

Transverse Reinforcement in Reinforced Concrete Columns

Štefan Gramblička, Peter Veróný

Slovak University of Technology in Bratislava
Civil Engineering Faculty, Department of Concrete structures and Bridges
Radlinského 11, 813 68 Bratislava I, Slovakia
stefan.gramblicka@stuba.sk
peter.verony@stuba.sk

Abstract

In the article we are dealing with the influence of transverse reinforcement to the resistance of a cross-section of the reinforced concrete columns and also with the effective detailing of the column reinforcement. We are verifying the correctness of design guides for detailing of transverse reinforcement. We are also taking into account the diameter of stirrups and its influence over transverse deformation of column.

Key words: concrete columns, transverse reinforcement, transverse strain

1 Detailing of reinforced columns

For the design of elements and structures it is not enough to verify performance of the ultimate limit states and serviceability, but it is necessary to perform the detailing of reinforcement as well. It should be noted that the performance of detailing ensures reliability in those areas, where the calculation is not verified directly. This is mostly in those cases of loads, where the calculation would be disproportioned difficult, due to the achieved results, respectively cases, where it is not yet enough theoretical input dates to calculate (e.g. for durability).

In most cases detailing gives results on the conservative side and it is because these requirements must cover the whole range of different input dates. The use of these dates with the next precision would be too difficult.

1.1 Detailing of longitudinal reinforcement

The detailing of longitudinal reinforcement in the reinforced columns according to STN EN 1992-1-1, also taking into consideration STN EN 1992-1-1 / NA is: min. diameter of reinforcement: $\phi_s = 10 \text{ mm}$; min. amount of total longitudinal reinforcement:

$A_{s,min} = 0,10 \cdot N_{Ed} / f_{yd}$, $A_{s,min} \geq 0,002 \cdot A_c$; max. amount of reinforcement: $A_{s,max} \leq 0,04 \cdot A_c$ (in the lap area $A_{s,max} \leq 0,08 \cdot A_c$), where: N_{Ed} is design value of compressive axial force and A_c is area of concrete cross-section. The min. number of reinforcing bars: at least one bar in each corner and in a circular cross-section 4 (better 6).

Spacing of reinforcement bars must enable correct location and correct compaction of concrete, thus ensuring adequate bond of reinforcement and concrete. Horizontal and vertical clear distance between parallel reinforcement bars should be not smaller than the max. of values: $1,5 \cdot \varnothing_{max}$; 20 mm; $d_g + 5$ mm, where d_g is max. diameter of aggregate and \varnothing_{max} is max. diameter of reinforcement bar. In determining the min. spacing between reinforcing bars are therefore also take into account the size of the max. diameter of aggregate, which is necessary to indicate in the proposed concrete on design documentation.

Because of lapped longitudinal bars it is recommended minimum clear distance between bars of longitudinal reinforcement in columns 40mm. In the lap area the distance between the two lapped bars should be equal 0.

The values of the minimum distance between the longitudinal reinforcement of monolithic reinforced concrete columns should be unconditionally secure. By precast concrete elements and specific methods of compacting, such centrifugation, is assumption that we have not fully fulfill with those recommended values of min. spacing between the reinforcement [1].

1.2 Detailing of transverse reinforcement

Reinforced concrete columns are mainly subjected to relatively great axial forces and bending moments. The shear is usually very small. The main role of transverse reinforcement in reinforced concrete columns is not to transfer the shear stress as it is mainly in the beams, but it is prevention buckling of longitudinal bars and transfer of tensile stresses, that arise in the orthogonal direction to the direction of compressive force action in the column.

Transverse reinforcement needs to be anchored adequately if it is to function effectively. By failure of the columns it comes to the buckling of longitudinal bars (Fig. 1.).



