THE COMPARISON ANALYSIS OF DEVELOPMENT LENGTH IN ACCORDANCE WITH ARMENIAN AND FOREIGN BUILDING STANDARDS

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Abstract: *The study of a development length determination according to Armenian and foreign building standards is presented. For analysis implementation different concrete classes (B20, B25, B30) and rebar diameters (25mm, 28mm, 32mm) were chosen. Reinforcement bar class A500C was taken. Two different cases were considered: in one case, the reinforcement is taken in tension, in the other case, in compression. The results show that in the cases of both tension and compression, the value of the anchorage length obtained by Armenian building standards is 23.1% more than by Russian codes received. In the case of tension, the value of the anchorage length obtained by American codes is 16.7-20.8% more than the one obtained by the Armenian building standards. Consequently, the anchorage length also should be checked by the American building standards for structure design.*

Keywords: *development length, anchoring, reinforced concrete structure, building standards, seismic design.*

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Received: 24.10.2022

Revised: 04.11.2022

Accepted: 22.11.2022

Introduction

Anchoring is a very important process on the correctness of which the quality, durability and ability to withstand various loads of the reinforced concrete monolith depends. Reinforcement reinforces concrete structure, to absorb and take the loads, to make the monolith durable, reliable and solid. Reinforcement elements can be rigid or flexible, and are usually made of steel or composite materials.

The size and type of anchoring is largely determined by the characteristics and operating conditions of certain areas where loads are transferred from the metal bars to the material. There are several methods of anchoring and it is important to carry out correct calculations beforehand by determining key parameters such as method of anchoring, length of reinforcement anchorage, etc.[1] [1,2, 11-13].

Provision of appropriate development is an important aspect of safe construction practices. Proper development length in reinforcement bars shall be provided as per the steel grade considered in design.

Otherwise in scenarios where less development length against the required is provided the structures will be prone to encounter failure due to slippage of joints, bonds, anchors and laps, in such cases the bars will not yield first but the failure will happen at joints and laps prior to yielding of reinforcement bars[2] [3,4].

The main purpose of the paper is to analyze the development length calculations, according to varies building standards and estimate the differences between them.

Materials and Methods

To implement the comparison analyses of development lengths (Fig.1) were chosen Russian and American building standards RA[3], RF[4], USA[5], inasmuch as given codes are widespread in the sphere. For future analyses the possible alternative standards will be included.

In accordance with Armenian current building standards "RA" the required anchorage design length of the

[1] https://1beton.info

[2] https://theconstructor.org

[3] Betone yev yerkatbetone konstruktsianer (nakhagtsman normer), HHSHN 52-01-21 (in Armenian).

[4] СП 63.13330.2018 Betonnyye i zhelezobetonnyye konstruktsii (in Russian).

[5] Building Code Requirements for Structural Concrete (ACI 318-19).

bar taking into account the constructive solution of the element in the anchorage zone, is determined by the following formula:

$$l_{an} = 1,3 \cdot \alpha \cdot \frac{R_s}{\eta_1 \cdot \eta_2 \cdot R_{bt}} \cdot \frac{A_s}{u_s} \cdot \frac{A_{s,cal}}{A_{s,ef}}, \tag{1}$$

where:

α is a coefficient that takes into account the influence of the stress state of concrete and reinforcement, as well as the constructive solution of the element in the anchorage zone on the length of the anchorage,

R_s is the design resistance of the reinforcement bar,

η_1 is a factor that takes into account the effect of the surface appearance of the reinforcement bar,

η_2 is a factor that takes into account the effect of the size of the reinforcement bar's diameter,

R_{bt} is a design resistance of concrete by axial tension,

A_s and u_s respectively, are the cross-sectional area of the reinforcing bar and the perimeter of its cross-section,

$A_{s,cal}$ and $A_{s,ef}$ respectively, are the cross-sectional areas of the reinforcement required by calculation and actually installed.

For non-prestressed reinforcement bar, when anchoring of bars with straight edges of periodic grid (straight anchorage) or without additional anchoring devices with staples or hinges of flat surface reinforcement, $\alpha = 1.0$ is taken for tensioned bars and $\alpha = 0.75$ for compressed bars.

