_s lapped at one section*	≤ 20	25	33	50	> 50
α_b	1.2	1.4	1.6	1.8	2.0

* Defined as lap splices with mid lengths within $0.65 l_s$ on either side of the mid length of the splice under consideration.

Table 4
Values of co-efficient α_b : Eurocode 2

Percent of A_s lapped at one section*	< 25	33	50	> 50
α_b **	1.2	1.4	1.6	1.8

* Defined as lap splices with mid lengths within $0.65l_s$ on either side of the mid length of the splice under consideration. ** Intermediate values may be determined by interpolation.

2.3 Eurocode 2 (2003)

The splice length provisions of Eurocode 2 have many similarities to those of CEB-FIP Model Code. The splice length is determined the l_d by the factor α_b given in table 4.The l_d is expressed as

$$l_d = \frac{1}{1.26}\left(1.15 - 0.15\frac{c_{\min}}{d_b}\right)\left(1 - k\frac{\sum A_{tr} - \sum A_{tr,\min}}{A_b}\right)\frac{\eta f_{sd}}{f_{ck}^{2/3}} d_b \tag{4}$$

where f_{sd} is the design stress of the bar at the position from where anchorage is measured at the ultimate limit state = f_{yd} (As required)/ (As provided). The other terms are as defined for CEB-FIP Model Code 1990, except that the value of f_{ck} used here is limited to a maximum of 60MPa unless it can be demonstrated that the average bond strength increases above this limit, and $A_{tr,\min}$ for splice length is taken as $A_b\left(\frac{f_{sd}}{f_{yd}}\right)$, where A_b is the area of the largest bar being spliced. $\alpha_b = (\rho_1 / 25)^{1/2} \le 1.5$, where ρ_1 is the percentage of reinforcement lapped within $0.65l_s$ of the centre of the lap length. Splice length in tension is limited as shown in Equation 5.

$$l_{s,\min} = \max\left[\frac{0.3\alpha_b}{1.26}\frac{\eta f_{sd}}{f_{ck}^{2/3}} d_b ; 15d_b ; 200mm\right] \tag{5}$$

2.4 BNBC Code (1993)

The minimum splice length in tension for BNBC (1993) provision is class A or class B splice. Class A splice required a length of $1.0l_d$ as well as class B required a length of $1.3l_d$. Where the term l_d represents development length of deformed bars in tension and determined as the product of the basic development length l_{db} and the applicable modification factors, which are expressed as

Basic development length,

$$l_{db} = \frac{0.02 * A_b f_y}{\sqrt{f_c'}} \text{ (for 36 mm } \phi \text{ bar or smaller)} \tag{6}$$

$$l_{db} = \frac{25 f_y}{\sqrt{f_c'}} \text{ (for 45 mm } \phi \text{ bar)} \tag{7}$$

$$l_{db} = \frac{35 f_y}{\sqrt{f_c'}} \text{ (for 55 mm } \phi \text{ bar)} \tag{8}$$

where, f_y is the yield strength of reinforcement in MPa; f'_c is the compressive strength of concrete in MPa ; and A_b is the area of an individual bar in mm^2.

a) The basic development length is further multiplied by: 1.0

For all bars satisfying any one of the following conditions:

i) Bars in beams or columns with minimum cover not less than 40 mm ,transverse reinforcement satisfying tie requirements ,minimum stirrup requirements of sec 6.2.7.4(d) and 6.2.7.4e (ii) along the development length ,and with clear spacing of not less than 3d_b ,

ii) Bars in beams or columns with minimum cover not less than 40 mm (for primary reinforcement) and enclosed within transverse reinforcement A_{tr} along the development length satisfying $A_{tr} \geq \frac{d_b sn}{40}$.

iii) Bars in the inner layer of slab or wall reinforcement and with clear spacing of not less than 3d_b.

iv) Bars in the inner layer of slab or wall reinforcement and with clear spacing of not less than 3d_b.

b) For bars with a cover of d_b or less or with a clear spacing of 2d_b or less: 2.0

c) For other bars not satisfying (a) or (b) above: 1.4

d) 0.8 for 35 mm ϕ bar and smaller ,with clear spacing not less than 5 d_b ,and with at least 2.5d_b clear from face of member to edge of bar.

e) 0.75 for reinforcement enclosed within spiral reinforcement not less than 6 mm diameter and not more than 100 mm pitch.

However, the basic development length multiplied by the previous factors shall not be taken less than $\frac{0.375 d_b f_y}{\sqrt{f_c^{'}}}$.

The basic development length also is multiplied by the following factors:

1.3 for Top horizontal reinforcement so placed that more than 300 mm of concrete is cast in the member bellow the bar; 1.5 for Epoxy coated reinforcement with cover less than 3d_b `or clear spacing less than 6d_b; 1.2 epoxy coated bars for all other conditions. The product of factor for top reinforcement and the factor for epoxy coated reinforcement not need to be taken greater than 1.7.

The development length may be reduced by the factor $\frac{A_s\ (required)}{A_s\ (provided)}$ = where reinforcement in a flexural member is in excess of that required by analysis except where anchorage or development for f_y is specially required.

2.5 AASHTO (2007)

The minimum lap splice length in tension according to AASHTO (2007) provisions is class A, Class B or class C splice. Class A splice is required a length of 1.0l_d , class B is required a length of 1.3l_d and a class C is required a length of 1.7l_d. Where the term l_d is the development length of deformed bars in tension and determined as the product of the basic development length l_{db} and the applicable modification factors, which are expressed bellow. The class of lap splice for deformed bars in tension is specified in Table 5.

Table 5
Classes of tension lap splices: AASHTO (2007)

Ratio $\frac{((A)_s\, provided)}{((A)_s\, required)}$	Maximum percent of A_s spliced within required lap length		
	50	75	100
≥ 2	A	A	B
< 2	B	C	C

The tension development length l_d in mm can be calculated by the following equations. But the tension splice length shall not be less than 300 mm.

$$l_{bd} = \frac{0.02 * A_b f_y}{\sqrt{f_c^{'}}} \text{ (For 36 mm } \phi \text{ bar or smaller)} \quad 9(a)$$

but not less than $0.06 d_b f_y$.