Figure 1: Buckling of longitudinal bar by failure of column [1]

The transverse reinforcement, placed in reinforced concrete columns is in the form of rectangular stirrups or in the form of spirals or circular stirrups. Detailing of column stirrups according to [3], is also taken into consideration NA :

diameter of stirrups: $\phi_{ss} \geq \max [0,25 \phi_{sl,max} ; 6 \text{ mm}]$

distance of stirrups: $s_{cl,t} \leq 300 \text{ mm}$ $s_{cl,t} \leq \min [b; h]$ $s_{cl,t} \leq 15 \phi_{sl,min}$

where: $\phi_{sl,max}$ - max. diameter of longitudinal column bars

$\phi_{sl,min}$ - min. diameter of longitudinal column bars

$s_{cl,t}$ - distance of transverse reinforcement

The distance of stirrups in the place of: 1.) laps of longitudinal bars, 2.) within a distance equal to the larger dimension of the column cross section above or below a beam or slab should be reduces to the value as follows: $s'_{cl,t} \leq 0,6 s_{cl,t}$

Every longitudinal bar in a corner should be held by transverse reinforcement. No bar within a compression zone should be further than 150 mm from a restrained bar. If there is a longitudinal bar in the greater distance, so it should be held with an another stirrup (Fig. 2.).

In the case of spiral stirrups is valid: $\phi_{ss} \geq 6 \text{ mm}$; $\phi_{ss} \geq 1/4 \phi_{sl,max}$

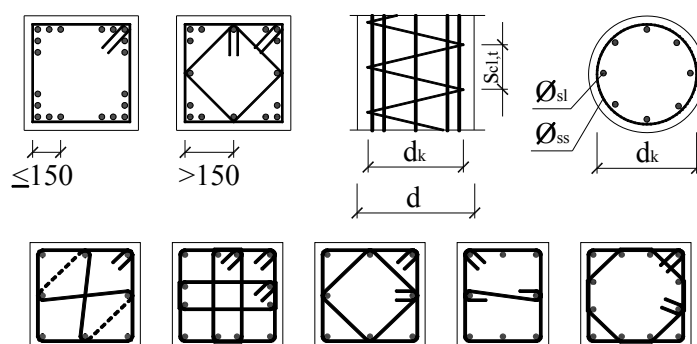


Figure 2: Transverse reinforcement of columns

The distance between spirals should be determined from these conditions:

$$s_{cl,t} \leq 0,2 d_k ; s_{cl,t} \leq 100 \text{ mm} ; s_{cl,t} > 20 \text{ mm} + \phi_{ss}$$

d_k - diameter of the spiral,

ϕ_{ss} - diameter of transverse reinforcement,

ϕ_{sl} - diameter of longitudinal bar,

$s_{cl,t}$ - distance between spirals

2 The influence of transverse reinforcement to the resistance of a column

Transverse reinforcement with small diameter works as a tie member between opposite corners of the rectangular stirrup, because the bending stiffness of stirrup is very small and stirrups deviate to the outside before, as they should act against the transverse strain of concrete between corners. In this case it is protected against transverse strain of concrete only at the corners of the stirrup (Fig. 3. a, b, c). It is supposed, that the area of effective influence of column stirrups creates a kind of arches between the points where the stirrups cause pressure on the concrete. Improvement of the effect of transverse reinforcement to the

resistance of column can be achieved by placing the transverse reinforcement in smaller distances.