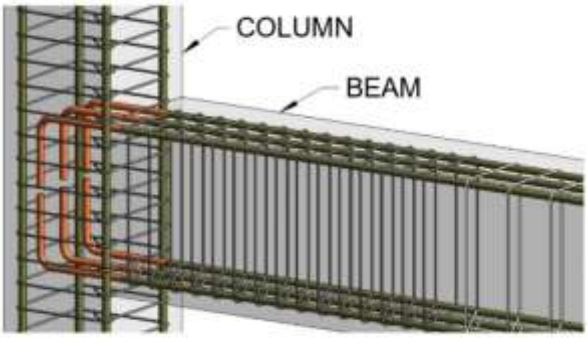

Fig. 1. *Scheme of development length*

For non-prestressed reinforcement bar the η_1 coefficient is equal to 1.5 in case of flat surface reinforcement bar, 2.0 in case of cold-deformed reinforcement with a periodic pattern and 2.5 in case of periodical grid - rolled and thermomechanical treated rebars. Moreover, for non-prestressed reinforcement bar the η_2 coefficient is equal to 1.0 when the diameter of rebar is less than *32mm* and is equal to 0.9 when the diameter of rebars are *36mm* and *40mm.*

In accordance with Russian current building standards "RF" the required anchorage design length of the bar, is determined by the following equation:

$$l_{an} = \alpha \cdot \frac{R_s}{\eta_1 \cdot \eta_2 \cdot R_{bt}} \cdot \frac{A_s}{u_s} \cdot \frac{A_{s,cal}}{A_{s,ef}}. \tag{2}$$

In all cases, according to the Armenian and Russian building standards, respectively the actual length of the anchorage is accepted not less than *25ds* and *300mm*, *15ds* and *200mm,* and for non-prestressing bars, also not less than $0.5l_{0,an}$ and $0.3l_{0,an}$, likewise the length of anchorage of reinforcing bars is allowed to be reduced depending on the number and diameter of the transverse reinforcement, the type of anchoring equipment (welding of the transverse reinforcement, curvature of the edges of the periodic bars) and the transverse compression of the concrete in the anchorage zone (for example, support displacement), but not more than *30%.*

The base (main) length of the anchor [5,6], which is necessary to transfer the resistance stress of the reinforcement to the concrete with the full design value, in accordance with the Armenian (3) and Russian (4) building standards, respectively is determined by the following formula:

$$l_{0,an} = 1,3 \cdot \frac{R_s}{\eta_1 \cdot \eta_2 \cdot R_{bt}} \cdot \frac{A_s}{u_s}, \tag{3}$$

$$l_{0,an} = \frac{R_s}{\eta_1 \cdot \eta_2 \cdot R_{bt}} \cdot \frac{A_s}{u_s}. \tag{4}$$

Design resistances of concrete according to axial compression (R_b) and axial tension (R_{bt}), are determined by the following formulas:

$$R_b = \frac{R_{b,n}}{\gamma_b}, \tag{5}$$

$$R_{bt} = \frac{R_{bt,n}}{\gamma_{bt}}, \tag{6}$$

where:
$R_{b,n}$ and $R_{bt,n}$ respectively, are the normative axial compression and axial tension,
γ_b and γ_{bt} respectively, are the reliability factors of concrete in compression and tension.

In the case of compression, the values of the concrete reliability coefficient are taken as equal:

1. the first group for calculation with limit states
   a. 1.3 – for heavy, fine-grained, tension and light concretes,
   b. 1.5 – for cellular concrete,
2. the second group is taken equal to 1.0 in case of calculation with limit states.

In the case of tension, the values of the reliability coefficient of concrete are taken equal to:

1. the first group for calculation with limit states, when the class of concrete is defined according to compressive strength
   a. 1.5 – for heavy, fine-grained, tension and light concretes,
   b. 2.3 – for cellular concrete,
2. the first group for calculation with limit states, when the class of concrete is defined according to tensile strength
   a. 1.3 – for heavy, fine-grained, tension and light concretes,
3. the second group is taken equal to 1.0 in case of calculation with limit states.