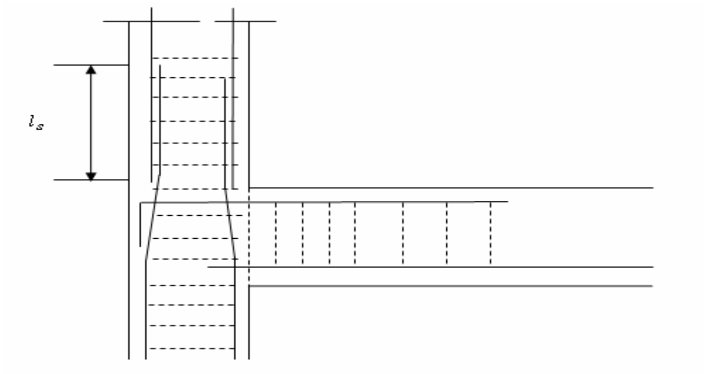
$$l_{db} = \frac{25 f_y}{\sqrt{f_c^{'}}} \text{ (For 43 mm } \phi \text{ bars)} \quad 9(b)$$

$$l_{db} = \frac{34 f_y}{\sqrt{f_c^{'}}} \text{ (For 57 mm } \phi \text{ bars)} \quad 9(c)$$

where, A_b is the area of bar (mm^2), f_y yield strength of reinforcing bars in MPa, $f_c^{'}$ Compressive strength of concrete at 28 days, unless another age is specified in MPa, and d_b diameter of the bar in mm. The development lengths given in Eq. (11) are multiplied by one or more factors: 1.4 for horizontal or nearly horizontal reinforcement placed with more than 300mm of fresh concretecast below the reinforcement (top-bar factor); $l_{db} = \frac{34 f_y}{\sqrt{f_c^{'}}}$ for low-density concrete, where f_{ct} is the splitting tensile strength of the concrete; 1.3 for concrete in which all aggregate is lightweight or 1.2 for sand-lightweight concrete ,where f_{ct} is not specified; 1.5 for epoxy-coated bars with cover less than $3 d_b$ or clear spacing less than $6\, d_b$, or 1.2 for epoxy-coated bars not covered by the previous criterion. The product obtained when combining the factor for top reinforcement with the factor for epoxy coated bars need not be taken greater than 1.7 under the assumption that the reduced contact area, because of concrete settlement, and the lower coefficient of friction for epoxy-coated bars are not fully additive. In addition, development or splice lengths may be multiplied by 0.8 for reinforcement being developed in the length under consideration when it is spaced not less than 150mm center-to-center, with not less than 75mm clear cover measured in the direction of spacing, (As required)/(As provided) when anchorage of the full yield strength of the reinforcement is not required or when reinforcement in flexural members is in excess of that required by analysis, and 0.75 when reinforcement is enclosed within a spiral composed of bars of not less than 6mm in diameter and spaced at not more than a 100mm pitch. The AASHTO provisions recognize no other cases in which confining reinforcement contributes to bond strength.

3.0 Parametric study for splice length

Figure 3 shows a beam-column joint in a continuous building frame .Column dimensions are 300 mm x 525 mm, longitudinal bars are subjected to tensile stress for all load combinations. Transverse reinforcement is used at 100 mm spacing.



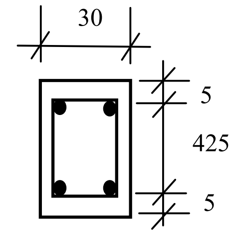


Fig.3. Beam column joint

Table 6
Parameters

Concrete Compressive Strength	10 MPa, 15 MPa, 20.5 MPa, 23.9 MPa, 26.67 MPa, 30 MPa and 35 MPa.
Yield Strength of Reinforcing Bars Bar Diameter	274 MPa, 410 MPa and 500 MPa. 12mm, 16 mm, 20 mm, 22 mm, 25 mm, 28 mm,32 and 36 mm.

4.0 Results and Discussion

The following table demonstrates the splice length required for various design code with different strength of concrete and reinforcing bars of different bar sizes. These are obtained by conducting the parametric study of concrete strength 10 MPa, 15 MPa, 20.5 MPa, 23.9 MPa, 26.67 MPa, 30 MPa and 35 MPa. The yield strength of reinforcing bars is 274 MPa, 410 MPa and 500 MPa.

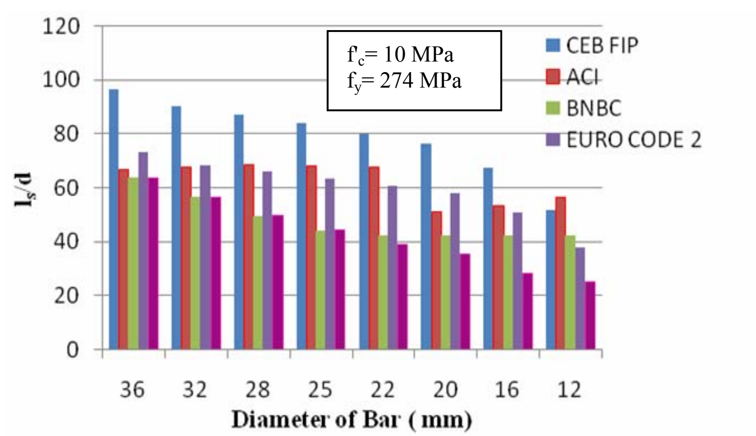


Fig. 4. Tension splices length of Reinforcing bar.