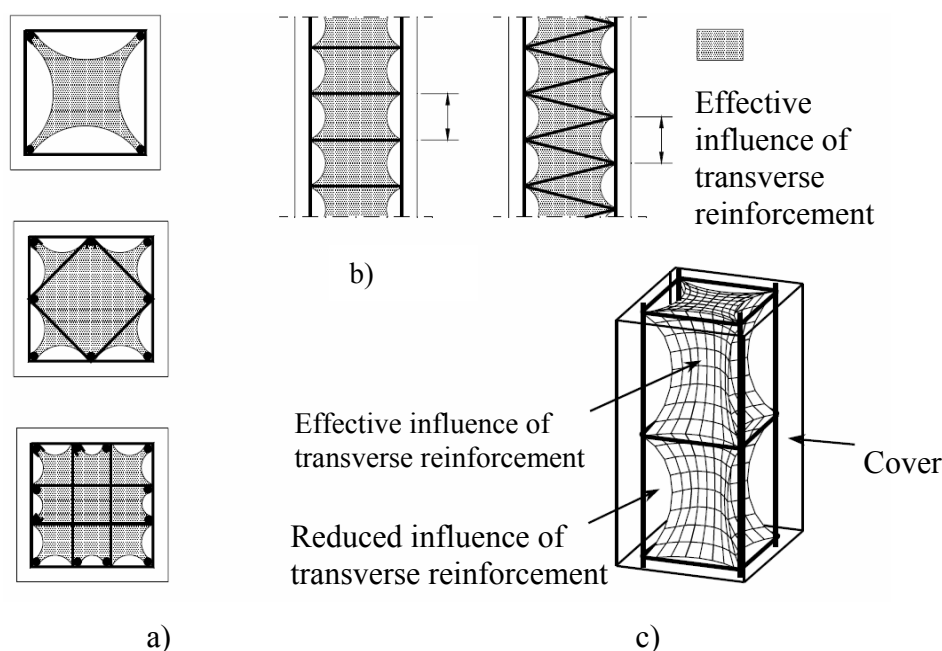


Figure 3: Effective influence of transverse reinforcement; a) squared and b) circular cross-section; c) column of squared cross-section in axonometry

When the arch arises smaller (the distances between stirrups are smaller), then it is more effective protect against the transverse strain of concrete. The effectiveness of protection of concrete transverse strain of the rectangular shape stirrups can be rapidly increased by using additional stirrups (Fig.3. a).

The suitable spaced of longitudinal bars in the perimeter of cross-section also help to increase the column's resistance. The longitudinal bars resist of the strained concrete and the reactions from these bars are transferred to the transverse reinforcement. So the effectiveness of transverse reinforcement to the resistance of the column depends on the distances of arches, which arise between the longitudinal reinforcement and also between transverse reinforcement (Fig. 3. b, c) [2].

The longitudinal reinforcement has usually sufficient bending stiffness between stirrups. However it resists transverse pressure and if the reinforcement is in larger distances from each other, bending stiffness is no sufficient. To effectively protect against the transverse strain, it is also necessary closely spaced the longitudinal bars.

3 Calculation model

To determine the size of the influence of the transverse and longitudinal reinforcement to the resistance of column cross-section, the effectiveness of the detailing of column

reinforcement and the size of transverse strain of column, we used calculation in program ATENA 3D. The program is designed for non-linear analysis of structures and members based on the finite elements method.

3.1 Material characteristics, geometry and reinforcement of columns

We used in the models of columns concrete class C20/25 due to the relatively small modulus of elasticity and thus the better readability of the results – strain in the transverse direction. For the longitudinal and transverse reinforcement was used reinforcing steel Bst500. All columns had length of 1800mm and the cross-sections are on the Fig. 4..

These types of cross-sections were chosen in the order to observe the behavior of the stirrups depending on the distance of longitudinal bar from the corner of stirrup. In the case of column cross-section 300x300mm was the distance of longitudinal bar from the corner of stirrup shorter than 150mm. In the case of column cross-section 350x350mm, this distance was approximately 150mm and in the case of column cross-section 400x400mm this distance was longer than 150mm (Fig. 4.).

Transverse reinforcement was modeled in all cases with equal distances „s“, so the differences in the results should be cause only with the diameter of the stirrup.

Column's cross-sections of series I. and II.

Column's cross-sections of series III. and IV.