If necessary, the calculated values of concrete strength [7,8] characteristics are multiplied by the following coefficients of γ_{bi} working conditions, which take into account the specifics of concrete work in structures (nature of loading, environmental conditions, etc.):

1. γ_{b1} – for concrete and reinforced concrete structures, is introduced with the calculated resistance values of concrete R_b and R_{bt} and takes into account the duration of static load impact;
   a. $\gamma_{b1} = 1.0$ in case of non-permanent (short-term) impact of the load,
   b. $\gamma_{b1} = 0.9$ in the case of continuous (long-term) exposure to the load.

For cellular and porous concretes $\gamma_{b1} = 0.85$. In the case of lightweight concrete, for the R_b resistance value $\gamma_{b1} = 0.85$ (the reduction of the R_{bt} resistance value is regulated by the γ_{b6} factor).

2. γ_{b2} – for concrete structures, is introduced with the values of calculated resistances of concrete R_b and takes into account the nature of decay of similar structures, $\gamma_{b2} = 0.9$.

In accordance with American current building standards "USA" the required anchorage design length of the bar in tension, is determined by the following formula:

$$l_d = \left(\frac{f_y}{1{,}1 \cdot \lambda \cdot \sqrt{f_c^{'}}} \cdot \frac{\psi_t \cdot \psi_e \cdot \psi_s}{\left(\frac{C_b + K_{tr}}{d_b} \right)} \right) \cdot d_b, \tag{7}$$

in which the confinement term $\frac{C_b + K_{tr}}{d_b}$ shall not be taken greater than 2.5, and

$$K_{tr} = \frac{40 \cdot A_{tr}}{s \cdot n}, \tag{8}$$

where:
f_y is a specifed yield strength for nonprestressed reinforcement,
f_c' is a specifed compressive strength of concrete,

d_b is a nominal diameter of bar, wire, or prestressing strand,

A_{tr} is a total cross-sectional area of all transverse reinforcement within spacing that crosses the potential plane of splitting through the reinforcement being developed,

s is a center-to-center spacing of items, such as longitudinal reinforcement, transverse reinforcement, tendons, or anchors,

n is the number of bars or wires being spliced or developed along the plane of splitting. It shall be permitted to use $K_{tr} = 0$ as a design simplification even if transverse reinforcement is present.

The modification factors are shown in Table 1 and Table 2.

In accordance with American current building standards "USA" the required anchorage design length of the bar in compression shall be greater than (9) and (10):

$$l_{dc} \geq \left(\frac{0,24 \cdot f_y \cdot \psi_r}{\lambda \cdot \sqrt{f_c^{'}}} \right) \cdot d_b , \quad (9)$$

$$l_{dc} \geq 0,043 \cdot f_y \cdot \psi_r \cdot d_b . \quad (10)$$

Table 1. Modification factors for tension

Modification factor	Condition	Value of factor
Lightweight λ	Lightweight concrete	0.75
	Normalweight concrete	1.0
Reinforcement Grade ψ_g	Grade 280 or Grade 420	1.0
	Grade 550	1.15
	Grade 690	1.3
Epoxy* ψ_e	Epoxy-coated or zinc and epoxy dual-coated reinforcement with clear cover less than $3d_b$ or clear spacing less than $6d_b$	1.15
	Epoxy-coated or zinc and epoxy dual-coated reinforcement for all other conditions	1.2
	Uncoated or zinc-coated (galvanized) reinforcement	1.0
Size ψ_s	No. 22 and larger bars	1.0
	No. 19 and smaller bars and deformed wires	0.8
Casting Position* ψ_t	More than 300 mm of fresh concrete placed below horizontal reinforcement	1.3
	Other	1.0

***The product $\psi_t \psi_e$ need not exceed 1.7.

Table 2. Modification factors for compression

Modification factor	Condition	Value of factor
Lightweight λ	Lightweight concrete	0.75
	Normalweight concrete	1.0
Confining Reinforcement ψ_r	Reinforcement enclosed within (1), (2), (3), or (4): (1) a spiral (2) a circular continuously wound tie with $d_b \geq$ 6mm and pitch 100 mm (3) No. 13 bar spaced ≤ 100 mm on center (4) hoops in accordance with 25.7.4 spaced ≤ 100 mm on center	0.75
	Other	1.0

Results and Discussion

A comparison values of the anchorage lengths was made between different grades of concrete (B20, B25, B30) and diameters (25mm, 28mm, 32mm) considering three foreign building standards. Reinforcement bar class was adopted unchanged, A500C class. Two different cases were considered: in one case, the reinforcement is taken in tension, in the other case, in compression. The calculation results are presented bellow graphically using the "Wolfram Mathematica" software package [9-11] (Fig. 2-5).