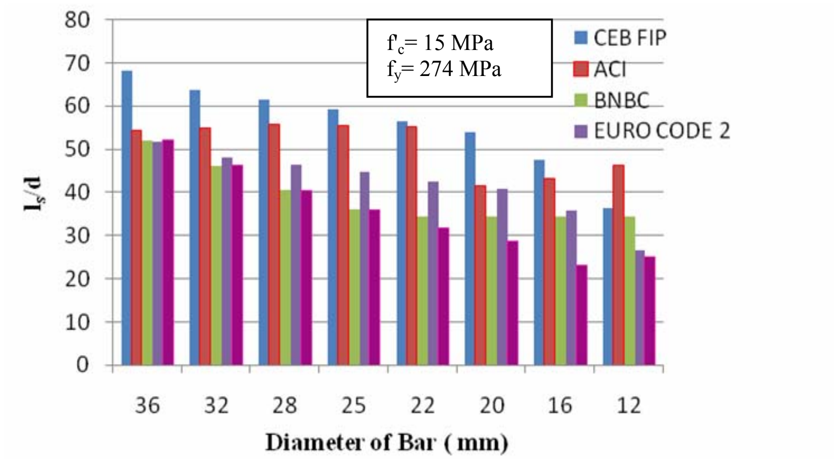


Fig. 5. Tension splices length of Reinforcing bar

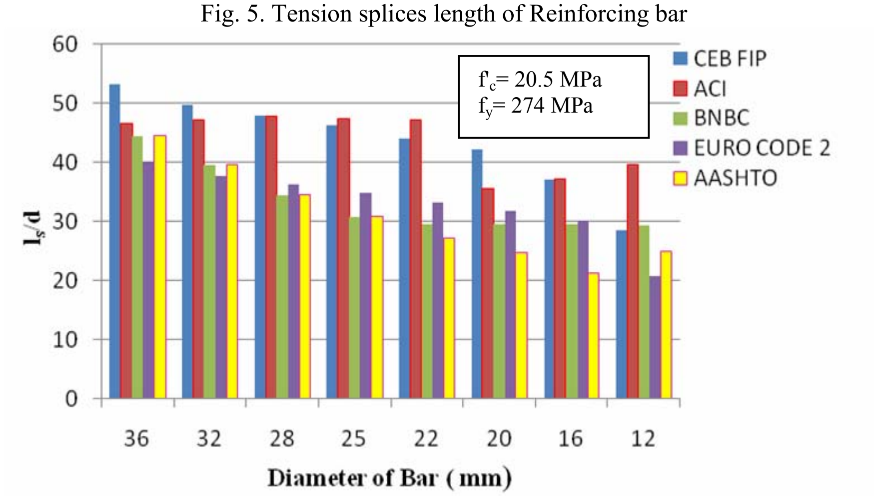


Fig. 6. Tension splices length of Reinforcing bar.