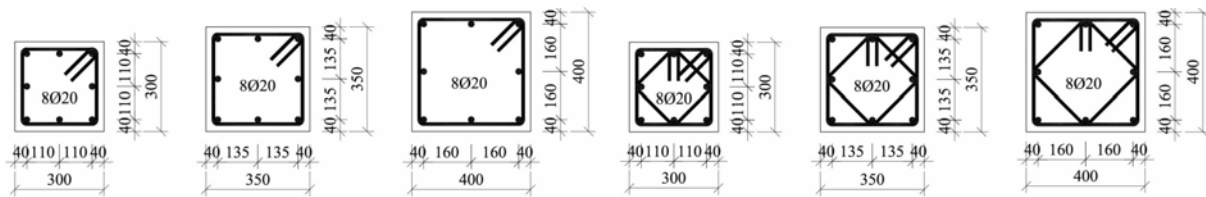


Figure 4: Cross-sections of analyzed columns

The distances of the transverse reinforcement in the head and in the foot of the column were smaller due to stress concentration in the head and in the foot of the column. The smaller distances were according to the results of models, those we analyzed before. In the head and in the foot of the column, steel plates of thickness 100mm were modeled (Fig. 5.).

3.2 Monitoring of results and loading of a column

Results were monitored by five monitors. One monitor was placed in the head of the column on the spread plate. This monitor monitored column load and its progress at each step. The other monitors were marked with letters „A“, „B“, „C“, „D“ and they monitored the progress of transverse strain. Monitor „A“ monitored transverse strain in the corner of the stirrup, monitor „B“ in the middle of the stirrup, monitor „C“ and „D“ on the longitudinal bars (Fig. 5.).

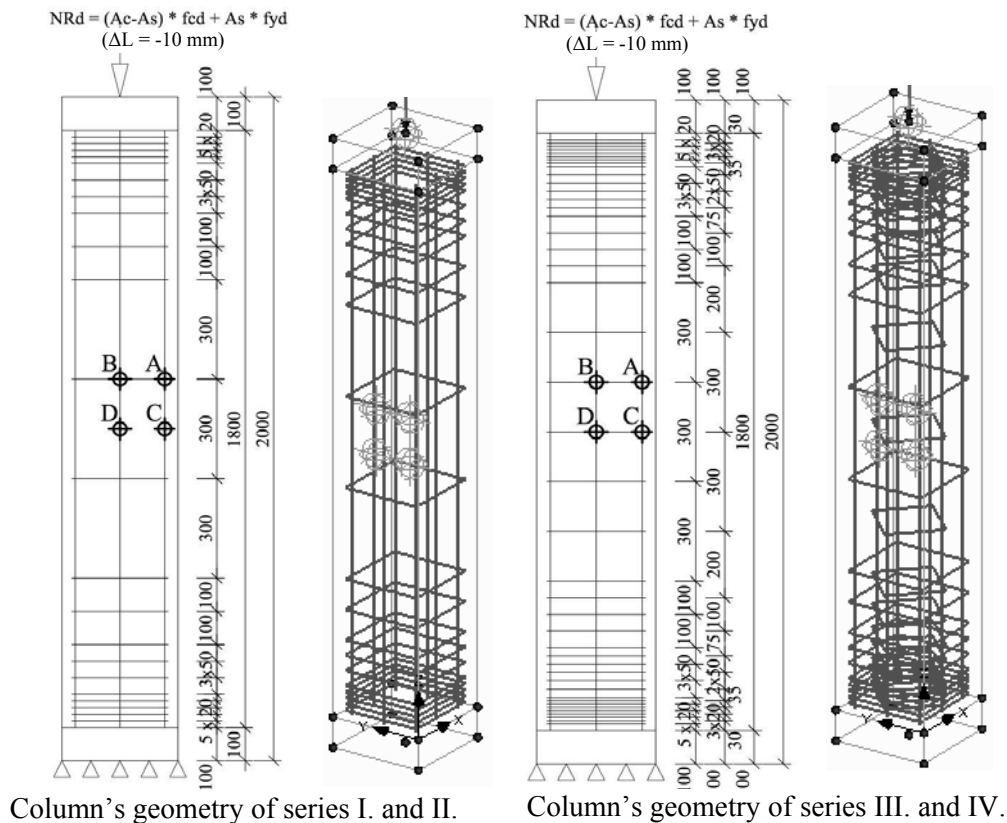


Figure 5: Geometry, load and reinforcement of columns/location of monitors on the columns

All the columns were loaded by centric compression, respectively by centric force in order to eliminate transverse movements due to column buckling. Load was transmitted into the steel plate that ensures the spreading of the load into the column cross-section. Two of the four series were loaded by centric force that has risen during the calculation. Load-strain curves were generated.