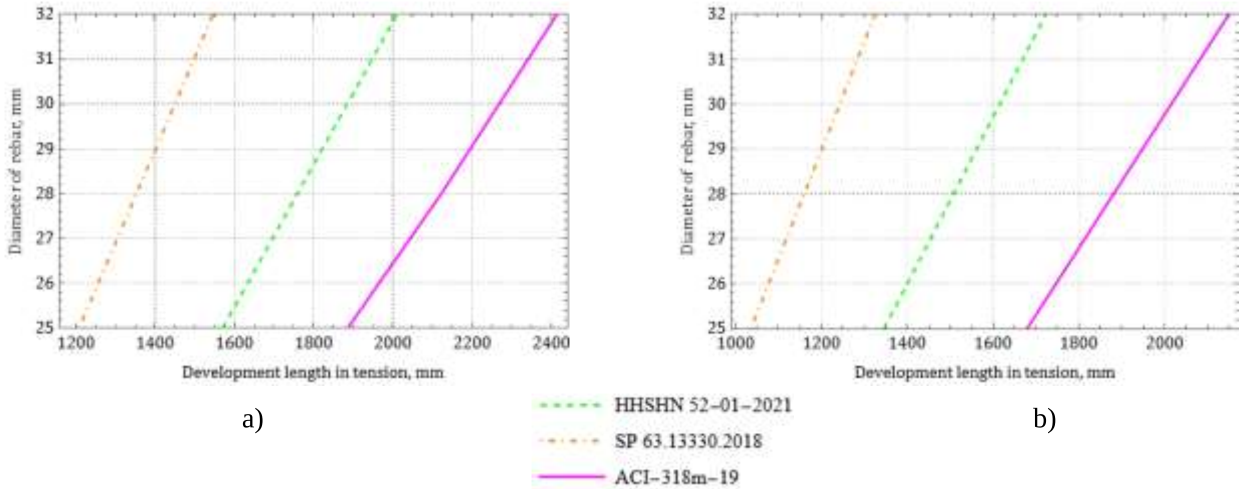

Fig. 2. *Values of anchorage lengths of tension reinforcement in case of concrete class B20 (a) and B25 (b)*

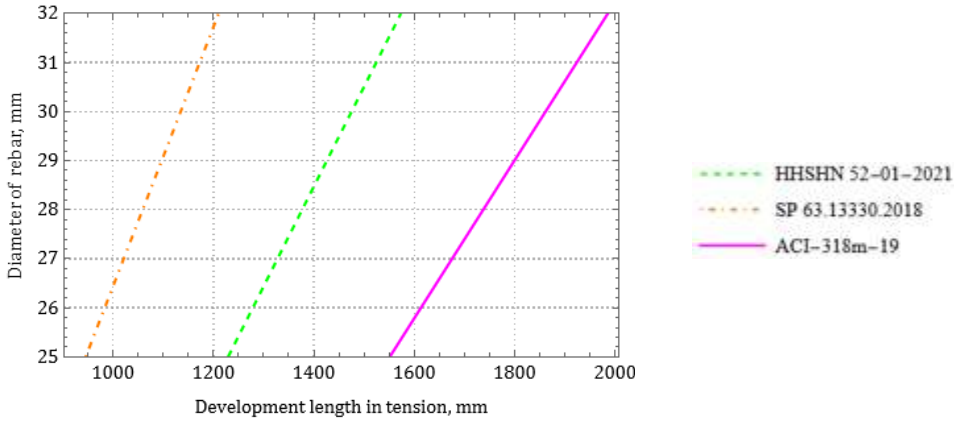

Fig. 3. *Values of anchorage lengths of tension reinforcement in case of concrete class B30*