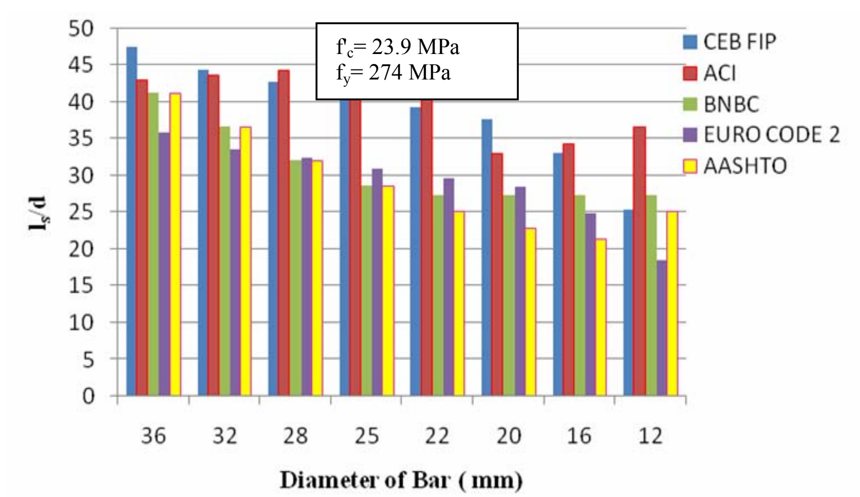


Fig. 7. Tension splices length of Reinforcing bar

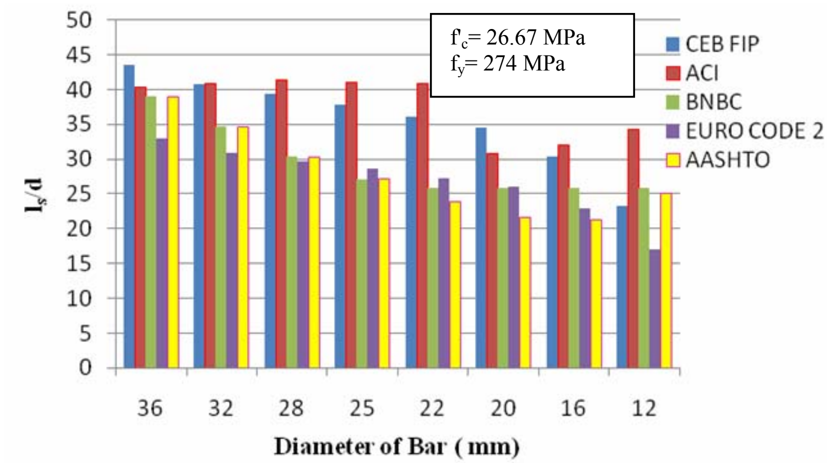


Fig. 8. Tension splices length of Reinforcing bar

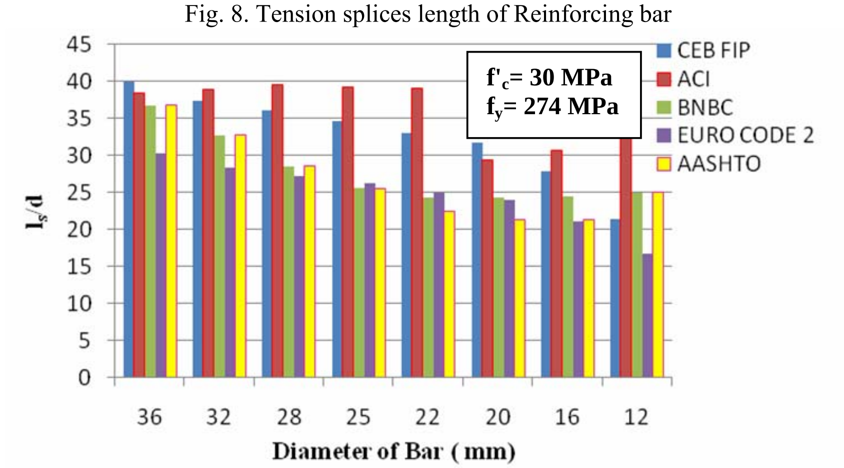


Fig. 9. Tension splices length of Reinforcing bar

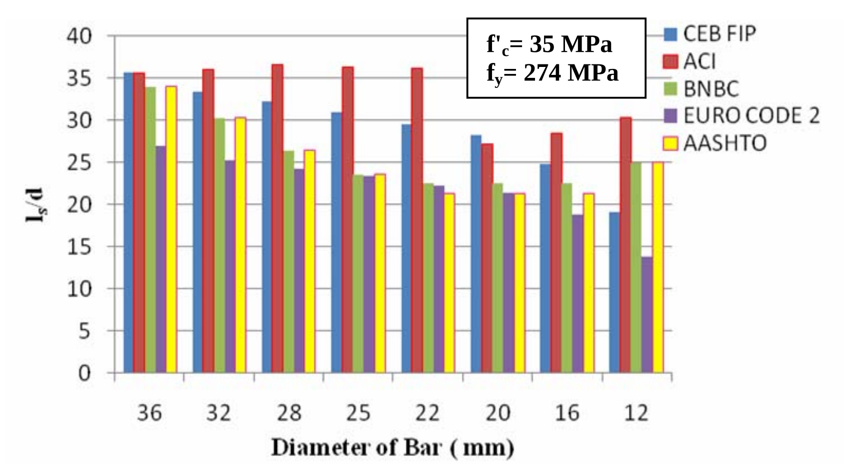


Fig. 10. Tension splices length of Reinforcing bar

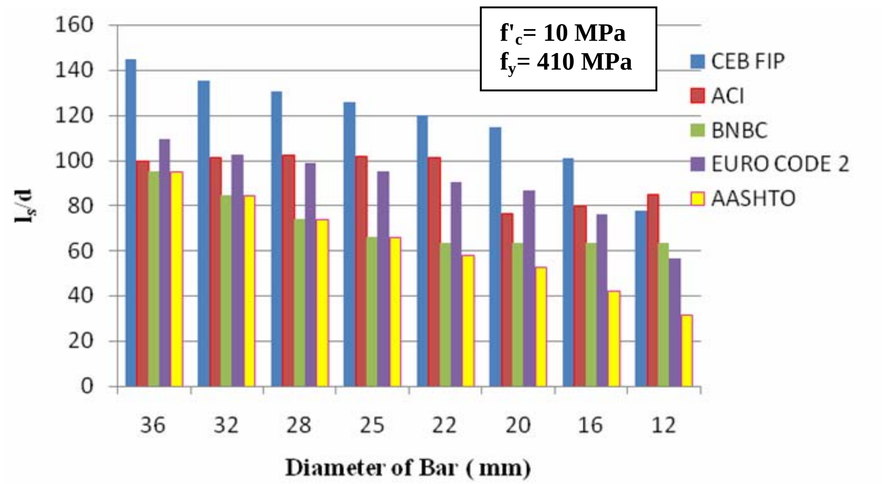


Fig. 11. Tension splices length of Reinforcing bar

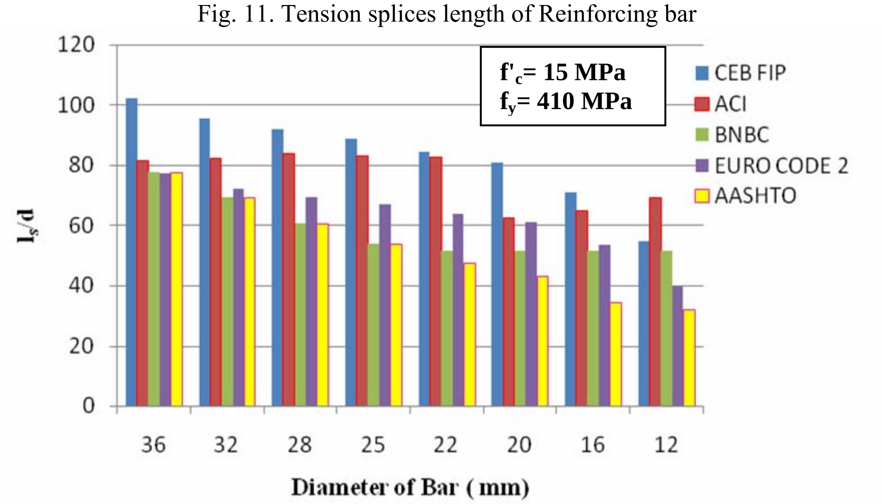