The final size of the force was calculated from the equation $N_{Rd} = (A_c - A_s) \cdot f_{cd} + A_s \cdot f_{yd}$. It results that each column with different cross-section was loaded by another force. (Fig.6.):

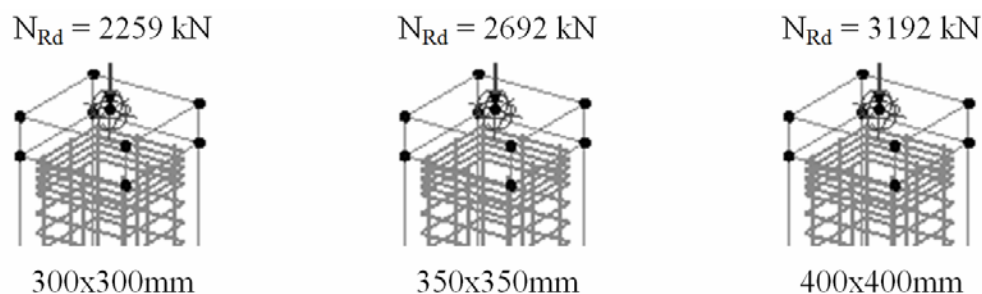


Figure 6: The maximum load of columns for each cross-section

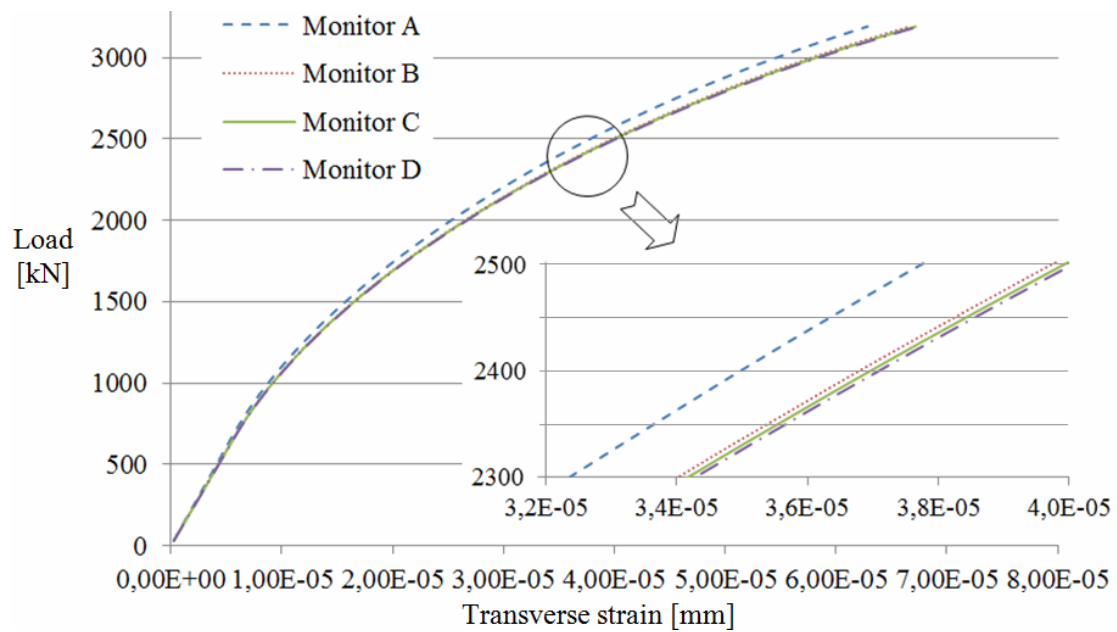


Figure 7: Load-strain curves of loading by the force (column S 1.7 N)