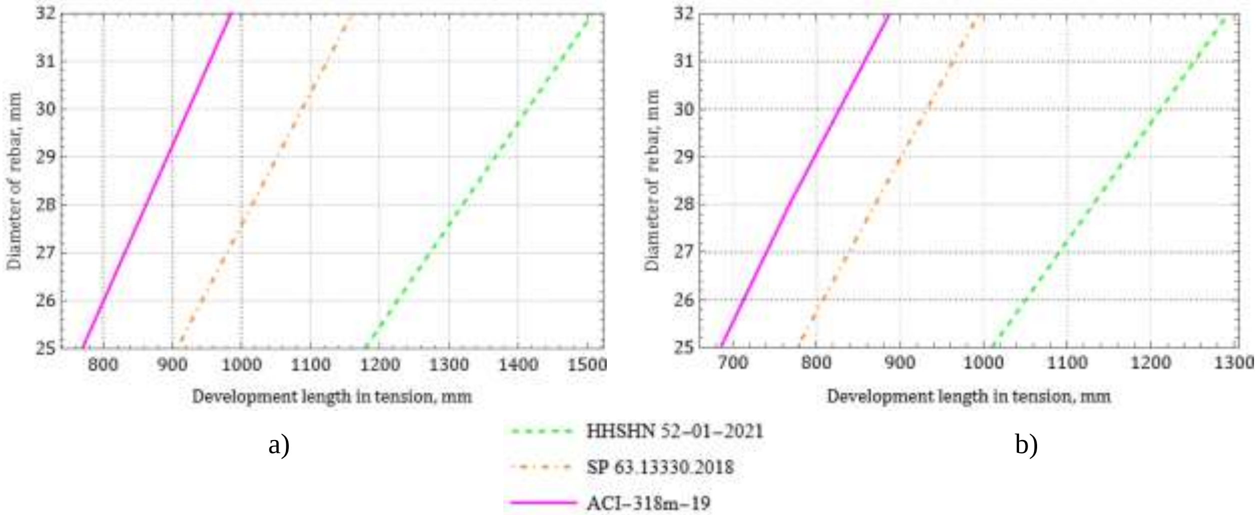

Fig. 4. *Values of anchorage lengths of compression reinforcement in case of concrete class B20 (a) and B25 (b)*

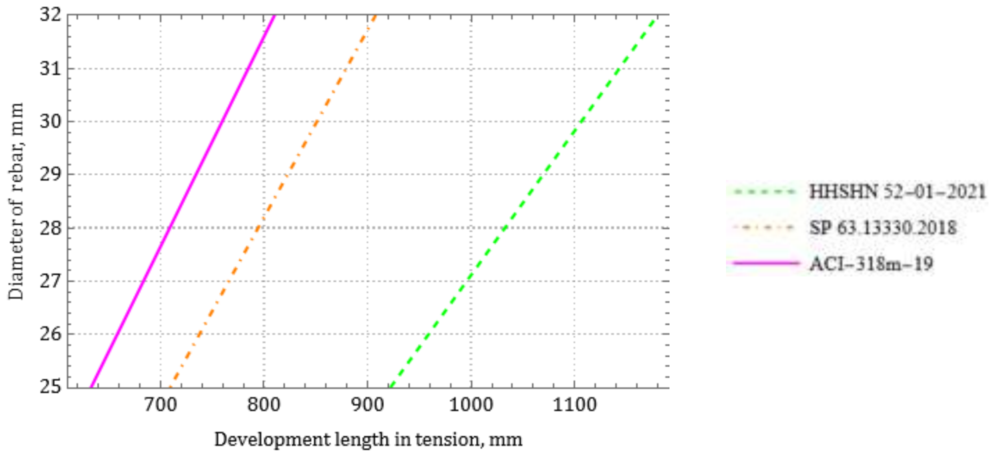

Fig. 5. *Values of anchorage lengths of compression reinforcement in case of concrete class B30*

After analyzing the results of the calculation, it becomes clear that the maximum anchorage length of tension reinforcement is required according to "USA", and in the case of compression reinforcement, it is according to "RA". The results are shown in Table 3.