Fig. 12. Tension splices length of Reinforcing bar

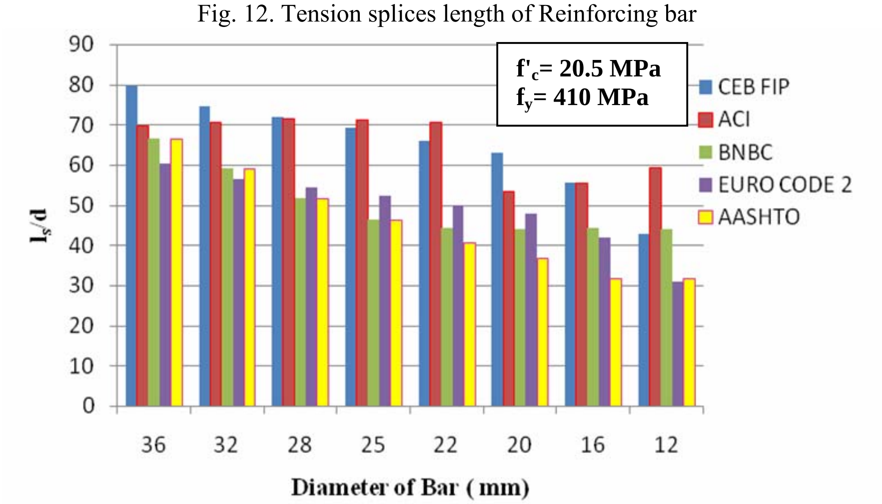


Fig. 13. Tension splices length of Reinforcing bar

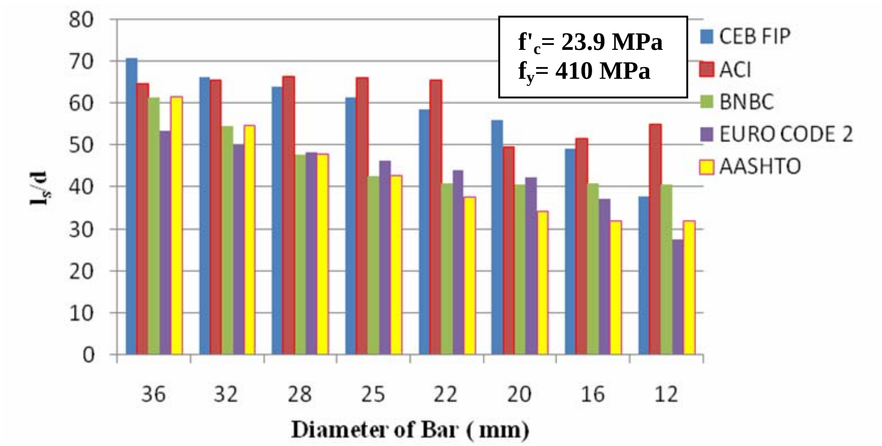


Fig. 14. Tension splices length of Reinforcing bar

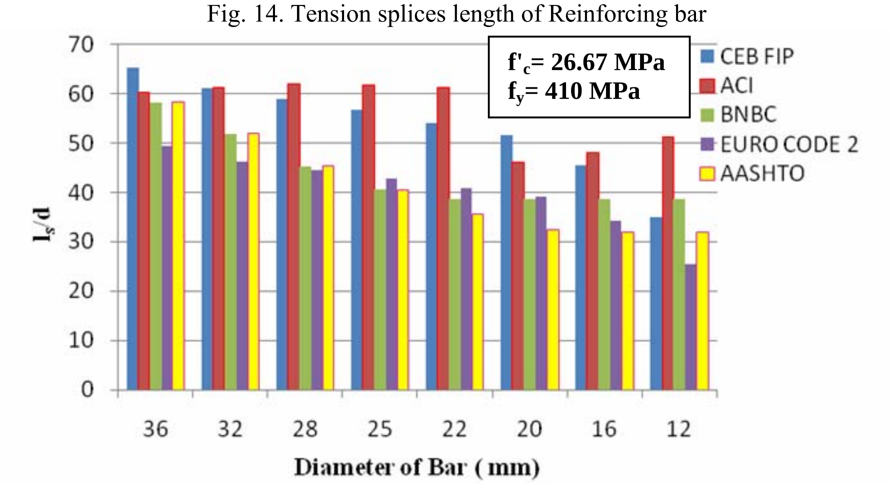


Fig. 15. Tension splices length of Reinforcing bar

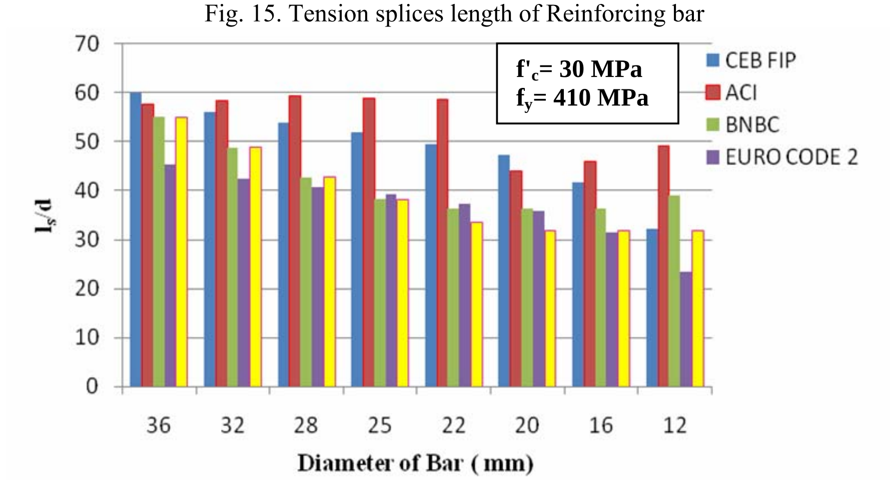


Fig. 16. Tension splices length of Reinforcing bar

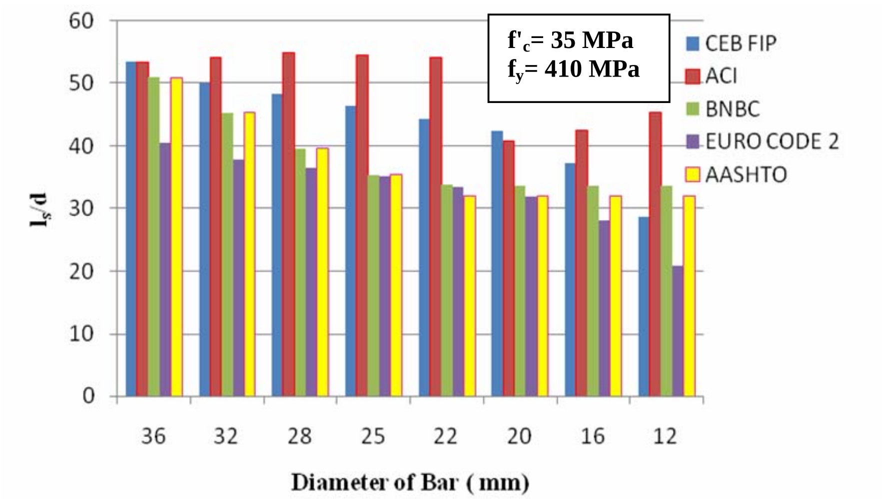


Fig. 17. Tension splices length of Reinforcing bar.