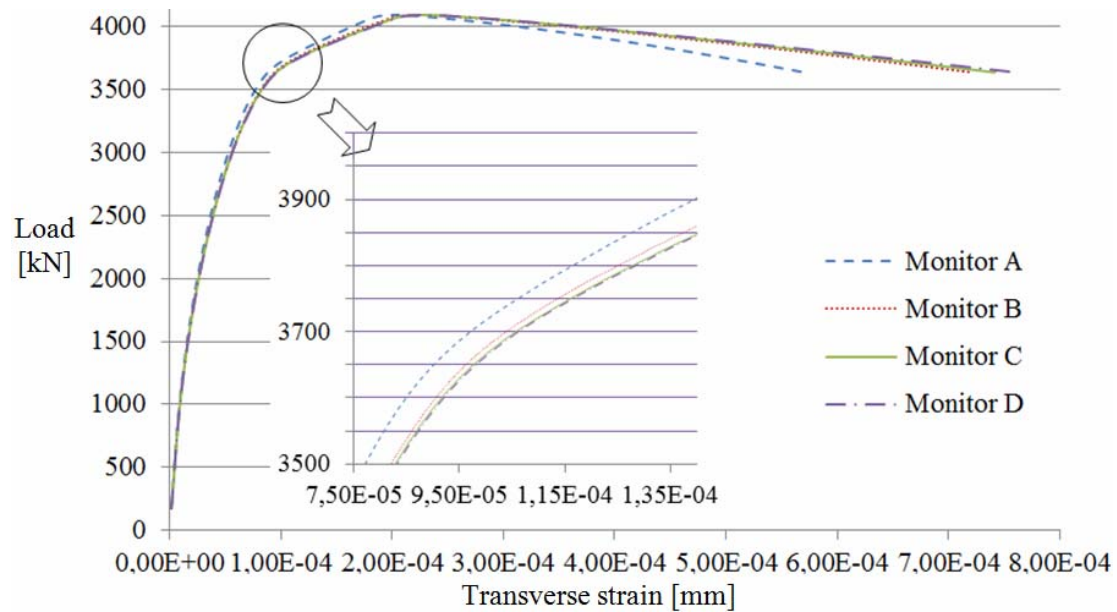


Figure 8: Load-strain curves of loading by the support displacement (column S 1.7 N)

Such a load of columns allowed us to compare the columns of the same cross-section with different diameter of stirrup and thus to determine the influence of the stirrup to buckling of longitudinal bar. However we also would like to compare the efficiency of stirrup diameter at different distances of longitudinal bar from the corner of the stirrup so we had loaded the

column in this way that the longitudinal and transverse stresses in cross-section were the same in all three types of cross-sections.

The other two series of columns were loaded by vertical displacement of the final value $\Delta l = -10\text{mm}$. This displacement increased in the process of calculation, what also ensured results in the form of load-strain curves. (Fig.7. and Fig.8.).

The calculation was in both cases of the loading in progress with 100 following steps. The size of the diameter of stirrup ($\emptyset 6$, $\emptyset 8$ and $\emptyset 10$) and using of additional stirrups were variable values in the compared columns. Overview of the types of modeled columns is in the Table 1:

Table 1: List of analyzed columns (N-loading by increasing force, L- loading by increasing support displacement)