Table 3. The development length results compare to HHSHN 52-01-21

Codes	Tension			Compression		
	25mm	28mm	32mm	25mm	28mm	32mm
	B20 class concrete					
СП 63.13330.2018	0.769	0.769	0.769	0.769	0.769	0.769
ACI 318-19	1.167	1.171	1.167	0.653	0.653	0.653
	B25 class concrete					
СП 63.13330.2018	0.769	0.769	0.769	0.769	0.769	0.769
ACI 318-19	1.199	1.199	1.199	0.679	0.679	0.687
	B30 class concrete					
СП 63.13330.2018	0.769	0.769	0.769	0.769	0.769	0.769
ACI 318-19	1.208	1.199	1.199	0.687	0.687	0.687

Summing up the results obtained, it can be noted that the anchorage length also should be checked by the American building standards when designing buildings and structures.

Conclusion

Thus, it becomes clear that in the cases of both tension and compression, all concrete classes and rebar diameters, the value of the anchorage length obtained by "RA" is 23.1% more than the one obtained by the "RF". In the case of tension, the value of the anchorage length obtained by "USA" is 16.7-20.8% more than the one obtained by the "RA", and in the case of compression, the value obtained by the "RA" is 31.3-34.7% more than that obtained by "USA" (Fig. 6).

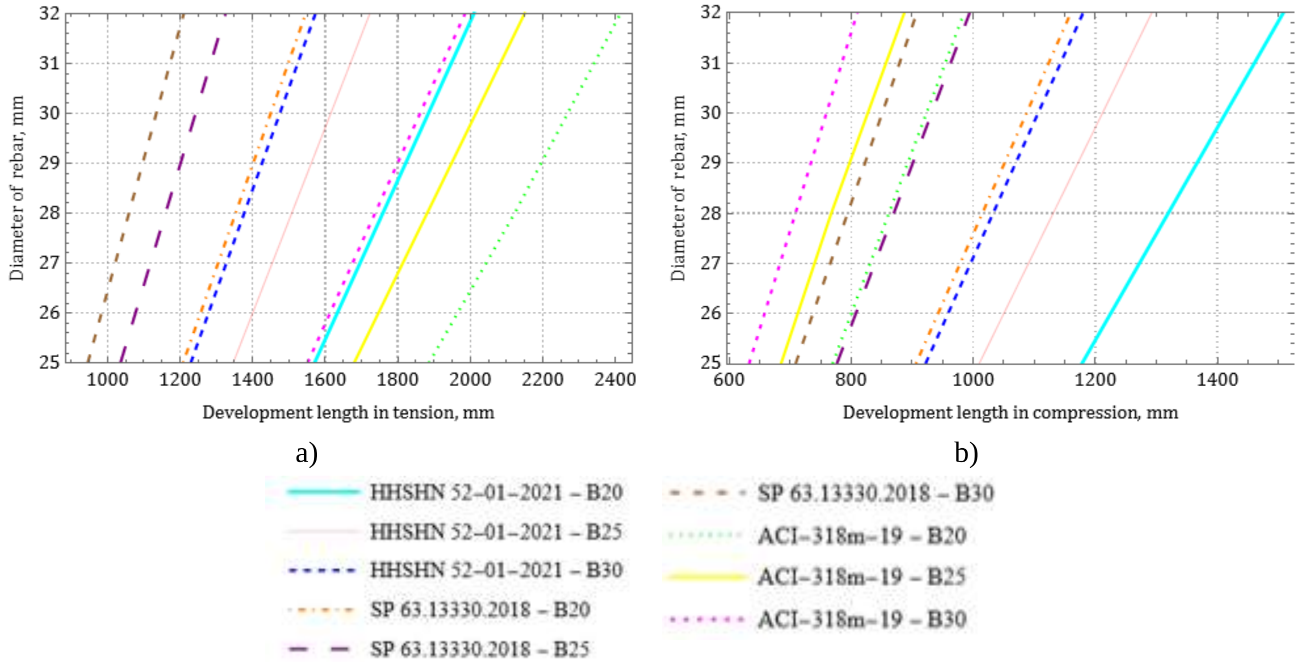

Fig. 6. *Comparison of the values of the anchorage lengths of the tensioned (a) and compressional (b) reinforcement in the case of concrete of class B20, B25 and B30*

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