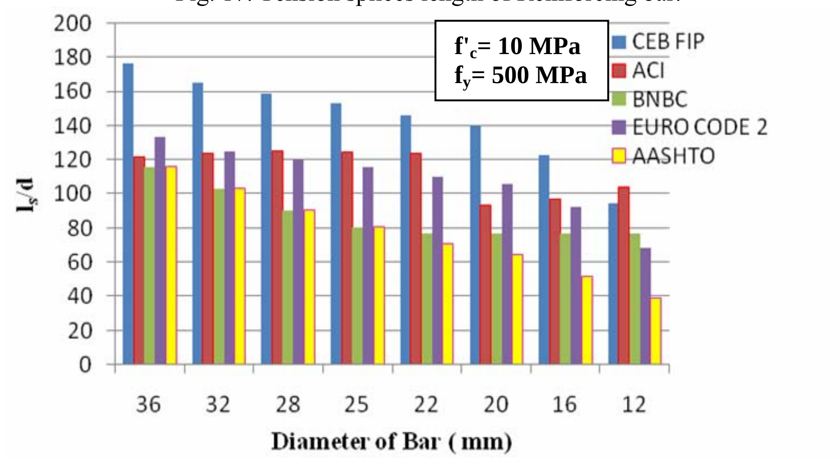


Fig. 18. Tension splices length of Reinforcing bar

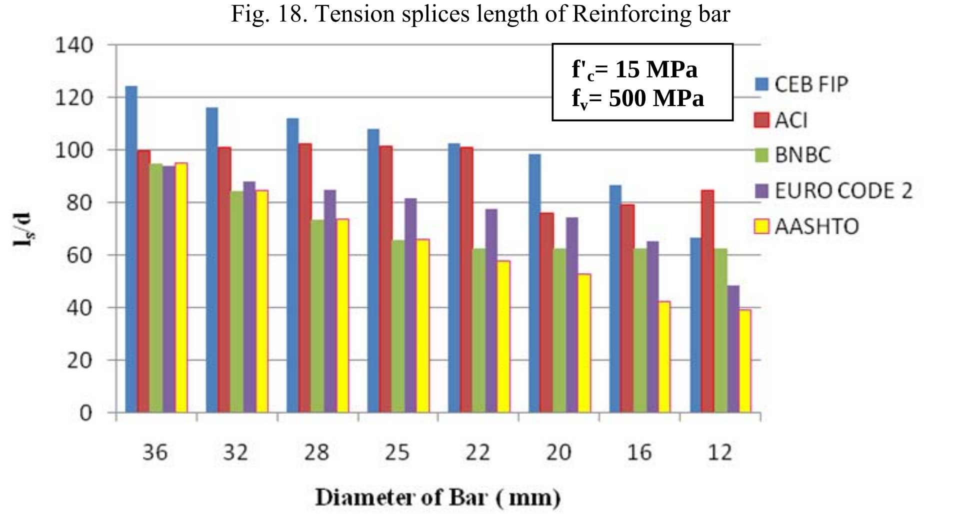


Fig. 19. Tension splices length of Reinforcing bar

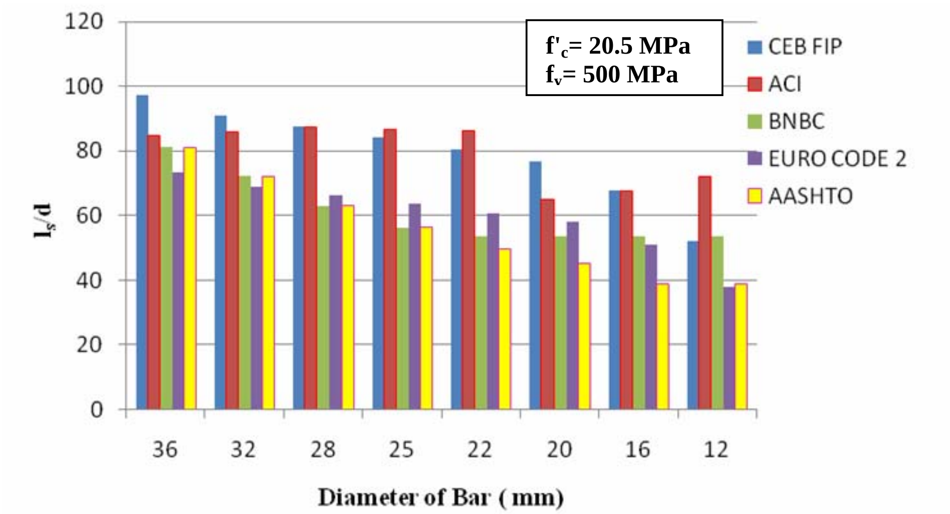


Fig. 20. Tension splices length of Reinforcing bar

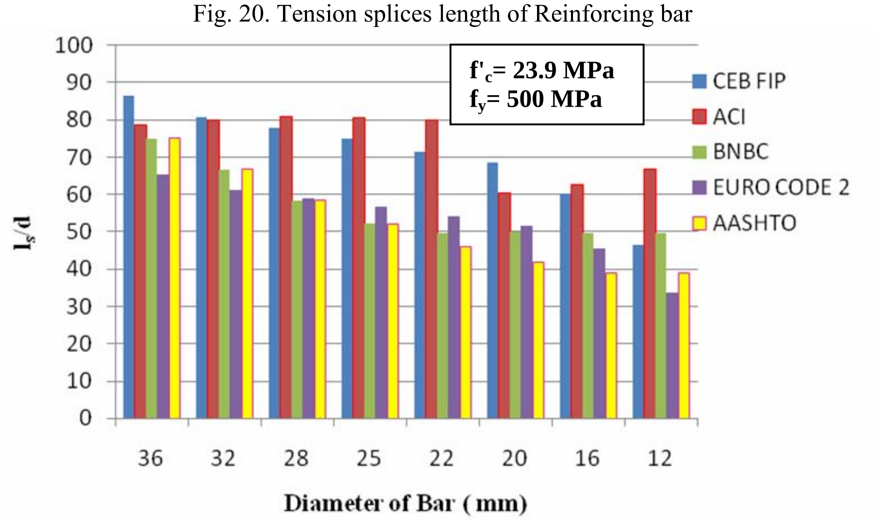


Fig. 21. Tension splices length of Reinforcing bar

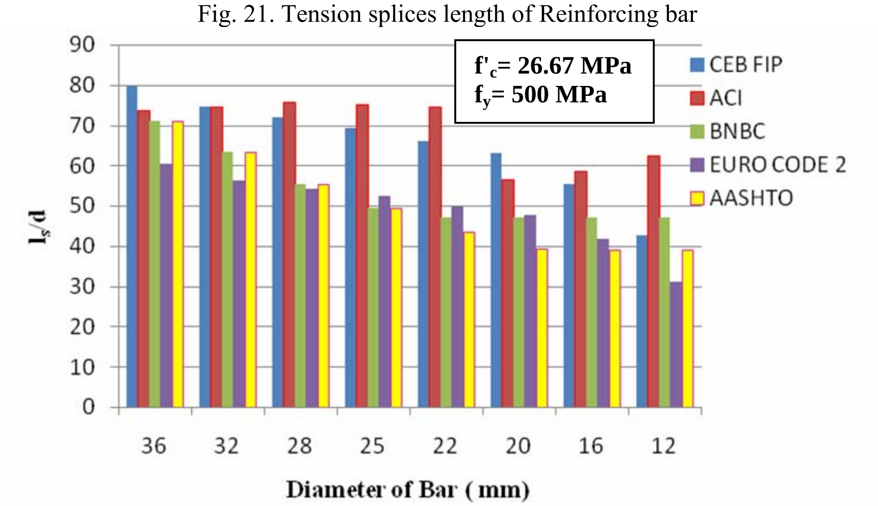


Fig. 22. Tension splices length of Reinforcing bar

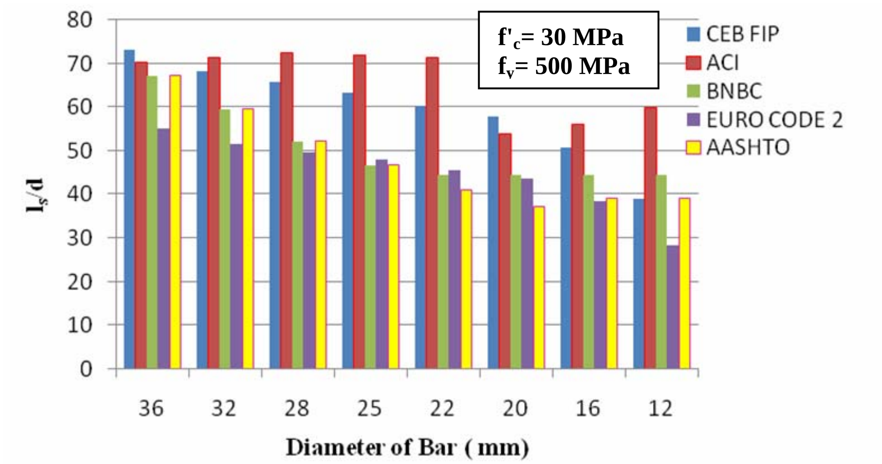


Fig. 23. Tension splices length of Reinforcing bar

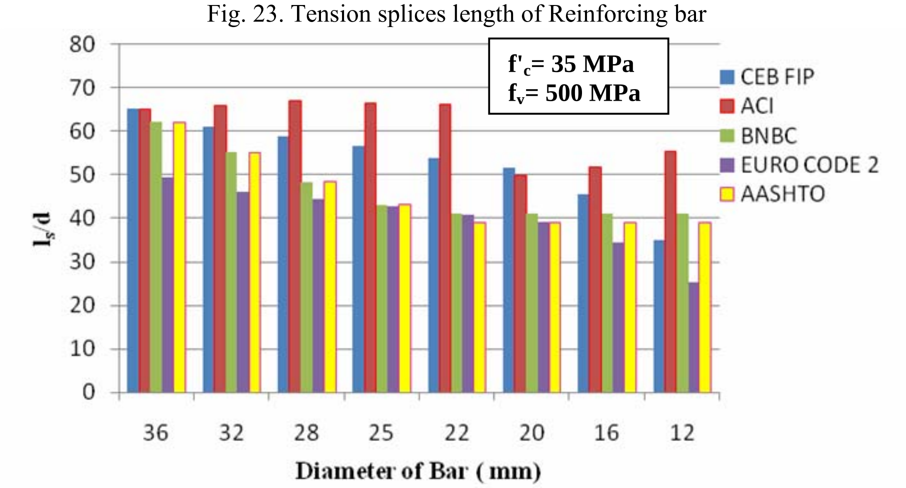


Fig. 24. Tension splices length of Reinforcing bar

5.0 Conclusions

The design codes ACI (2002), BNBC (1993), AASHTO (2007), CEB-FIP Model (1990), And EURO Code 2(2003) have been reviewed, it has been found that BNBC (1993) recommends the highest value of splice lengths for 22 mm ϕ and larger diameter bars relative to other codes. In this study the authors found that the normalized splice length is decreasing with increasing the concrete strength for specific yield strength while, normalized splice length is increasing with increasing the steel strength for a specific concrete strength. After performing a parametric study it has been found that,for BNBC (1993), the normalized splice length remains the same up to 22 mm diameter bars and for larger diameter bars the normalized splice length increases significantly. In contrast, ACI (2002) recommends the same normalized splice length for 22 mm and larger diameter bars. CEB-FIP Model (1990) advised the larger normalized splice length than ACI (2002) for lower strength of concrete. With increasing of concrete strength CEB-FIP Model exhibits the largest normalized splice length.

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Appendix A: Numerical example

The calculation of splice length as per the ACI (2002), BNBC (1993), AASHTO (2007), CEB-FIP Model (1990), and EURO Code 2(2003) .The splice length requirement is calculated based on the following data. Compressive strength of concrete is 10 MPa, 15 MPa, 20.5 MPa, 23.9 MPa, 26.67 MPa, 30 MPa, and 35 MPa. Tensile strength of reinforcing bars is 274 MPa, 410 MPa, 500 MPa, Diameter of bar 12 mm, 16 mm, 20 mm, 22 mm, 25 mm, 28 mm, 32 mm and 36 mm.