series	Marking	cross-section	diameter of stirrup	series	Marking	cross-section	diameter of stirrup	diameter of add. stirrup
I.	S 1.1 N	300x300	$\emptyset 6$	III.	S 2.1 N	300x300	$\emptyset 6$	$\emptyset 6$
	S 1.2 N		$\emptyset 8$		S 2.2 N		$\emptyset 8$	$\emptyset 8$
	S 1.3 N		$\emptyset 10$		S 2.3 N		$\emptyset 10$	$\emptyset 10$
	S 1.4 N	350x350	$\emptyset 6$		S 2.4 N	350x350	$\emptyset 6$	$\emptyset 6$
	S 1.5 N		$\emptyset 8$		S 2.5 N		$\emptyset 8$	$\emptyset 8$
	S 1.6 N		$\emptyset 10$		S 2.6 N		$\emptyset 10$	$\emptyset 10$
	S 1.7 N	400x400	$\emptyset 6$		S 2.7 N	400x400	$\emptyset 6$	$\emptyset 6$
	S 1.8 N		$\emptyset 8$		S 2.8 N		$\emptyset 8$	$\emptyset 8$
	S 1.9 N		$\emptyset 10$		S 2.9 N		$\emptyset 10$	$\emptyset 10$
II.	S 1.1 L	300x300	$\emptyset 6$	IV.	S 2.1 L	300x300	$\emptyset 6$	$\emptyset 6$
	S 1.2 L		$\emptyset 8$		S 2.2 L		$\emptyset 8$	$\emptyset 8$
	S 1.3 L		$\emptyset 10$		S 2.3 L		$\emptyset 10$	$\emptyset 10$
	S 1.4 L	350x350	$\emptyset 6$		S 2.4 L	350x350	$\emptyset 6$	$\emptyset 6$
	S 1.5 L		$\emptyset 8$		S 2.5 L		$\emptyset 8$	$\emptyset 8$
	S 1.6 L		$\emptyset 10$		S 2.6 L		$\emptyset 10$	$\emptyset 10$
	S 1.7 L	400x400	$\emptyset 6$		S 2.7 L	400x400	$\emptyset 6$	$\emptyset 6$
	S 1.8 L		$\emptyset 8$		S 2.8 L		$\emptyset 8$	$\emptyset 8$
	S 1.9 L		$\emptyset 10$		S 2.9 L		$\emptyset 10$	$\emptyset 10$

4 Results from the analysis

Results are in Tables 2.-13. From the tables placed side by side it is shown that the additional stirrups reduce transverse strain of column.

Table 2: Transverse strain of columns of series I. for cross-section 300x300mm [mm]

cross-section	300 x 300 mm		
marking	$\emptyset 6$	$\emptyset 8$	$\emptyset 10$
Monitor A	6,462E-05	6,237E-05	5,973E-05
Monitor B	6,700E-05	6,642E-05	6,580E-05
Monitor C	6,735E-05	6,700E-05	6,661E-05
Monitor D	6,743E-05	6,713E-05	6,681E-05

Table 3: Transverse strain of columns of series III. for cross-section 300x300mm [mm]

cross-section	300 x 300 mm		
marking	$\emptyset 6$	$\emptyset 8$	$\emptyset 10$
Monitor A	6,447E-05	6,220E-05	5,955E-05
Monitor B	6,700E-05	6,648E-05	6,594E-05
Monitor C	6,676E-05	6,614E-05	6,551E-05
Monitor D	6,327E-05	6,043E-05	5,735E-05

Table 4: Transverse strain of columns of series I. for cross-section 350x350mm [mm]

cross-section	350 x 350 mm		
marking	Ø6	Ø8	Ø10
Monitor A	6,523E-05	6,367E-05	6,180E-05
Monitor B	6,696E-05	6,660E-05	6,617E-05
Monitor C	6,719E-05	6,682E-05	6,639E-05
Monitor D	6,727E-05	6,694E-05	6,656E-05

Table 5: Transverse strain of columns of series III. for cross-section 350x350mm [mm]

cross-section	350 x 350 mm		
marking	Ø6	Ø8	Ø10
Monitor A	6,503E-05	6,336E-05	6,138E-05
Monitor B	6,682E-05	6,638E-05	6,587E-05
Monitor C	6,673E-05	6,610E-05	6,539E-05
Monitor D	6,465E-05	6,258E-05	6,020E-05

Table 6: Transverse strain of columns of series I. for cross-section 400x400mm [mm]

cross-section	400 x 400 mm		
marking	Ø6	Ø8	Ø10
Monitor A	6,562E-05	6,438E-05	6,258E-05
Monitor B	6,702E-05	6,687E-05	6,664E-05
Monitor C	6,785E-05	6,756E-05	6,719E-05
Monitor D	6,800E-05	6,775E-05	6,745E-05

Table 7: Transverse strain of columns of series III. for cross-section 400x400mm [mm]

cross-section	400 x 400 mm		
marking	Ø6	Ø8	Ø10
Monitor A	6,548E-05	6,411E-05	6,241E-05
Monitor B	6,694E-05	6,667E-05	6,628E-05
Monitor C	6,748E-05	6,694E-05	6,628E-05
Monitor D	6,625E-05	6,478E-05	6,303E-05

Table 8: Transverse strain of columns of series II. for diameter of stirrup Ø6 [mm]

marking	Ø6		
cross-section	300x300	350x350	400x400
Monitor A	4,244E-04	4,959E-04	5,629E-04
Monitor B	4,826E-04	5,435E-04	6,071E-04
Monitor C	4,857E-04	5,475E-04	5,935E-04
Monitor D	4,894E-04	5,476E-04	5,910E-04

Table 9: Transverse strain of columns of series IV. for diameter of stirrup Ø6 [mm]

marking	Ø6		
cross-section	300x300	350x350	400x400
Monitor A	4,985E-04	5,874E-04	6,636E-04
Monitor B	5,798E-04	6,561E-04	7,344E-04
Monitor C	5,726E-04	6,602E-04	7,504E-04
Monitor D	4,466E-04	5,861E-04	7,033E-04

Table 10: Transverse strain of columns of series II. for diameter of stirrup Ø8 [mm]

marking	Ø8		
cross-section	300x300	350x350	400x400
Monitor A	4,146E-04	5,102E-04	5,794E-04
Monitor B	5,295E-04	6,044E-04	6,702E-04
Monitor C	5,310E-04	6,156E-04	6,826E-04
Monitor D	5,404E-04	6,223E-04	6,904E-04

Table 11: Transverse strain of columns of series IV. for diameter of stirrup Ø8 [mm]

marking	Ø8		
cross-section	300x300	350x350	400x400
Monitor A	4,821E-04	6,001E-04	6,863E-04
Monitor B	6,495E-04	7,292E-04	8,193E-04
Monitor C	6,446E-04	7,282E-04	8,367E-04
Monitor D	3,707E-04	5,842E-04	7,484E-04

Table 12: Transverse strain of columns of series II. for diameter of stirrup Ø10 [mm]

marking	Ø10		
cross-section	300x300	350x350	400x400
Monitor A	3,739E-04	4,946E-04	5,703E-04
Monitor B	5,721E-04	6,489E-04	7,211E-04
Monitor C	5,691E-04	6,613E-04	7,418E-04
Monitor D	5,846E-04	6,756E-04	7,606E-04

Table 13: Transverse strain of columns of series IV. for diameter of stirrup Ø10 [mm]

marking	Ø10		
cross-section	300x300	350x350	400x400
Monitor A	4,143E-04	5,747E-04	6,720E-04
Monitor B	7,375E-04	7,840E-04	8,849E-04
Monitor C	7,371E-04	7,685E-04	8,918E-04
Monitor D	3,015E-04	5,402E-04	7,479E-04

5 Conclusion

The resistance of column was higher by using a stirrup of diameter Ø10, than the resistance by using a stirrup of diameter Ø8 resp. Ø6 and from what the larger stress results in the core of column cross-section and with that bigger transverse strain by maximum column resistance. At the same load of individual cross-sections by using stirrups of diameter Ø6 were observed larger transverse strains than by using stirrups of diameter Ø8 or Ø10.

Currently according to [3], no bar within a compression zone should be further than 150 mm from a restrained bar. It is evident from the results, that the design of additional stirrups also depends on other parameters, as for example: diameter of stirrup, diameter of longitudinal reinforcement, quality of concrete, etc.

The results confirm expected behavior of stirrups in the column. They confirmed that the bending stiffness of transverse reinforcement influences on the transverse column strains and also buckling of the stirrup and the longitudinal reinforcement too. Even a stirrup diameter is supposed to determine both, in the case of a structural design of stirrups and about the use of an additional stirrup.

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