Cover to reinforcement = 50 mm
Side cover = 50 mm
Spacing of reinforcement (Tie Spacing) = 125 mm, Area of transverse reinforcement, $A_{tr} = 78.53 mm^2$
Normal weight concrete is used,

1 MPa = 146.34 Psi.

Assume,

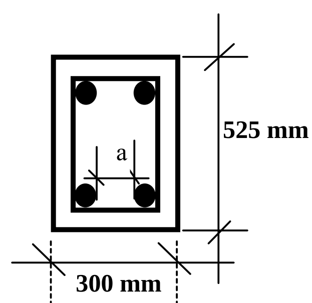
i) Excess reinforcement = $\frac{A_{s(req)}}{A_{s(pro)}} = 1.0$ $\frac{A_{s(req)}}{A_{s(pro)}} = 1.0$

ii) Splice is being of same diameter of bars, Covering 50 mm, 50% reinforcement is spliced.

iii) The term (1-0.04P) = 1.0

CEB-FIP model (1990)

<u>Calculation for 36 mm ϕ bar,</u>



$\eta = 1.00$ for $d_b \leq 32$ mm, $\eta = \frac{100}{132 - d_b}$ for $d_b > 32$ mm

$\eta = \frac{100}{132 - d_b} = \frac{100}{132 - 36} = 1.041$

$c_{min} = \min(a/2, c_1, c2)$ a = 300-2*10 - 2*50 - 2*36

$c_{min} = \min(54, 50, 50)$ a = 108 mm

$c_{min} = 50$ mm

k = 0.1 A_b = Area of the largest bar being spliced = 1017.87 mm^2

$\sum A_{str} = 0.25 * \pi * (12)^2 = 113.097 mm^2$ $\sum A_{str,\min} = 0.25 * \pi * (36)^2 = 1017.87 mm^2$

$$f_{yk} = 1.06 f_y = 1.06 * 274 = 290 \text{ MPa}$$

$$f_{yd} = \frac{f_{yk}}{1.15} = \frac{290.44}{1.15} = 252.55 \text{ MPa}$$

$$f_{ck} = f_c^{'} - 2.75 = 10 - 2.75 = 7.25 \text{ MPa}$$

$$l_d = \frac{1}{1.228}\left(1.15 - 0.15 * \frac{c_{\min}}{d_b}\right)\left(1 - k\frac{\sum A_{str} - \sum A_{str,\min}}{A_b}\right)\eta \frac{f_{yd}}{f_{ck}^{2/3}} d_b$$

$$= \left(\frac{1}{1.228}\right)\left(1.15 - 0.15 * \frac{50}{36}\right)\left(1 - 0.1 * \frac{113.097 - 1017.87}{1017.87}\right) * (1.041) * \frac{252.55}{(7.25)^{2/3}} * 36$$

=1935 mm

$\alpha_b = 1.8$ (50% reinforcement is to be spliced)

$$\frac{l_d}{d} = \frac{1.8 * 1935}{36} = 96.75 \text{ mm}$$

Similarly, the normalized splice length for bar diameter 32 mm, 28 mm, 25 mm, 22 mm, 20 mm, 16 mm and 12 mm are 90.50, 87.25, 84.00, 80.04, 76.55, 67.37 and 51.83.

ACI (2002)

Calculation for 36 mm ϕ bar,

$\alpha = 1.0$

$\beta = 1.0$ (For uncoated reinforcement)

$\gamma = 1.0$ (For uncoated reinforcement)

50% reinforcement is spliced,and $\frac{(\mathbf{A_s Provided})}{(\mathbf{A_s required})} = 1.0$ so, B class splice is used.

For 22 mm diameter or Larger diameter bars

$f_y = 274$ MPa = 40000 Psi, $\quad f_c^{'} = 10$ MPa = 1463 Psi.

$$(l_s / d_b) = 1.3 * \frac{f_y}{20 * \sqrt{f'_c}} \qquad = 1.3 * \frac{40000}{20 * \sqrt{1463}}$$

$(l_s / d_b) = 66.55$

Similarly, the normalized splice length for bar diameter 32 mm, 28 mm, 25 mm, 22 mm, 20 mm, 16 mm and 12 mm are 67.43, 68.42, 67.96, 67.54, 50.95, 53.06 and 56.58.

BNBC (1993)

Calculation for 36 mm ϕ bar,

yield strength $f_y = 274$MPa.

Concrete strength $f_c^{'} = 10$MPa.

Area of the reinforcement $A_b = 1017.87\text{mm}^2$.

Assume,

i) Min cover satisfying that specified in sec. 8.1.8.1 in BNBC.

ii) Transverse reinforcement satisfying tie requirements of sec.8.1.10.4.

so, modification factor = 1.0

a= 300-2*(10+50+36) = 108 mm > $3d_b$

$$l_{db} = \frac{0.02 A_b f_y}{\sqrt{f_c^{'}}} = \frac{0.02*1017.87*274}{\sqrt{10}} = 1763\text{mm}$$

$l_d = 1763$mm

But, minimum development length $l_{d(\min)} = \dfrac{0.375 d_b f_y}{\sqrt{f_c^{'}}} = \dfrac{0.375*36*274}{\sqrt{10}}$

=1169 mm

$l_s = 1.3 l_d = 1.3*1763 = 2291$mm

$(l_s / d_b) = 63.69$

Similarly, the normalized splice length for bar diameter 32 mm, 28 mm, 25 mm, 22 mm, 20 mm, 16 mm and 12 mm are 56.59, 49.53, 44.20, 42.22, 42.20, 42.18 and 42.16.

AASHTO (2007)

Calculation for 36 mm ϕ bar,But not less than $0.06 d_b f_y$.

yield strength $f_y = 274$MPa.

Concrete strength $f_c^{'} = 10$MPa.

Area of the reinforcement $A_b = 1017.87\text{mm}^2$.

Assume,

i) Min cover satisfying that specified in sec. 8.1.8.1 in BNBC.

ii) Transverse reinforcement satisfying tie requirements of sec.8.1.10.4.

so, modification factor = 1.0

a= 300-2*(10+50+36) = 108 mm > $3d_b$

$$l_{db} = \frac{0.02 A_b f_y}{\sqrt{f_c^{'}}} = \frac{0.02*1017.87*274}{\sqrt{10}} = 1763\text{mm}$$

$l_d = 1763$mm

But, minimum development length $l_{d(\min)} = \dfrac{0.375 d_b f_y}{\sqrt{f_c^{'}}} = \dfrac{0.375*36*274}{\sqrt{10}}$

=1169 mm